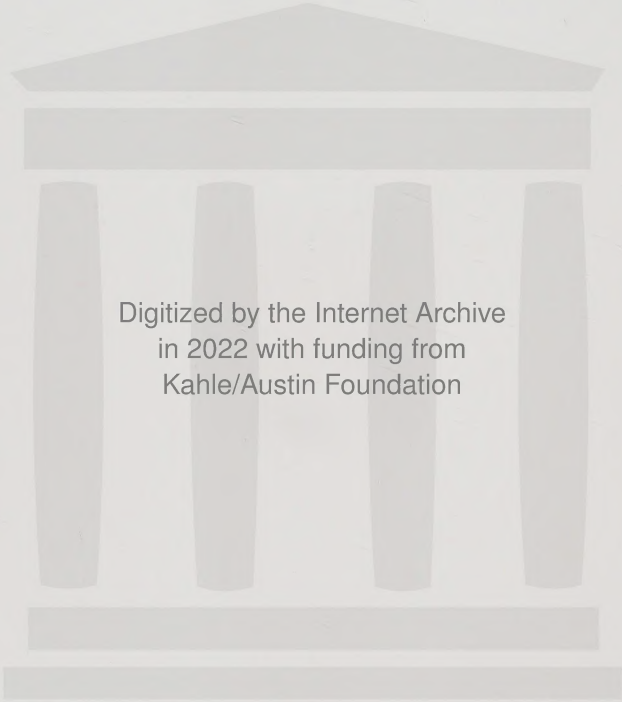


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Metaphysics

Metaphysics is the philosophical study whose object is to determine the real nature of things—to determine the meaning, structure, and principles of whatever is insofar as it is. Although this study is popularly conceived as referring to anything excessively subtle and highly theoretical and although it has been subjected to many criticisms, it is presented by metaphysicians as the most fundamental and most comprehensive of inquiries, inasmuch as it is concerned with reality as a whole.

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Nature and scope of metaphysics

ORIGIN OF THE TERM

Etymologically the term *metaphysics* is unenlightening. It means "what comes after physics"; it was the phrase used by early students of Aristotle to refer to the contents of Aristotle's treatise on what he himself called "first philosophy," and was used as the title of this treatise by Andronicus of Rhodes, one of the first of Aristotle's editors. Aristotle had distinguished two tasks for the philosopher: first, to investigate the nature and properties of what exists in the natural, or sensible, world, and second, to explore the characteristics of "Being as such" and to inquire into the character of "the substance that is free from movement," or the most real of all things, the intelligible reality on which everything in the world of nature was thought to be causally dependent. The first constituted "second philosophy" and was carried out primarily in the Aristotelian treatise now known as the *Physica;* the second, which Aristotle had also referred to as "theology" (because God was the unmoved mover in his system), is roughly the subject matter of his *Metaphysica.* Modern readers of Aristotle are inclined to take both the *Physica* and the *Metaphysica* as philosophical treatises; the distinction their titles suggest between an empirical and a conceptual inquiry has little foundation. Aristotle was not indifferent to factual material either in natural or in metaphysical philosophy, but equally he was not concerned in either case to frame theories for empirical testing. It seems clear, nevertheless, that if the two works had to be distinguished, the *Physica* would have to be described as the more empirical, just because it deals with things that are objects of the senses, what Aristotle himself called "sensible substance"; the subject matter of the *Metaphysica,* "that which is eternal, free of movement, and separately existent," is on any account more remote. It is also evident that the connection marked in the original titles is a genuine one: the inquiries about nature carried out in the *Physica* lead on naturally to the more fundamental inquiries about Being as such that are taken up in the *Metaphysica* and indeed go along with the latter to make up a single philosophical discipline.

The background to Aristotle's divisions is to be found in the thought of Plato, with whom Aristotle had many disagreements but whose basic ideas provided a framework within which much of his own thinking was conducted. Plato, following the early Greek philosopher Parmenides, who is known as the father of metaphysics, had sought to distinguish opinion, or belief, from knowledge and to assign distinct objects to each. Opinion, for Plato, was a form of apprehension that was shifting and unclear, similar to seeing things in a dream or only through their shadows; its objects were correspondingly unstable. Knowledge, by contrast, was wholly lucid; it carried its own guarantee against error, and the objects with which it was concerned were eternally what they were, and so were exempt from change and the deceptive power to appear to be what they were not. Plato called the objects of opinion phenomena, or appearances; he referred to the objects of knowledge as noumena (objects of the intelligence) or quite simply as realities. Much of the burden of his philosophical message was to call men's attentions to these contrasts and to impress them with the necessity to turn away from concern with mere phenomena to the investigation of true reality. The education of the Platonic philosopher consisted precisely in effecting this transition: he was taught to recognize the contradictions involved in appearances and to fix his gaze on the realities that lay behind them, the realities that Plato himself called Forms, or Ideas. Philosophy for Plato was thus a call to recognize the existence and overwhelming importance of a set of higher realities that ordinary men—even those, like the Sophists of the time, who professed to be enlightened—entirely ignored. That there were such realities, or at least that there was a serious case for thinking that there were, was a fundamental tenet in the discipline that later became known as metaphysics. Conversely, much of the subsequent controversy about the very possibility of metaphysics has turned on the acceptability of this tenet and on whether, if it is rejected, some alternative foundation can be discovered on which the metaphysician can stand.

Appearances and realities for Plato

CHARACTERIZATIONS OF METAPHYSICS

Before considering any such question, however, it is necessary to examine, without particular historical references, some ways in which actual metaphysicians have attempted to characterize their enterprise, noticing in each case the problems they have in drawing a clear line between their aims and those of the practitioners of the exact and empirical sciences. Four views will be briefly considered; they present metaphysics as: (1) an inquiry into what exists, or what really exists; (2) the science of reality, as opposed to appearance; (3) the study of the world as a whole; (4) a theory of first principles. Reflection on what is said under the different heads will quickly establish that they are not sharply separate from one another, and, indeed, individual metaphysical writers sometimes invoke more than one of these phrases when asked to say what metaphysics is—as, for example, the British Idealist F.H. Bradley does in the opening pages of his work *Appearance and Reality* (1893).

An inquiry into what exists. A common set of claims on behalf of metaphysics is that it is an inquiry into what exists; its business is to subject common opinion on this matter to critical scrutiny and in so doing to determine what is truly real.

Unreliability of common opinion

It can be asserted with some confidence that common opinion is certainly an unreliable guide about what exists, if indeed it can be induced to pronounce on this matter at all. Are dream objects real, in the way in which palpable realities such as chairs and trees are? Are numbers real, or should they be described as no more than abstractions? Is the height of a man a reality in the same sense in which he is a reality, or is it just an aspect of something more concrete, a mere quality that has derivative rather than substantial being and could not exist except as attributed to something else? It is easy enough to confuse the common man with questions like these and to show that any answers he gives to them tend to be ill thought-out. It is equally difficult, however, for the metaphysician to come up with more satisfactory answers of his own. Many metaphysicians have relied, in this connection, on the internally related notions of substance, quality, and relation; they have argued that only what is substantial truly exists, although every substance has qualities and stands in relation to other substances. Thus, this tree is tall and deciduous and is precisely 50 yards north of that fence. Difficulties begin, however, as soon as examples like these are taken seriously. Assume for the moment that an individual tree—what might be called a concrete existent—qualifies for the title of substance; it is just the sort of thing that has qualities and stands in relations. Unless there were substances in this sense, no qualities could be real: the tallness of the tree would not exist unless the tree existed. The question can now be raised what the tree would be if it were deprived of all its qualities and stood in no relations. The notion of a substance in this type of metaphysics is that of a thing that exists by itself, apart from any attributes it may happen to possess; the difficulty with this notion is to know how to apply it. Any concrete thing one selects to exemplify the notion of substance turns out in practice to answer a certain description; this means in effect that it cannot be spoken of apart from its attributes. It thus emerges that substances are no more primary beings than are qualities and relations; without the former one could not have the latter, but equally without the latter one could not have the former.

There are other difficulties about substance that cannot be explored here—*e.g.*, whether a fence is a substance or simply wood and metal shaped in a certain way. Enough has already been said, however, to indicate the problems involved in defining the tasks of metaphysics along these lines. There is, nevertheless, an alternative way of understanding the notion of substance: not as that which is the ultimate subject of predicates but as what persists through change. The question "What is ultimately real?" is, thus, a question about the ultimate stuff of which the universe is made up. Although this second conception of substance is both clearer and more readily applicable than its predecessor, the difficulty about it from the metaphysician's point of view is that it sets him in direct rivalry with the scientist. When the early Greek philosopher Thales inquired as to what is ultimately real and came up with the surprising news that all is water, he might be taken as advancing a scientific rather than a philosophical hypothesis. Although it is true that later writers, such as Gottfried Wilhelm Leibniz, a German Rationalist philosopher and mathematician, were fully aware of the force of scientific claims in this area and, nevertheless, rejected them as metaphysically unacceptable, the fact remains that the nonphilosopher finds it difficult to understand the basis on which a Leibniz rests his case. When Leibniz said that it is monads (*i.e.*, elementary, unextended, indivisible, spiritual substances that enter into composites) that are the true atoms of nature and not, for example, material particles, the objection can be raised as to what right he has to advance this opinion. Has he done any scientific work to justify him in setting scientific results aside with such confidence? And if he has not, why should he be taken seriously at all?

The ultimate stuff of the universe

The science of ultimate reality. To answer these questions, another description of metaphysics has been proposed: that it is the science that seeks to define what is ultimately real as opposed to what is merely apparent.

The contrast between appearance and reality, however, is by no means peculiar to metaphysics. In everyday life people distinguish between the real size of the Sun and its apparent size, or again between the real colour of an object (when seen in standard conditions) and its apparent colour (nonstandard conditions). A cloud appears to consist of some white, fleecy substance, although in reality it is a concentration of drops of water. In general, men are often (though not invariably) inclined to allow that the scientist knows the real constitution of things as opposed to the surface aspects with which ordinary men are familiar. It will not suffice to define metaphysics as knowledge of reality as opposed to appearance; scientists, too, claim to know reality as opposed to appearance, and there is a general tendency to concede their claim.

Components in the metaphysical conception of reality

It seems that there are at least three components in the metaphysical conception of reality. One characteristic, which has already been illustrated by Plato, is that reality is genuine as opposed to deceptive. The ultimate realities that the metaphysician seeks to know are precisely things as they are—simple and not variegated, exempt from change and therefore stable objects of knowledge. Plato's own assumption of this position perhaps reflects certain confusions about the knowability of things that change; one should not, however, on that ground exclude this aspect of the concept of reality from metaphysical thought in general. Ultimate reality, whatever else it is, is genuine as opposed to sham. Second, reality is original in contrast to derivative, self-dependent rather than dependent on the existence of something else. When Aristotle sought to inquire into the most real of all things, or when medieval philosophers attempted to establish the characteristics of what they called the *ens realissimum* ("the most real being"), or the original and perfect being, they were looking for something that, in contrast to the everyday things of this world, was truly self-contained and could accordingly be looked upon as self-caused. Likewise, the 17th-century Rationalists defined substance as that which can be explained through itself alone. Writers like René Descartes and Benedict de Spinoza were convinced that it was the task of the metaphysician to seek for and characterize substance understood in this sense; the more mundane substances with which physical scientists were concerned were, in their opinion, only marginally relevant in this inquiry. Third, and perhaps most important, reality for the metaphysician is intelligible as opposed to opaque. Appearances are not only deceptive and derivative, they also make no sense when taken at their own level. To arrive at what is ultimately real is to produce an account of the facts that does them full justice. The assumption is, of course, that one cannot explain things satisfactorily if one remains within the world of common sense, or even if one advances from that world to embrace the concepts of science. One or the other of these levels of explanation may suffice to produce a sort of local sense that is enough for practical purposes or that forms an adequate basis on which to make predictions. Practical reliability of this kind, however, is very different from theoretical satisfaction; the task of the metaphysician is to challenge all assumptions and finally arrive at an account of the nature of things that is fully coherent and fully thought-out.

The task of the metaphysician

It should be obvious that, to establish his right to pronounce on what is ultimately real in the sense analyzed, the metaphysician has a tremendous amount to do. He must begin by giving colour to his claim that everyday ways of thinking will not suffice for a full and coherent description of what falls within experience, thus arguing that appearances are unreal—although not therefore nonexistent—because they are unstable and unintelligible. This involves a challenge to the final acceptability of such well-worn ideas as time and space, thing and attribute, change and process—a challenge that metaphysicians have not hesitated to make, even though it has been treated with skepticism both by ordinary men and by some of their fellow philosophers (*e.g.*, G.E. Moore, a 20th-century British

thinker who has greatly influenced modern Analytic philosophy). Second, granted that there are contradictions or incoherences in the thought of common sense, the metaphysician must go on to maintain that they cannot be resolved by deserting common sense for science. He will not deny that the concepts of science are in many respects different from those of everyday thought; to take one aspect only, they are altogether more precise and sharply defined. They permit the scientist to introduce into his descriptions a theoretical content that is lacking at the everyday level and in so doing to unify and render intelligible aspects of the world that seem opaque when considered singly. The metaphysician will argue, however, that this desirable result is purchased at a certain price: by ignoring certain appearances altogether. The scientist, in this way of thinking, does not offer a truer description of the phenomena of which ordinary thought could make no sense but merely gives a connected description of a selected set of phenomena. The world of the scientist, restricted as it is to what can be dealt with in quantitative terms, is a poor thing in comparison with the rich if untidy world of everyday life. Alternatively, the metaphysician must try to show that scientific concepts are like the concepts of common sense in being ultimately incoherent. The premises or presuppositions that the scientist accepts contain unclarities that cannot be resolved, although they are not so serious as to prevent his achieving results that are practically dependable. Many ingenious arguments on these lines have been produced by philosophers, by no means all of whom could be said to be incapable of a true understanding of the theories they were criticizing. (Leibniz, for example, was a physicist of distinction as well as a mathematician of genius; G.W.F. Hegel, a 19th-century German Idealist, had an unusual knowledge of contemporary scientific work; and Alfred North Whitehead, a pioneer of 20th-century metaphysics in the Anglo-Saxon world, was a professor of applied mathematics, and his system developed from physics and contained a wealth of biological ideas.) The fact remains, nevertheless, that few if any practicing scientists have been seriously troubled by such arguments.

Even if the metaphysician were thus able to make good the negative side of his case, he would still face the formidable difficulty of establishing that there is something answering to his conception of what is ultimately real and of identifying it. The notion of an original being, totally self-contained and totally self-intelligible, may not itself be coherent, as the 18th-century British philosopher David Hume and others have argued; alternatively, there may be special difficulties in saying to what it applies. The fact that different metaphysicians have given widely different accounts of what is ultimately real is certainly suspicious. Some have wanted to say that there is a plurality of ultimately real things, others that there is only one; some have argued that what is truly real must be utterly transcendent of the things of this world and occupy a supersensible realm accessible only to the pure intellect, while others have thought of ultimate reality as immanent in experience (the Hegelian Absolute, for example, is not a special sort of existent, but the world as a whole understood in a certain way). That metaphysical inquiry should issue in definitive doctrine, as so many of those who engaged in it said that it would, is in these circumstances altogether too much to hope for.

The science of the world as a whole. Another way in which metaphysicians have sought to define their discipline is by saying that it has to do with the world as a whole.

The implications of this phrase are not immediately obvious. Clearly, a contrast is intended in the first place with the various departmental sciences, each of which selects a portion or aspect of reality for study and confines itself to that. No geologist or mathematician would claim that his study is absolutely comprehensive; each would concede that there are many aspects of the world that he leaves out, even though he covers everything that is relevant to his special point of view. By contrast, it might be supposed that the metaphysician is merely to coordinate the results of the special sciences. There is clearly a need for the coordination of scientific results because scientific research has become increasingly specialized and departmentalized; individual scientific workers need to be made aware of what is going on in other fields, sometimes because these fields impinge on their own, sometimes because results obtained there have wider implications of which they need to take account. One can scarcely see metaphysicians, however, or indeed philosophers generally, performing this function of intellectual contact man in a satisfactory fashion. It might then be supposed that their concern with the world as a whole is to be interpreted as a summing up and synthesizing of the results of the particular sciences. Plato spoke of the philosopher as taking a synoptic view, and there is often talk about the need to see things in the round and avoid the narrowness of the average specialist, who, it is said, knows more and more about less and less. If, however, it is a question of looking at scientific results from a wider point of view and so of producing what might be called a scientific picture of the world, the person best qualified for the job is not any philosopher but rather a scientist of large mind and wide interests. Metaphysics cannot be satisfactorily understood as an account of the world as a whole if that description suggests that the metaphysician is a sort of superscientist, unlimited in his curiosity and gifted with a capacity for putting together other people's findings with a skill and imagination that none of them individually commands. Only a scientist could hope to become such a superscientist.

Metaphysics as a unified account of the world

More hope for the metaphysician can be found, perhaps, along the following lines. People want to know not only what the scientist makes of the world but also what significance to assign to his account. People experience the world at different levels and in different capacities: they are not only investigators but also agents; they have a moral and a legal, an aesthetic and a religious life in addition to their scientific life. Man is a many-sided being; he needs to understand the universe in the light of his different activities and experiences. There are philosophers who appear to find no problem here; they argue that there can be no possibility of, say, a moral or a religious vision of the world that rivals the scientific vision. In this view, morals and religion are matters of practice, not of theory; they do not rival science but only complement it. This neutralist attitude, however, finds little general favour; for most thinking people find it necessary to choose whether to go all the way with science, at the cost of abandoning religion and even morals, or to stick to a religious or moral world outlook even if it means treating scientific claims with some reserve. The practice of the moral life is often believed to proceed on assumptions that can hardly be accepted if science is taken to have the last word about what is true. Accordingly, it becomes necessary to produce some rational assessment of the truth claims of the different forms of experience, to try to think out a scheme in which justice is done to them all. Many familiar systems of metaphysics profess to do just that; among others there are Materialism, which favours the claims of science; Idealism, which sees deeper truth in religion and the moral life; and the peculiar dualism of the 18th-century German philosopher Immanuel Kant, which holds that science gives the truth about phenomena, while reserving a noumenal, or supersensible, sphere for moral agency.

This conception of metaphysics as offering an account of the world or, as is more often said, of experience as a whole, accords more obviously with the position of those who see ultimate reality as immanent, or inherent in what is immediately known, than of those who take it to be transcendent, or beyond the limits of ordinary experience. It is possible, in fact, to subscribe to the legitimacy of metaphysics as so understood without postulating the existence of any special entities known only to the metaphysician—a claim that plain men have often taken to connect metaphysics with the occult. This is not to say, of course, that metaphysical problems admit of easy solutions when understood along these lines. There is a variety of widely different ways of taking the world as a whole: depending on which aspect or aspects of experience the individual metaphysician finds especially significant; each claims to be comprehensive and to confute the claims

of its rivals, yet none has succeeded in establishing itself as the obviously correct account. Even systems that are widely condemned as impossible, such as Materialism, turn out in practice to command constantly renewed support as new discoveries in the sciences suggest new ways of dealing with old difficulties. A cynic might take such facts as meaning that people subscribe to theories of this sort more as a matter of emotional than of rational conviction; metaphysics, as Bradley remarked with surprising frankness, consists in the finding of bad reasons for what one believes upon instinct.

The science of first principles. Another phrase used by Bradley in his preliminary discussion of metaphysics is "the study of first principles," or ultimate, irrefutable truths.

First principles as basic truths

Metaphysics could be said to provide a theory of first principles if it furnished men with a set of concepts in the light of which they could arrive at the connected account of experience as a whole just spoken of, and the two descriptions of the subject would thus be two sides of a single coin. The idea that metaphysics has to do with first principles, however, has wider implications.

The term "first principles" is a translation of the Greek word *archai*. An arche is something from which an argument proceeds—it can be either a primary premise or an ultimate presupposition. Plato, in a famous passage in *Politeia* (*The Republic*), contrasted two different attitudes to archai: namely that of the mathematician, who lays down or hypothesizes certain things as being true and then proceeds to deduce their consequences without further examining their validity; and that of the dialectician, who proceeds backward, not forward, from his primary premises and then seeks to ground them in an arche that is not hypothesized at all. Unfortunately, no concrete details exist of the way in which Plato himself thought this program could be carried out; instead he spoke of it only in the most general terms. The suggestion, nevertheless, that metaphysics is superior to any other intellectual discipline in having a fully critical attitude toward its first principles is one that still continues to be made, and it needs some examination.

As regards mathematics, for example, it might be said that mathematicians could be uncritical about the first principles of their science in the following ways: (1) They might take as self-evidently true or universally applicable some axiom or primary premise that turned out later not to possess this property. (2) They might assume among their first principles certain propositions about existence—to the effect that only certain kinds of things could be proper objects of mathematical inquiry (rational as opposed to irrational numbers, for example)—and time might indeed reveal that the assumption was inappropriate. The remedy for both sorts of error, however, is to be found within the realm of mathematics itself; the development of the discipline has consisted precisely in eliminating mistakes of this kind. It is not clear even that the discovery and removal of antinomies in the foundations of mathematics is work for the metaphysician, although philosophically minded persons like Gottlob Frege, a German mathematician and logician, and Bertrand Russell, perhaps the best known English philosopher of the 20th century, have been much concerned with them. The situation is not fundamentally different when the empirical sciences are considered. Admittedly, the exponents of these sciences give more hostages to fortune insofar as they have to assume from the first the general correctness of the results of other disciplines; there can be no question of their checking on these for themselves. Mathematicians, too, begin by assuming the validity of common argument forms without making any serious attempt to validate them, and there is nothing seriously wrong with their proceeding in this manner. If confidence in bad logic has sometimes been responsible for holding up mathematical advance, bolder mathematicians have always known in practice that the right thing to do is to let the argument take them wherever it will on strictly mathematical lines, leaving it to logicians to recognize the fact and adjust their theory at their convenience.

It thus seems that the assertion that a special science like mathematics is uncritical about its archai is false; there is a sense in which mathematicians are constantly strengthening their basic premises. As regards the corresponding claim about metaphysics, it has at one time or another been widely believed (1) that it is the business of metaphysics to justify the ultimate assumptions of the sciences, and (2) that in metaphysics alone there are no unjustified assumptions. Concerning (1), the question that needs to be asked is how the justification is supposed to take place. It has been argued that the metaphysician might, on one interpretation of his function, be said to offer some defense of science generally by placing it in relation to other forms of experience. To do this, however, is not to justify any particular scientific assumptions. In point of fact, particular scientific assumptions get their justification, if anywhere, when a move is made from a narrower to a more comprehensive science; what is assumed in geology, for example, may be proved in physics. But this, of course, has nothing to do with metaphysics. The difficulty with (2) is that of knowing how any intellectual activity, however carefully conducted, could be free of basic assumptions. Some metaphysicians (such as Bradley and his Scottish predecessor J.F. Ferrier) have claimed that there is a difference between their discipline and others insofar as metaphysical propositions alone are self-reinstating. For example, the Cartesian proposition *cogito, ergo sum* ("I think, therefore I am") is self-reinstating: deny that you think, and in so doing you think; deny that you exist, and the very fact gives proof of your existence. Even if it could be made out that propositions of this kind are peculiar to metaphysics, however, it would not follow that everything in metaphysics has this character. The truth is, rather, that no paradox is involved in denying most fundamental metaphysical claims, such as the assertion of the Materialist that there is nothing that cannot be satisfactorily explained in material terms or the corresponding principle of Aristotle that there is nothing that does not serve some purpose.

Metaphysicians as self-critical

The view that metaphysics, or indeed philosophy generally, is uniquely self-critical is among the myths of modern thought. Philosophers rely on the results of other disciplines just as other people do; they do not pause to demonstrate the legitimacy of the principles of simple arithmetic before entering on calculations in the course of their work, nor do they refrain from employing the reductio ad absurdum type of refutation (*i.e.*, showing an absurdity to which a proposition leads when carried to its logical conclusion) until they have assured themselves that this is a valid way of confuting an opponent. Even in their own field they tend, like painters, to work within traditions set by great masters rather than to think everything out from scratch for themselves. That philosophy in practice is not the fully self-critical activity its exponents claim it to be is shown nowhere more clearly than in the reception that philosophers give to theories that are unfashionable; they more often subject them to conventional abuse than to patient critical examination. It is, nevertheless, from the conviction that philosophy, and especially metaphysical philosophy, operates without unjustified assumptions that current claims about the superiority of this branch of thinking derive their force. This conviction connects with the views already mentioned, that metaphysics is the science of first principles and that the principles in question are ineluctable in the sense that they are operative in their own denial.

METAPHYSICS AND OTHER BRANCHES OF PHILOSOPHY

The view of metaphysics as the queen of the sciences

It may be useful at this point to consider the relations of metaphysics to other parts of philosophy. A strong tradition, derided by Kant, asserted that metaphysics was the queen of the sciences, including the philosophical sciences. The idea presumably was that those who worked within fields such as logic and ethics, as well as physicists and biologists, proceeded on assumptions that in the last resort had to be approved or corrected by the metaphysician. Logic could be conceived as a special study complete in itself only if the logician were allowed to postulate a correspondence between the neat and tidy world of propositions, which was the immediate object

of his study, and the world existing in fact; metaphysics might and sometimes did challenge the propriety of this postulate. Similarly, ethics, like law, could get nowhere without the assumption that the individual agent is a self-contained unit answerable in general terms for what he does; metaphysics had the duty of subjecting this assumption to critical examination. As a result of such claims it was widely believed that any results obtained by logicians or ethicists must at best be treated as provisional; followers of Hegel, who advanced these claims with passionate conviction, were inclined in consequence to regard logic and ethics alike as minor branches of philosophy. It has been a feature of 20th-century philosophical thought, especially in Britain and the United States, to dispute these Hegelian contentions and argue for the autonomy of ethics and logic; that is, for their independence of metaphysics. Thus, formal logicians of the school of Frege and Russell were apt to claim that the principles of logic applied unequivocally to all thinking whatsoever; there could be no question of their having to await confirmation, still less correction, from the metaphysician. If metaphysical arguments suggested that fundamental laws of logic such as the principle of noncontradiction—that a statement and its contradictory cannot both be true—might not be in order, the only conclusion to draw was that such arguments must be confused: without observation of the laws of logic there could be no coherent thinking of any sort.

Similarly, G.E. Moore, in a celebrated section of his *Principia Ethica* (1903), tried to show that statements like "This is good" are *sui generis* and cannot be reduced to statements of either natural or metaphysical fact; the Idealist belief that ethics ultimately depends on metaphysics rested on a delusion. Moore perhaps failed to see the force of the Idealist challenge to the individualist assumptions on which much ethical thinking proceeds, and he did not note that, in one respect at least, ethical results can be dependent on those of metaphysics: if metaphysics shows that the world is other than it is initially taken to be, conclusions about what to do must be altered accordingly. Again, the reaction among logicians to Hegelian attempts to merge logic into metaphysics certainly went too far. There is a genuine philosophical problem about the relation between the world of logic and the world of fact, and it cannot be solved by simply repeating that logic is an autonomous discipline whose principles deserve respect in themselves. None of this, however, shows that metaphysics is the fundamental philosophical discipline, the branch of philosophy that has the last word about what goes on in all other parts of the subject.

METAPHYSICS AND ANALYSIS

Modern British and American philosophers commonly describe themselves as engaged in philosophical analysis, as opposed to metaphysics. The interests of a metaphysician, according to this view, are predominantly speculative; he wants to reveal hitherto unknown facts about the world and on that basis to construct a theory about the world as a whole. In so doing he is necessarily engaged in activities that rival those of the scientist, with the important difference that scientific theories can be brought to the test of experience, whereas metaphysical theories cannot. Eschewing this conception of philosophy as impossible, the critic of metaphysics believes that philosophy should confine itself to the analysis of concepts, which is a strictly second-order activity independent of science and which need involve no metaphysical commitment.

Analysis in philosophy

The notion of analysis in philosophy is far from clear. Analysis on any account is meant to result in clarification, but it is not evident how this result is to be achieved. For some, analysis involves the substitution for the concept under examination of some other concept that is recognizably like it (as Gilbert Ryle, an English Analyst, elucidated the concept of mind by replacing it with the notion of "a person behaving"); for others, analysis involves the substitution of synonym for synonym. If the latter understanding of analysis is required, as in Moore's classic example of the analysis of brother as male sibling, not much enlightenment is likely to ensue. If, however, the philosopher is permitted to engage in what is sometimes pejoratively described as "reductive analysis," he will produce interest at the cost of reintroducing speculation. Ryle's *Concept of Mind* (1949) is a challenging book just because it advances a thesis of real metaphysical importance—that one can say everything one needs to say about minds without postulating mental substance.

A further aspect of the situation that deserves mention is this. If it is the case, as is often claimed, that analysis can be practiced properly only when the analyst has no metaphysical presuppositions, by what means does he select concepts for analysis? Would it not be appropriate for him, in these circumstances, to take any concept of reasonable generality as a suitable subject on which to practice his art? It turns out, in fact, however, that the range of concepts commonly recognized as philosophical is more limited than that, and that those concepts to which Analytic philosophers give their attention are chosen because of their wider philosophical bearings. Thus, recent philosophers have paid particular attention to the concept of knowledge not just because it is a notion whose analysis has long proved difficult but also because on one account at least it involves an immediately experienced mental act—something that many Analysts would like to proscribe as mythical. Similarly, the celebrated analysis of the idea of causality put forward by David Hume was not undertaken out of idle curiosity but with a wider purpose in mind: to undermine both the Aristotelian and the Cartesian views of the world and to substitute for them an atomism of immediate appearances in which all objects were "loose and separate"—that is, logically independent one of another. The insight into the constitution of nature promised in different ways by Aristotle and Descartes was an illusion, the truth being that scientific advance serves only to "stave off our ignorance a little." What Hume said about causation connects internally with his views about what exists. Despite his polemic against books of "divinity and school metaphysics," he had a metaphysics of his own to recommend.

Historical use of analysis by metaphysicians

The truth is that metaphysics and analysis are not separate in the way modern Analytic philosophers pretend. The speculative philosophers of the past were certainly not averse to analysis: witness the splendid discussion of the concept of knowledge in Plato's *Theaetetus*, or, for a more recent example, Bradley's account of the meanings of "self." The legend that a metaphysical philosopher has his eye so firmly set on higher things that he is entirely careless of the conceptual structure he seeks to recommend is absolutely without foundation. A metaphysical philosopher is a philosopher after all: argument and the passion for clarification are in his blood. Although some contemporary philosophers profess to undertake analysis entirely for its own sake and without explicit metaphysical motivation, it may be doubted if their claim is capable of being sustained. The "logical analysis" practiced by Russell in the early part of the 20th century was not metaphysically neutral, nor was the analysis of the Logical Positivists, who recommended a strongly scientific view of the world. Some current analytic work is motivated less by the desire to forward an overall theory than by a wish to destroy a prevailing or previously held theory that is considered objectionable. To seek to overthrow a metaphysical theory, however, is itself to engage in metaphysics—not very interesting metaphysics, perhaps, but metaphysics all the same.

It may be added, as a historical note, that the Rationalist philosophers of the 17th and 18th centuries, who emphasized the predominant role of reason in the construction of a system of knowledge, believed that the philosopher's task fell into two parts. He must first break down complex concepts into their simple parts; this was a matter of analysis. Then he must proceed to show how knowledge of these simples would serve to explain the detailed constitution of things; this would involve synthesis. That there are deep obscurities in this program—*e.g.*, whether it is a matter of analyzing concepts or getting down to the simplest elements of things—is less important in the present context than that analysis and synthesis were thus taken to be complementary. The classical statement of this point of view is to be found in Descartes's *Discours de la*

méthode (1637; *Discourse on Method*), with the corresponding passages in the *Regulae ad Directionem Ingenii* (published posthumously 1701; *Rules for the Direction of the Mind*). That the idea persisted well into the 18th century is evidenced by the remarks made by Kant in his essay *Untersuchung über die Deutlichkeit der Grundsätze der natürlichen Theologie und der Moral* (1764; *Inquiry into the Distinctness of the Principles of Natural Theology and Morals*), in which he said that metaphysics was not yet in a position to pass beyond the stage of analysis to that of synthesis. He did not mean that for the time being philosophy must remain entirely nonmetaphysical, in the way some moderns suppose it can, but rather that it needs to go on elaborating a conceptual scheme, which, however, cannot be used constructively until it is complete. Actually, Kant belied his own professions at the time insofar as he thought himself in possession of a definitive proof of God's existence, which he explained in his essay *Der einzig mögliche Beweisgrund zu einer Demonstration des Daseyns Gottes* (1763; "The Only Possible Ground for a Demonstration of the Existence of God"). This, however, only illustrates the not very surprising fact that philosophers are often less clear about the nature of their own activities than they think.

Problems in metaphysics

To give a comprehensive account of the main problems of metaphysics in the space of a few pages is clearly quite impossible. What follows is necessarily highly selective and to that extent misleading; it, nevertheless, attempts to offer an introduction to metaphysical thinking itself rather than reflection on the nature of metaphysics.

THE EXISTENCE OF FORMS, CATEGORIES, AND PARTICULARS

Forms. The early Greek philosophers asked the question *ti to on*, "What is existent?" or "What is really there?" They originally interpreted this as a question about the stuff out of which things were ultimately made, but a new twist was given to the inquiry when Pythagoras, in the late 6th century BC, arrived at the answer that what was really there was number. Pythagoras conceived what is there in terms not of matter but of intelligible structure; it was the latter that gave each type of thing its distinctive character and made it what it was. The idea that structure could be understood in numerical terms was probably suggested to Pythagoras by his discovery that there are exact correlations between the lengths of the strings of a lyre and the notes they produce. By a bold extrapolation he seems to have surmised that what held in this case must hold in all cases.

Platonic theory

The Pythagorean theory that what is really there is number is the direct ancestor of the Platonic theory that what is really there is Forms, or Ideas (*eidē*, or *ideai*). Plato's Forms were also intelligible structures and not material elements, but they differed from Pythagorean numbers by being conceived of as separately existent. There was, as Plato put it, a "place accessible to the intelligence," which was the place, or realm, of Forms. Each Form was a genuine existent, in the sense of being precisely what it pretended to be; the Form of Beauty, for example, was beautiful through and through. By contrast, the many particular things that partook of or resembled what was truly beautiful were one and all defective. However beautiful any one of them might be, it was also in another respect lacking in beauty. It turned out to possess contradictory characteristics, and as such could never be identified with true reality.

Plato had taken over from his predecessor Heracleitus, who flourished at about the beginning of the 5th century BC, the doctrine that the world of sensible things is a world of things in constant flux; as he put it in the *Theaetetus*, nothing *is* in this world because everything is in a state of becoming something else. Forms were needed to provide stable objects for knowledge as well as to answer the question of what is ultimately real. Although Plato played down the reality of sensible things, making them mere objects of opinion and describing them as falling between what is and what is not, he did not deny their existence. It was not his thesis that Forms alone exist. On the contrary, he appears to have held that God (who was certainly not a Form) had somehow fashioned the physical world on the model of the Forms, using space as his material. This is the description that is given in the *Timaeus*, in a passage that Plato perhaps meant his readers not to take quite literally but that stated his view as plainly as he thought it could be stated. In this passage God appears in the guise of the "Demiurge," although he is referred to freely in other Platonic dialogues. Souls were also distinct from Forms in Plato's thought.

In the discussions that developed around the theory of Forms, many difficulties were revealed, most of them familiar to Plato himself. The question of how the one Form was supposed to relate to the many particulars that participated in or resembled it was nowhere satisfactorily answered. The difficulty turned on how the Form was to be thought of at once as an existent and as a structure. Plato seemed on occasion to think of it as a structure hypostatized, or given real existence. This thesis led to the antinomies exposed in the "third man" argument. According to this theory, particular men were alleged to be human because of their relationship to "Man himself"; *i.e.*, the Form of man. But whence did the latter derive its nature? Must there not be a second Form to explain what the first Form and its particulars have in common, and will not this generate an infinite regress? Again, the problem of the precise population of the world of Forms never got a definitive solution, perhaps because the theory of Forms was put to more than one purpose. Sometimes it was said that there is a Form corresponding to every general word, but elsewhere the theory was that what is merely negative (*e.g.*, lifeless) has no need of a special Form, nor does what is manufactured. There is even a question as to whether trivial everyday things such as mud and hair and dirt have Forms, though it is agreed that there is a Form of man.

The problems just referred to were stated trenchantly in Plato's dialogue the *Parmenides*; the discussion there ends with the statement that the Forms must be retained if an account of intelligible discourse is to be given, but no indication is offered as to how the theory is to be refurbished. Some Platonic scholars have inferred that Plato virtually gave it up, but such evidence as there is suggests that he only transformed it into a theory of Form-numbers, more openly Pythagorean than the earlier version. There are many references in Aristotle to this theory of Form-numbers, but no writing of Plato's own on the subject has survived, and it is virtually impossible at this late stage to say what this theory really comprised.

One further feature of the theory of Forms must be mentioned here: the view that there is a supremely important Form, the Form of goodness, or of the Good, which somehow determines the contents of the world of Forms and brings order into it. In a celebrated but brief and tantalizing passage in *Politeia*, the Form of the Good is spoken of as being to the intelligible realm what the sun is to the visible realm; just as the sun makes living things grow and renders them visible, so the Good is responsible for the existence and intelligibility of Forms, though it is itself "on the other side of Being." This passage had a tremendous historical influence on the Neoplatonists, who saw it as anticipating the ultimate ineffable reality—the One, from which everything describable was in some way an emanation—in which they came to believe. It seems possible, however, that Plato had no such mystical thoughts in mind but simply wanted to say that the world of Forms is ordered through and through, everything in it being there for a purpose. The Form of Good is, in fact, the counterpart of the nous (Mind) of Anaxagoras, another of Plato's predecessors, which was supposed to arrange everything for the best.

Aristotelian doctrine

Categories and universals. The most famous critic of Plato's theory of Forms was Aristotle, who devised his doctrine of categories largely to counter it. According to this doctrine, "being is spoken of in many ways": one can say that there are such things as individual horses, but one can also say that there is such a thing as being a horse, or as being upside down. Expressions can be classified

under various heads: predicates signify substances (*e.g.*, "man" or "horse"), qualities (*e.g.*, "white"), relations (*e.g.*, "greater"), quantities (*e.g.*, "three yards long"), time (*e.g.*, "last year"), and so on—sometimes Aristotle listed ten categories, sometimes only eight. The kind of being that any predicate possesses, however, is derivative in comparison with the being of an individual substance, a particular man or a particular horse. It is such things that exist in the primary sense, and it is upon their existence that the existence of other types of being depends. Or, to put the point in not quite Aristotelian terms, primary substances are the only concrete existents; Socrates, the bearer of a proper name, exists in a way in which humanity or whiteness or being greater do not. The latter are really no more than abstractions, and nothing but confusion can arise from neglecting that fact.

Mention has already been made of the difficulties into which this doctrine led when it came to describing primary substances; it appeared that these entities could not be characterized but only named or pointed to, a conclusion accepted much later by Ludwig Wittgenstein, a 20th-century philosopher, in his *Tractatus Logico-Philosophicus* and by Russell in his lectures on logical atomism. These difficulties, however, were not seen at the time the theory was promulgated, and it is more important here to emphasize the fact that it undermined any doctrine of the Platonic type. To argue that Forms, or numbers, alone are real is to argue for the reality of abstractions; to put the point succinctly, beauty exists only so long as something is beautiful, and that something must be a concrete individual. Or if this is not quite true (for, after all, it could be said that there is such a thing as having a million sides even if nothing in fact has a million sides), concrete existence must precede abstract existence in some cases at least: the "*x*" in "*x* is red" must sometimes be replaceable by an actual rather than a merely possible entity.

The problem of universals

A prominent subject of philosophical discussion in the Middle Ages was what came to be known as the problem of universals, which concerned the ontological status, or type of existence, to be assigned to the referents of general words. One of Plato's critics had said, "I see particular horses, but not horseness"; and Plato had answered, "That is because you have eyes but no intelligence." There can be no doubt that Plato thought that horseness, the Form of horse, or Horse itself, to use his own expression, was something that existed separately; it could be discerned not by the bodily eyes but by the eye of the soul. The view that besides individual horses there also exists the Form of horse was known in the Middle Ages as Realism. Aristotle was also alleged to be a Realist, because he too thought that Forms were really there, although only as embodied in particular instances. More skeptical philosophers denied the reality of universals altogether, some identifying them with thoughts (conceptualists), others with mere names (nominalists).

The dispute about universals was in fact very confused. At least two quite separate issues were involved. First of all, there was the question about the status to be assigned to whatever it was that predicates referred to; this question seemed urgent just because, for example, geometricians were able to discuss the properties of the triangle or the circle. What and where were the triangle and the circle? In fact, the Aristotelian doctrine of categories had already indicated that the being of any predicate was necessarily different from that of primary substances; the circle did not and could not exist as this man or this horse did. When Aristotle is described as a Realist in the dispute about universals, the description is very misleading. In one sense he did not believe that universals are real at all; in another sense, however, he did, and this is where the second issue arose. Some people who denied the reality of universals wanted to say that all classification is artificial; the descriptions men give of things depend upon their interests as much as upon what is really there. Aristotle, by contrast, believed in a doctrine of natural kinds; he thought that every particular horse, for example, embodied the form or objective essence of horse, which was accordingly a genuine, if abstract, constituent of the world. The question of the extent to which classification is artificial is clearly quite different from that of the status of universals; it remains to be answered even if the latter problem is dismissed, as it is by modern philosophers who say that only proper names and individuating phrases have referents; general words do not. These differences, however, were not clearly seen either in the Middle Ages or during the 17th century, when the whole question was discussed at length by philosophers such as Thomas Hobbes and John Locke.

Basic particulars. In discussions of the problem of universals, it was frequently claimed, especially by nominalists, that only particulars exist. The notion of a particular is in many respects unclear. Strictly speaking, the terms particular and universal are correlatives; a particular is an instance of universal (for example, this pain, that noise). It would seem from this that particulars and individuals should be the same, but there are writers who distinguish them. Bradley, in his *Principles of Logic* (1883), treated particulars as mere momentary instantiations of universals and contrasted them with individuals as continuants possessing internal diversity. An individual can be not merely identified but also re-identified; because it lasts through time, it may possess incompatible attributes at different periods of its history. A particular, on the other hand, is nothing but an instantiation of an attribute and as such must possess that attribute if it is to be anything. Similarly, a particular can be met with once, but not again; as time moves on, it passes out of existence and is replaced by another particular that may resemble it but is not literally identical with it.

If particulars and individuals are thus distinguished, it is by no means clear that only particulars exist, or indeed that they exist at all; it could be that they are no more than abstract aspects of genuinely concrete entities such as persons or material things. But there are arguments on the other side, advanced in a variety of forms by David Hume and Bertrand Russell. Hume believed that the ultimate constituents of the world were either impressions or their fainter copies, ideas; both were species of perceptions. Impressions he defined as "internal and perishing existences"; they were of various kinds, embracing feelings as well as such things as experienced colours and smells, but all were at best extremely short-lived. Impressions arose in human consciousness from unknown causes; their existence could not, however, be denied. By contrast, the existence of continuing and independent material objects and of continuing minds was extremely precarious; analysis showed both to be no more than bundles of perceptions, united by certain relations, and Hume more than once referred to them as "fictions," although it turned out on examination that they were not fictions in the way ghosts are. Hume's reasons for advancing these views were primarily epistemological; he thought that statements about continuants were all open to doubt, although statements about the contents of immediate experience could not be challenged. When it was a question of what really existed, the only sure answer was items in consciousness—namely, impressions and ideas.

Hume's theory of particulars

Russell, who was generally sympathetic to this answer, added another argument derived from logic: proper names, he said, were names of particulars, which must accordingly exist. Ordinary proper names (such as "Socrates") had other functions than to denote, but logically proper names ("this" was Russell's example) served simply to pick out objects of immediate acquaintance. Russell was apparently unabashed by the consequence that such objects would be both private to the experience of particular persons and of very brief duration; he thought his doctrine of "logical constructions," which allowed for "inferred entities" on the basis of what is immediately certain, would provide the publicity and continuity necessary to do justice to actual experience. These assumptions, however, have met with serious criticism. P.F. Strawson, a British philosopher whose thought centres on the analysis of the structure of ordinary language, especially in his *Individuals: An Essay in Descriptive Metaphysics* (1959), not only attacked Russell's account of proper names but argued that experience demands a framework of basic particulars that are not Russell's momentary private objects but continuing

Russell's theory of particulars

public existents—in fact, individuals in the terminology explained above. If experience consisted of nothing but sounds, the minimum prerequisite of intelligibility would be that there should be a continuing master sound, an analogue in this medium of continuing material substance in the material order. Without such basic particulars as continuing material things, identification and reidentification would be impossible. Strawson conceded that persons as well as things were genuine continuants, but maintained all the same that the hypothesis that reality might consist of nothing but minds was quite untenable. Minds are no more than aspects of persons, and persons have bodies as well as minds. Strawson agreed that disembodied existence was logically possible, but added that such existence would make no sense except as a survival of embodied existence in a common public world.

If this is correct, what exists cannot consist, as Hume supposed, of momentary items but must rather take the form of substances in the Aristotelian sense. These act as basic particulars in the actual intellectual scheme men adopt. Strawson, however, was not content merely to assert this fact; he wanted to argue that things must be like this if reference and description in their familiar form are to be possible at all. His main theory, which plainly owes a debt to Kant as well as to Wittgenstein, was worked out with primary reference to the physical world. It would be interesting to know if an examination of social reality would yield comparable results: whether individual persons or something larger—continuing societies or institutions—should be taken as basic particulars in that sphere. Many philosophers assert dogmatically that a society is nothing but an aggregate of its individual members. Nevertheless, men are members of society in virtue of their performance of a number of social roles, and role itself is a concept that makes sense only if the notion of society is presupposed. In one sense, a society is nothing apart from its members; remove them, and it would disappear. Equally, however, the members themselves are what they are because of their various roles; it is arguable that they would be nothing apart from their social relations. Hence, the force of Bradley's remark is evident, namely, that "the 'individual' apart from the community is not anything real."

It remains to add here that a number of philosophers have tried to argue that the basic items in reality should be described not as substances but in some other terms. Russell at one stage in his career spoke of the world as consisting of events; his former colleague A.N. Whitehead made the notion of process central in his metaphysics. Developments in modern physics undoubtedly lend a certain plausibility to these and similar views. Yet it remains difficult to understand what an event could be in which nothing was concerned, or how there could be a process in which nothing was in process. Event and process, in fact, are expressions that belong to derivative categories in the general Aristotelian scheme; like all other categories, they depend on the category of substance. If the latter is removed, as these metaphysicians propose to remove it, it is hard to know what is left.

THE EXISTENCE OF GOD

Proofs of the existence of God

Perhaps the most celebrated issue in classical metaphysics concerned the existence of God. God in this connection is the name of "the perfect Being" or "the most real of all things"; the question is whether it is necessary to recognize the existence of such a being as well as of things that either are or might be objects of everyday experience. A number of famous arguments have been advanced from the time of the Greeks in favour of the thesis that such a recognition is necessary. The neatest and most ingenious was the a priori argument of St. Anselm in the 11th century, who said that "that than which nothing greater can be conceived" must exist in fact as well as in thought, for if it existed only in thought and not in fact, something greater than it could be conceived, namely the same thing existing in fact. God necessarily exists, because the idea of God is the idea of that than which nothing greater can be conceived. This is the argument later known as the ontological proof. Relatively few philosophical theologians, either in the Middle Ages or later, could bring themselves to accept this bold piece of reasoning (although Descartes, Spinoza, Leibniz, and Hegel all accepted it in principle); most preferred to ground their case for God's existence on premises that claimed to be empirical. Thus, St. Thomas Aquinas, perhaps the most influential Scholastic philosopher, in the 13th century argued that to explain the fact of motion in the world, the existence of a prime mover must be presupposed; that to account for contingent or dependent being the existence of something that is necessary or self-contained must be presumed; that to see why the world is orderly and why the different things in it fit together harmoniously, a situation that might not have obtained, a Creator who fashioned it on these lines must be postulated—adding in each case "and this all men call 'God'." These are versions of the first cause argument and the argument from design, which were to figure prominently in the thinking of later theistically inclined metaphysicians.

The first cause argument should, perhaps, be examined in somewhat greater detail, because it both has an immediate plausibility and lies at the basis of many different kinds of metaphysical systems (that of Hegel, for example, as well as that of Aquinas). The argument begins with the innocent-looking statement that something contingent exists; it may be some particular thing, such as oneself, or it may be the world in general (thus, the description of the proof as being *a contingentia mundi,* or "from the contingency of the world"). In describing oneself or the world as contingent, one means only that the thing in question does not exist through itself alone; it owes its being to the activity of some other thing, as a person owes his being to his parents. Contingent things are not self-complete; they each demand the existence of something else if they are to be explained. Thus, the move is made from contingent to necessary being; it is felt that contingent things, of whatever order, cannot be endlessly dependent on other contingent things but must presuppose a first cause that is self-complete and so exists necessarily. In Hegel the necessary being is not a separate existent but, as it were, an order of things; the loose facts of everyday life and even of science are said to point to a system that is all-embracing and in which everything is necessarily what it is. The principle of the argument, however, is unchanged despite the change in the conclusion.

Criticisms of proofs

Damaging criticism was brought against all the traditional arguments for God's existence by Hume and Kant in the 18th century. The ontological proof was undermined by the contention that "being is not a real predicate"; existence is not part of the concept of God in the way in which, for example, being all-powerful is. To say that something exists is not to specify a concept further but to claim that it has an instance; it cannot be discovered whether a concept has an instance by merely inspecting it. The first cause argument, it was contended, suffers from two fatal weaknesses. Even if it is correct in its assertion that contingent being presupposes necessary being, it cannot identify the necessary being in question with God (as happened in each of the Thomistic proofs) without resurrecting the ontological argument. If it is true, as supporters of the causal proof suppose, that God alone can answer the description of a necessary being, then whatever exists necessarily is God and whatever is God exists necessarily. Modern supporters of the causal proof have tried to meet this objection by saying that the equivalence is one of concepts, not of concept and existent; the existence of a necessary being is already established in the first part of the argument, and the equivalence in the second part of the argument is between the concept of necessary being and the concept of God. In other words, they distinguish between existence and essence. In the first part of the argument, the existence of a necessary being is proved; in the second part of the argument, the essence of that necessary being is identified with what men call God. Beyond this first contended weakness, however, there are grave difficulties in the move from contingent to necessary existence. Things in the experienced world are causally related, and some account of this relationship can be given in terms of the temporal relations of events; causal relations hold primarily between kinds of events, and a cause is, at least,

a regular antecedent of a specific kind of effect. But when an attempt is made to extend the notion of causality from a relationship that holds within experience to one that connects the experienced world as a whole to something that falls wholly outside it, there is no longer anything firm on which to hold. The activities of God cannot precede happenings in the world because God is, by definition, not in time; and how the relationship is to be understood in these circumstances becomes highly problematic. Some metaphysicians, like some recent theologians, seek to evade the difficulty by saying that God is not the cause of the world but its ground, or again by distinguishing causes of becoming, which are temporal, from a cause of being, which is not. It is doubtful whether these moves do more than restate the problem in different terms.

The argument from design is itself a form of causal argument and accordingly suffers from all the difficulties mentioned above, together with some of its own, as Hume and Kant both point out. Even on its own terms it is wrong to conclude the existence of a Creator rather than an architect. Furthermore, it infers that the being in question has unlimited powers, when all that the evidence seems to warrant is that its powers are very great. The argument lost much of its force by the publication of the English naturalist Charles Darwin's theory of natural selection. The unbroken reign of law throughout natural evolution is impressive, but as a line of reasoning it does not seem to bear close examination.

The metaphysical problem of God's existence is more of an issue today than the problem of universals; there are still thinkers who hope to restate the old proofs in more convincing ways. The ontological proof, in particular, has won renewed attention from thinkers such as Norman Malcolm, a philosopher strongly influenced by Wittgenstein, and Charles Hartshorne, an American Realist whose form of theism is called panentheism (the doctrine of a God who has an unchanging essence but who completes himself in an advancing experience). Increasingly, however, philosophers of religion are preoccupied not with these metaphysical abstractions but with the status and force of actual religious claims. "The most real of all things" is no longer at the centre of their attention: they seek to investigate God as a suitable object for worship.

THE SOUL, MIND, AND BODY

Platonic and Aristotelian theories of the soul

The soul–body relationship. As well as believing in the reality of Forms, Plato believed in the immortality of the human soul. The soul was, he thought, an entity that was fundamentally distinct from the body although it could be and often was affected by its association with the body, being dragged down by what he called in one passage "the leaden weights of becoming." The soul was simple, not composite, and thus not liable to dissolution as were material things; further, it had the power of self-movement, again in contrast to material things. Ideally the soul should rule and guide the body, and it could ensure that this situation persisted by seeing that the bodily appetites were indulged to the minimum extent necessary for the continuance of life. The true philosopher, as Plato put it in the *Phaedo,* made his life a practice for death because he knew that after death the soul would be free of bodily ties and would return to its native element. He also thought that the soul was "akin" to the Forms; it was through the intellect, the purest element in the soul, that the Forms were discovered.

Plato mentioned and attempted to refute alternative accounts of the relationship of soul and body, including a Pythagorean view that described the soul as an "attunement" of the body and thus tried to explicate it as a form or structure rather than an independently existing thing. A theory of this kind was worked out but not taken to its logical conclusion by Aristotle in his treatise *De anima* (*On the Soul*). Aristotle defined soul in terms of functions. The soul of a plant was concerned with nutrition and reproduction, that of an animal with these and with sensation and independent movement, that of a man with all these and with rational activity. The soul was, in each case, the form of some body, and the clear implication of this was that it would disappear as the body in question dissolved. To be more accurate, the soul was the principle of life in something material; it needed the material element to exist, although it was not itself either material or immaterial but, to put it crudely, an abstraction. Even though Aristotle was clearly committed by everything he said in the earlier parts of the *De anima* to the view that the soul is not anything substantial, he nevertheless distinguished toward the end of this work between what he called the active and the passive intellects and spoke of the former in Platonic terms. The active intellect was, it appears, separate from the rest of the soul; it came "from outside" and was in fact immortal. It was, moreover, essential to the soul considered as rational, for "without this nothing thinks." Aristotle thus showed the Platonic side of his thought in the very act of trying to emancipate himself from this aspect of Platonism.

Cartesian theory

The mind–body relationship. In more recent metaphysics less has been heard of the soul and more of the mind; the old problem of the relationship of soul and body is now that of the relationship of mind and body. Most, if not all, subsequent discussion of this subject has been affected by the thinking of Descartes. In his *Meditationes de Prima Philosophia* (1641; *Meditations on First Philosophy*), he argued that there was a total and absolute distinction between mental and material substance. The defining characteristic of matter was to occupy space; the defining characteristic of mind was to be conscious or, in a broad sense of the term, to think. Material substance was, so to speak, all one, although packets of it were more or less persistent; mental substance existed in the form of individual minds, with God as the supreme example. The mental and the material orders were each complete in themselves, under God; it was this fact that made it appropriate for him to use the technical term substance in this context: mental substance and material substance. The logical consequence of this view, drawn by some later Cartesians, was that there can be no interaction between mind and body; all causality is immanent, within one order or the other, and any appearance of mind affecting body or of body affecting mind must be explained as the result of a special intervention by God, who, on the occasion of changes in one substance, brings it about that there are corresponding changes in the other. Descartes himself, however, had no sympathy with this view, which was called occasionalism. On the contrary, he stated explicitly that he was not in his body as a pilot is in a ship but was "more intimately" bound up with it. Mind could affect body and vice versa because mind and body had a specially close relationship, which was particularly evident in the aspects of conscious life that have to do with sensation, imagination, and emotion as opposed to pure thought.

Descartes's conviction that, despite their intimate union in this life, mind is really distinct from body sprang from his confidence in the cogito argument. It was possible, he believed, to doubt the existence of his body (what was certain was only that he had the experience of having a body, and this might be illusory) but not the existence of his mind, for the very act of doubting was itself mental. That mind existed was evident from the immediate testimony of consciousness; that body existed was something that needed an elaborate proof, involving his doctrine of clear and distinct ideas and his attempt to establish the existence of a God who is no deceiver. Apart from this, Descartes appealed to arguments of a broadly Platonic type to bring out what was truly distinctive about mind. He admitted that sensation and imagination could be understood only if referred to the mind–body complex but contended that acts of the pure intellect and of will (here his thought was influenced by that of St. Augustine, the great 5th-century Christian thinker) belonged to the mind as it was in itself. Descartes did not claim to have a philosophical proof of the immortality of the soul—that, in his view, required the assurance of revelation—but he did think that his theory prepared the way for that doctrine by establishing the separate existence of mind.

The Cartesian account of mind and body had many critics even in Descartes's own day. Hobbes argued that nothing existed but matter in motion; there was no such thing

as mental substance, only material substance. Materialism of a sort was also supported by Descartes's correspondent Pierre Gassendi, a scientist and Epicurean philosopher.

Theory of Spinoza

A generation later Spinoza was to refashion the whole Cartesian metaphysics on bold lines. In place of the two distinct substances, each complete in itself yet each liable to external interference should God will it, Spinoza posited a single substance, God or Nature, possessed of infinite attributes, of which the mental and the material alone are known to men. The "modes," or manifestations, of this substance were what they were as a result of the necessities of its nature; arbitrary will neither did nor could play any part in its activities. Whatever manifested itself under one attribute had its counterpart in all the others. It followed from this that to every mental event there was a precisely corresponding physical event, and vice versa. A man was thus not a mysterious union of two different elements but a part of the one substance that, like all other parts, manifested itself in different ways under different attributes. Spinoza did not explain why it was that physical events could be correlated with mental events in the case of a human being but not in that of, for example, a stone. His theory of psycho-physical parallelism, however, has persisted independently of his general metaphysics and has found supporters even in modern times.

One way in which Spinoza threw fresh light on the mind–body problem was in calling attention to the influence of the body on the mind and in taking seriously the suggestion that they be treated as a single unit. In this respect, his work on the subject was far in advance of the Empiricist philosophers of the next century. Hume notoriously dismissed Cartesian substance as a "chimera" and argued that minds and bodies alike were nothing but "bundles of perceptions," interaction between which was always possible in principle; in practice, however, he stuck to the old-fashioned view that mind is one thing and body another and did nothing to explore their actual relationships. Empiricist philosophy of mind, both in Hume and in his successors, such as James Mill, was generally crude; it consisted largely in an attempt to explain the entire life of the mind in terms of Hume's ontology of impressions and ideas. Nor did Kant make much, if any, advance in this particular direction, convinced as he was of the necessity of accepting an empirical dualism of mind and body. It was left to Hegel and the Idealists to look at the problem afresh and to bring out the way in which mental life and bodily life are intimately bound together. The accounts of action and cognition given by T.H. Green and Bradley, and more recently by R.G. Collingwood, are altogether more enlightening than those of Empiricist contemporaries just because they rest on a less dogmatic basis and a closer inspection of fact.

Modern theories

No metaphysical problem is discussed today more vigorously than that of mind and body. Three main positions are held. First, there are still writers (*e.g.*, H.D. Lewis in his work *The Elusive Mind* [1969]) who think that Descartes was substantially right: mind and body are distinct, and the "I" that thinks is a separate thing from the "I" that weighs 170 pounds. The testimony of consciousness is invoked as the main support of this conclusion; it is alleged that all men know themselves to be what they are, or at least who they are, apart from their bodily lives; it is alleged again that their bodily lives present themselves as experiences—*i.e.*, as something mental. The existence of mind, as Descartes claimed, is certain, that of body dubious and perhaps not strictly provable. Second, there are writers such as Gilbert Ryle who would like to take the Aristotelian theory to its logical conclusion and argue that mind is nothing but the form of the body. Mind is not, as Descartes supposed, something accessible only to its owner; it is rather something that is obvious in whatever a person does. To put it crudely, mind is simply behaviour. Finally, there are many philosophers who, although more generally sympathetic to the second solution than to the first, wish to provide for an "inner life" in a way in which Behaviourism does not; P.F. Strawson is a typical example. To this end they try to assert that the true unit is neither mind nor body but the person. A person is something that is capable of possessing physical and mental predicates alike. This is, of course, to say that the "I" that knows simple arithmetic and the "I" that has lost weight recently are the same. How they can be the same, however, has not so far been explained by supporters of this view.

Aside from these main positions, an interesting development is the stress laid by writers—such as Stuart Hampshire, an "ordinary language" philosopher—on self-activity as the distinguishing characteristic of mind. According to this view, a human being is a body among bodies but is, as Plato said, self-moving as material things are not. That this should be so—that human beings are possessed of wills and can in favourable circumstances act freely—is taken as an ultimate fact neither requiring nor capable of explanation. It is often denied that any scientific discovery could give rational grounds for questioning this fact. It is also stressed that the causality of a human being is fundamentally different from that of a natural subject, intentional action being quite other than mere behaviour determined from without.

The problem of differentiating men and machines

Connected with these topics is the problem, much discussed in recent philosophy as a result of the rise of cybernetics, of what differentiates men from machines. Two answers used to be given: the power to think and consciousness. Now, however, there exist machines whose calculating abilities far surpass those of any human being; such machines may not literally think, but they certainly arrive at conclusions. Furthermore, it is not true that their operations are of a purely routine nature: there is a sense in which they can improve their performance in the light of their "experiences." They even have an analogue of consciousness in the sensitivity they show to external stimuli. These facts suggest that the gap between minds and machines is less wide than it has often been thought to be; they do not, however, destroy it altogether. Human beings possess powers of creative thought unlike anything found in machines; as Noam Chomsky, an American linguistics scholar, has stressed (and as Descartes urged in his *Discours de la méthode*), the ability of human beings to handle language in such a way that they comprehend any one of an infinite number of possible expressions is something that cannot be explained in mechanical terms. Again, as J.R. Lucas, a British philosopher, has argued, human beings have the ability to diagnose and correct their own limitations in a way to which there is no parallel in machines. As some older philosophers put it, man is a being with the power of self-transcendence; he can work within a system, but he can also move to another level and so see the shortcomings of the system. A machine can only work within a system; it operates according to rules but cannot change them of its own accord.

Finally, mention should be made of an extreme Materialist solution to the mind–body problem: this solution holds that states of mind are in fact states of the brain. Supporters of this theory agree that the two are separate in idea but argue that physiology shows that despite this they are contingently identical. What seems to be a state of mind, above all to its possessor, is really a state of the brain, and mind is thus reduced to matter after all. It is not clear, however, why physiologists should be granted the last word on a topic like this, and, even if it were agreed that they should be, the correlations so far established between mental occurrences and states of the brain are at best sketchy and incomplete. Central-state Materialism, as this theory is called, professes to have the weight of contemporary science behind it, but it turns out in fact to have drawn to a remarkable degree on what it thinks will be the science of tomorrow.

NATURE AND THE EXTERNAL WORLD

The problem of the existence of material things, first propounded by Descartes and repeatedly discussed by subsequent philosophers, particularly those working within the Empiricist tradition, belongs to epistemology, or the science of knowledge, rather than metaphysics; it concerns the question of how it can be known whether there is a reality independent of mind. There are, however, problems about nature and the external world that are genuinely metaphysical.

The reality of material things. There is first of all

the question of the status, or standing, of material things, the kind of being they possess. It has been repeatedly suggested by metaphysical philosophers that the external world is in some way defective in reality, that it is a mere phenomenon, something that seems to be what it is not. Plato, as has already been pointed out, held that objects of the senses generally answered this description; they each appeared to possess characteristics that they could not in fact have (water could not be at once hot and cold) and were to that extent delusive rather than real. There was no stability in the world of phenomena and therefore no true reality. In taking this view, Plato drew no contrast between the world of nature and the world of man, although he undoubtedly believed that souls had a superior status. Leibniz, a later philosopher who also followed this general line of thought, began by explicitly opposing souls to material things. To speak precisely, nothing truly existed except monads, and monads were souls, or spiritual beings: all had perceptions, although these varied enormously in degree of clarity (the perceptions of the monads constituting what is commonly called a stone were singularly faint). Although the final description of the world must thus be given in mental terms, it did not follow that nature as normally perceived is a total illusion. Men perceive as well as think, and, although perception is in fact simply a confused form of thought, it is not for that reason to be set aside altogether. The world of nature, the world of things in space and time, is, as Leibniz put it, a "well-founded phenomenon"; it is what all men must judge to be there, given that they are not pure intellects but necessarily remain to some extent prisoners of their senses.

The external world as defective in reality

A theory on somewhat similar lines was worked out by Kant in the *Kritik der reinen Vernunft* (1781; *Critique of Pure Reason*), despite Kant's explicit dissent from Leibniz' account of perception as confused thinking. Kant contrasted a realm of things as they are in themselves, or noumena, with a realm of appearances, or phenomena. The former are unknown, and indeed unknowable, though it seems clear that Kant tended to think of them on lines like those of Leibniz; phenomena do not exist independently but are dependent on consciousness, though not on any one person's consciousness. Kant expressed this position by saying that things phenomenal are empirically real but transcendentally ideal; he meant that they are undoubtedly there for the individual subject, though when examined from the point of view of critical philosophy, they turn out to be conditioned by the mind through the forms of sensibility and understanding imposed upon them. Kant's most striking argument for this conclusion was that space and time are neither, as the English physicist Sir Isaac Newton supposed, vast containers inside which everything empirical is situated nor, as Leibniz had suggested, relations between things confusedly apprehended but are rather what he mysteriously called "pure intuitions," factors inherent in the sensibilities of observers. Without observers space and time disappear along with their contents; but once the human point of view is assumed, in the form of percipients who are directly aware of the world through their senses, space and time become as real as anything—indeed, more real because of their pervasive character. There is nothing that falls within experience that does not have temporal relations, and all the data of the senses have spatial relations as well.

Kant's arguments in support of his revolutionary thesis about space and time unfortunately depend to a large extent on his mistaken philosophy of mathematics, and they have accordingly been discounted by later philosophers. In modern philosophy the issues raised in these discussions survive only in the form of an inquiry into the status of nature as investigated by the natural scientist. Descartes already pointed out that material things in fact have properties different from those they seem to have; they appear to possess secondary qualities such as colour or smell but turn out when thought about strictly to be colourless and odourless lumps of matter occupying and moving about in space. Locke endorsed this distinction between primary qualities (such as extension, motion, figure, and solidity) and secondary qualities; but George Berkeley, a major British Empiricist of the early 18th century, criticized it sharply as absurd: to imagine something that has primary but no secondary qualities is psychologically impossible. For Berkeley the world of the scientist was a fiction and perhaps not even a necessary fiction at that. It seems clear, however, that Berkeley's arguments do not undermine the important distinction between primary and secondary qualities, where the former are treated as fundamental and the latter as derivative; they are valid only against Locke's mistaken claim that primary qualities are objective and secondary qualities subjective. Whatever the explanation, the fact remains that the scientist often knows why the phenomena are as they are, in contrast to the plain man; to that extent nature as he understands it is truer, if not more real, than nature as it is taken to be in everyday experience. Why this should be is not satisfactorily explained by philosophers who follow Berkeley's lead on this question. Nor has either party to the controversy noted sufficiently the extent to which nature as commonly thought of is conceived as penetrated by mind, both when it is taken as intelligible and, still more interestingly, when poets ascribe to it moods or treat it as kindly or hostile. There is analytic work to be done here to which critical philosophers have still to address themselves.

Primary and secondary qualities of material things

The organizing principles of nature. Connected with the questions just discussed are problems about the organizing principles of nature; *i.e.,* about natural causality. It has been said that the Greeks thought of the world as a vast animal (indeed, the conceptual scheme that Aristotle devised for dealing with nature makes sense only if something like this is presupposed). Nature is the sphere in which different kinds of things are all striving to realize their characteristic form; purpose, though not perhaps explicit purpose, governs it throughout. Aristotle was not entirely insensitive to what are now known as the physical and chemical aspects of the universe, but he treated them as subordinate to the biological aspect in a way modern thinkers find surprising. Even the four elements—earth, air, fire, and water—were seen by him as each seeking its natural place in the cosmos. The contrast between this view and that favoured by Descartes could hardly be sharper. According to Descartes nature is not an organism but a mechanism; everything in it, including animal and human bodies, although not including the human mind, must be understood on mechanical principles. In taking this line, Descartes was endorsing a way of thinking that was central in the new physical science developed by Galileo at the beginning of the 17th century and that was to remain central in the thought of Newton. Descartes himself was not a pure mechanist because he believed that mind was governed by principles of its own; his work, however, undoubtedly encouraged the thought, frequently debated at the time of the Enlightenment, that mental life equally with the physical world must be explicable in mechanical terms. This was a position whose validity at the theoretical level Kant reluctantly admitted, only to try to turn its edge by his dichotomy of theory and practice. Everything in nature, including human behaviour, was subject to causal determination. The dignity and uniqueness of man, however, could be preserved because of the fact that in moral action man raised himself above the sphere of nature by thinking of himself as part of a world of free spirits.

Nature as mechanical or teleological

Kant also produced interesting thoughts on the subject of living phenomena. Reflection on the concept of an organism had convinced him that a being of this sort could never be accounted for satisfactorily in mechanical terms; it was futile to hope that someday in the future there would appear a Newton of biology capable of explaining mechanically the generation of even so apparently simple a thing as a blade of grass. To judge or speak of organic phenomena demanded a special principle that was teleological (*i.e.,* related to design or purpose) rather than mechanical. Kant, however, refused to allow that this principle had constitutive force. It belonged, he said, only to "reflective judgment" and thus did not rank alongside the principles of understanding that were so important in physical science. Men must have recourse to a principle of purposiveness in order to speak of living things, but they must not imagine that such recourse would enable

them to explain their existence and behaviour in any strict sense of the term. They have insight only into what they can produce, and what they can produce are machines, not organisms. Many of Kant's detailed remarks on this subject seem outmoded in the light of subsequent scientific developments; nevertheless, the problem he raised is still the subject of vigorous debate among philosophically minded biologists. His emphasis on the uniqueness of the concept of an organism, which he says is only imperfectly explicated in the language of ends and purposes, is particularly valuable.

It remains to mention the seemingly eccentric view of nature taken by Hegel, who regarded it as at once the antithesis to and a prefiguration of the world of spirit. Nature had to exist to provide material for spirit to overcome, although it was a gross mistake to think of it as essentially a lifeless mechanism. Instead of reducing the organic to the inorganic, men should see the latter as pointing forward to the former, which in turn offered a foretaste of the rational structure exhibited by the world of mind. Hegel's disdain for scientists of proved ability, such as Newton and John Dalton, and his endorsement against them of amateur scientists such as the German writer Goethe, make it hard to take his philosophy of nature seriously. It contains, even so, some interesting points, not least the demonstration that in finding nature to be throughout subject to law the scientist is presupposing that it is thoroughly penetrated by mind. To understand these views properly, however, it is necessary to understand Hegel's system as a whole.

SPACE AND TIME

Many metaphysicians have argued that neither time nor space can be ultimately real. Temporal and spatial predicates apply only to appearances; reality, or what is real, does not endure through time, nor is it subject to the conditions of space. The roots of this view are to be found in Plato and beyond him in the thought of the Eleatic philosophers Parmenides and Zeno, the propounder of several paradoxes about motion. Plato conceived his Forms as eternal objects whose true location was nowhere. Similarly, Christian philosophers conceived of God as existing from everlasting to everlasting and as present in all parts of the universe. God was not so much in space and time as the source of space and time. Whatever falls within space and time is thereby limited, for one space excludes another and no two times can be simultaneous. God, however, is by definition an infinite being and so must exist timelessly and apart from space.

Theories of Kant and Bradley

Reference has already been made to the way in which Kant argued for an intimate connection between time and space and human sensibility: that human beings experience things as being temporally and spatially situated is to be connected with the nature of their minds, and particularly with their sensory equipment. Kant was entirely correct to describe space and time as "intuitions," by which he meant that they are peculiar sorts of particulars; he was right again to insist on the centrality in sensing of the notions of here and now, which can be indicated but not reduced to conceptual terms. It is highly doubtful, however, whether he had sufficient grounds for claiming a priori insight into the nature of space and still more that of time; his case for thinking that space and time are "pure" intuitions was palpably inadequate. The lesson to draw from his careful discussion of this subject might well be not that there must be a form of reality lying beyond space and time but rather that nothing can be real that does not conform to spatial and temporal requirements. Space and time are bound up with particularity, and only what is particular can be real.

It was only in a weak sense that Kant denied the reality of time and space. Other philosophers have certainly been bolder, though generally on the basis of a less solid grasp than Kant possessed of what it is to experience temporally and spatially. Thus, Bradley argued against the view that space and time are "principles of individuation" by alleging that no specification of spatial or temporal position, whether in terms of here and now or by the use of spatial coordinates or dating systems, could achieve uniqueness. Any descriptions such as "at 12 o'clock precisely on January 4, 1962" or "just 75 yards due north of this spot" might apply to infinitely many times or places in the universe, for there was nothing to prevent there being infinitely many temporal and spatial orders. Bradley forgot that the whole meaning of a spatial or temporal description is not exhausted when attention is given to the connotations of the terms used; what has to be considered is the words as used in their context, which is that of a person who can indicate his position in space and time because of the fact that he is himself situated in space and time. One cannot express uniqueness in words as such, but he can use words to express uniqueness. Bradley's suggestion that it is possible to conceive of many temporal and spatial orders is by no means free from controversy. In general, men think of all events as happening before, simultaneously with, or after the moment that is called "now," all spatial positions as relating in some way or other to the point that is called "here." In circumstances where this cannot be done, as with events or places in a dream, men dismiss them as quite unreal. That there might be events or places with no relation to their own now and here is something they often refuse to take seriously, though there are theories in modern science that suggest that they are wrong to do so.

It was pointed out earlier that to say that something is unreal in a metaphysical context is often to say that it is unintelligible, and it is not surprising to find that arguments about the unreality of space and time have often turned on conceptual considerations. Thus, it is alleged that there is an incoherency in the notion of space because it claims to be a whole that is logically prior to its parts, and nevertheless turns out in practice to be merely an indefinitely extensible aggregate. Everything that occupies space falls within a wider spatial context; the thought of space as such is, as Kant saw, involved in any spatial description. Yet space as such is something that constantly eludes man's grasp; space, as man knows it, is just one spatial situation after another.

Theory of Bergson

The difficulties found in the notion of time turn on the combination in it of the idea that time is continuous and the idea that it is made up of discrete parts. Henri Bergson, a French philosopher who was concerned with the notions of duration and movement, said that time was experienced as continuous; it was only the "spatialized" time measured by clocks that was taken to have separable parts (minutes, hours, weeks, and so on), and this "public" time was merely conventional. This, however, seems altogether too easy a solution of the problem, for privately experienced time also goes by (one stretch of it follows another), and the thesis that public time is merely conventional is at best highly controversial. It must be allowed that time is commonly thought of as at once flowing and, as it were, subject to arrest. Whether this is, in fact, openly inconsistent may be doubted, but it is on points like this that the metaphysical case in question rests.

Few British or American philosophers discuss these questions now, largely because they have been persuaded by Moore that any attack on such central notions in men's thought as these must be mistaken in principle. As a result, little attention is given to a question that deserves investigation; namely, what is to take the place of space and time in metaphysical thought. Idealist writers constantly said that space and time qualified appearances, and that nothing that did so could fail to be taken up in the higher experience that was experience of reality. But how is this supposed to be done? Time is perhaps cancelled and yet preserved in the idea of eternity, space in the thought of something that is at once omnipresent yet not in any particular place. But what is there that is positive about these notions? The eternal, it is sometimes said, is not to be identified with what lasts through all time; it is, strictly, outside time altogether. But what does it mean to say this? When it is said, for example, that numbers or truths are eternal, the proper inference is that they have nothing to do with time; to inquire when they came into or will go out of existence is to ask a question that is ill posed. When God, however, is said to be eternal, the impression is often given that he has temporal characteristics, although in some higher form. What this higher form is deserves

careful consideration, the result of which might be that it is not the conception of time that is incoherent but the conception of God.

THE CONCEPTION OF SPIRIT

As well as arguing for the separate existence of mental substance, metaphysicians have claimed that mind is, as it were, the key to the understanding of the universe. What exists is spirit, or at least is penetrated by spirit. This is the thesis of Idealism, a type of philosophy that is often derided but that, like its rival Materialism, has a constantly fresh appeal. This view is worth examining in more detail than has so far been possible.

It is best to begin by distinguishing the thesis of Idealism proper from some others with which it is readily confused. Leibniz said that the true atoms of nature were monads or souls; at bottom nothing existed except minds. Berkeley claimed that sensible things have no existence without the mind; there are spirits that experience, including an infinite spirit, and there are the contents of their experiences, but there is no independently existing world of matter. For the philosophers who followed Hegel, both Leibniz and Berkeley were "subjective" Idealists: they conceived of reality in terms of the experiences of individual minds.

Theory of Hegel

Hegel's view, by contrast, was that what exists is not so much pure mind as mind writ large; *i.e.,* the universe is penetrated by mind and exists for the sake of mind, and it cannot be understood unless this fact is grasped. Hegel was thus not committed to denying that there is an independent world of nature but, on the contrary, openly proclaimed it. Nature was there for mind to master it and in so doing to discover itself.

The field in which Hegel first worked out this theory was that of human affairs. The human world may be said to be mind made objective because it consists of a series of structures—examples would be a language, a set of moral or political procedures, a science, a practical art such as medicine—that constitute mental achievements. The mind involved in structures of this kind, however, is collective rather than personal. An art such as medicine or a science such as mathematics is not the invention of any particular individual; and although individuals have contributed and are contributing to the advancement of each structure, they do so not in their personal capacity but as embodying impersonal intelligence.

Because the human world thus embodies mind, or spirit, it needs to be understood in a special way—in terms of what Hegel called "concrete universals." Concepts of this kind are in order when it is a question of grasping a particular sort of subject matter—one in which there are intimate connections between the data under consideration. Connections in nature are, on the surface at any rate, of a purely external character; striking a match, for example, has nothing internally to do with producing a flame. When, however, a historian considers the different stages of some movement or process, or when an anthropologist studies the various aspects of the life of a society, the material they confront is internally related just because it represents the work of mind—not, of course, of mind working in a vacuum but of mind facing and reacting with greater or less intelligence to particular situations. It is not surprising in these circumstances to find that the conceptual structure employed by the student of human affairs is, in important respects, profoundly different from that employed by the student of nature. In the latter, what are in question are constant conjunctions, observed but not understood; in the former, men have insight into what happens or obtains because they can reenact in their own minds the thought behind the material they study.

All this is, or should be, comparatively uncontroversial; it represents the truth behind the claim of Wilhelm Dilthey, a German philosopher and historian of ideas, that human affairs can be understood, as it were, from within, by means of what he called *Verstehen* ("understanding"). But of course it is one thing to say this and another altogether to argue that the universe at large should be construed as if it were mind writ large. What makes Hegelianism intriguing to some and totally implausible to others is precisely that it makes this extravagant claim. As has already been mentioned, the world of nature for Hegel is in one way independent of mind: its being is certainly not its being perceived. It is, nevertheless, relevant to mind in all sorts of important ways: in providing a setting in which mind can act, in constituting an obstacle that mind can overcome, in presenting mind with something seemingly alien in which it can nevertheless find itself insofar as it discovers nature to be intelligible. If Hegel were asked why there was a world of nature at all, his answer would be "for the sake of mind." Just as man's social environment affords opportunities to the individual to come to full knowledge of himself by realizing his differences from and dependence upon others, so the world of nature affords similar opportunities. By transforming the natural scene, men make it their own. In so doing they come to know what they can do, and thus what they are.

All reality as spirit

There is, perhaps, more to this doctrine than appears at first sight. It is, however, easier to assent to it in general terms than to follow Hegel over it in detail. According to the Idealist account, there is in the end only one true description of the universe, namely that which is couched in terms of the concrete universal. Reality is a single self-differentiating system, all the parts of which are intimately connected; it is spirit that expresses itself in the natural and human worlds and comes to consciousness of itself in so doing. Any other account of the matter—for example, that given by the scientist in terms of experienced uniformities—must be dismissed as inadequate. To Hume's objection that there is an absolute logical difference between propositions expressing matters of fact and existence and propositions expressing relations of ideas, Hegel replies brusquely that the distinction is untenable. At a certain level, perhaps, facts are taken as "brute." Even the scientist, however, never abandons his aspiration to understand them—it is only provisionally that he talks in terms of "ultimate inexplicabilities"—and the philosopher knows that the demand to incorporate all knowledge in a single system is not to be denied. It is a demand that, as Hegelians are willing to admit, can in practice never be met but that, nonetheless, ceaselessly makes itself felt. That such is the case is shown by the extraordinary fascination exercised by this strange but remarkable type of philosophy.

To try to understand the universe in terms of spirit is characteristic of philosophers whose main extra-philosophical interests are in the humanities, particularly in historical studies. Relatively few scientifically minded thinkers have followed this line of thought, and many Idealists of repute, including Bradley and Benedetto Croce (an Italian philosopher and literary critic whose major philosophical work was published in four volumes between 1902 and 1917 under the general title *La filosofia dello spirito* ("The Philosophy of the Spirit"), have been least convincing when writing about science. Hegel himself, perhaps, had less sympathy with scientific than with historical aspirations; this is not to say, however, that he was ill-informed about contemporary science. He knew what was going on, but he saw it all from his own point of view, the point of view of one who was entirely convinced that science could not produce any ultimate answers. He valued science but rejected the scientific view of the world.

Types of metaphysical theory

To complement and, in a way, to correct this brief survey of the problems of metaphysics it will be useful at this point to insert a short summary of a number of overall metaphysical positions. Metaphysics, as already noted, professes to deal with "the world as a whole"; the thoughts of a metaphysician, if they are to make any impact at all, must be connected in a system. The object in what follows will be to present in outline metaphysical systems that have exercised and, indeed, continue to exercise a strong intellectual appeal. In all cases but one, these systems were given classical shape by particular philosophers of genius. Relatively little attention, however, will be paid to this fact here because the present concern is with types of view rather than with views actually held. Thus, reference will be made to Platonism instead of to the philosophy of Plato, and so on in other cases.

PLATONISM

The essence of Platonism lies in a distinction between two worlds, the familiar world of everyday life, which is the object of the senses, and an unseen world of true realities, which can be the object of the intellect. The ordinary man recognizes the existence of the former and ignores that of the latter; he fails to appreciate the extent to which his beliefs both about fact and about values are arbitrarily assumed and involve internal contradictions. The philosopher is in a position to show him how insubstantial is the foundation on which he takes his stand. The philosopher can demonstrate how little thought there is in popular conceptions of good and evil, and he can show that the very concept of sense knowledge involves difficulties because knowledge presupposes a stable object, and the objects of sense are constantly changing. The claim, however, is that he can do more than this. Because of the presence in him of something like a divine spark, he can, after suitable preparation, fix his intellectual gaze on the realities of the unseen world and, in the light of them, know both what is true and how to behave. He will not attain this result easily—to get to it will involve not only immense intellectual effort, including the repeated challenging of assumptions, but also turning his back on everything in life that is merely sensual or animal. Yet, despite this, the end is attainable in principle, and the man who arrives at it will exercise the most important part of himself in the best way that is open to him.

Distinction between the world of appearances and the world of realities

That this type of view has an immediate appeal to persons of a certain kind goes without saying. There is ample evidence in poetry and elsewhere of the frequently experienced sense of the unreality of familiar things and the presence behind them of another order altogether. Platonism may be said to build on "intuitions" of this kind; as a metaphysics, its job is to give them intellectual expression, to transfer them from the level of sentiment to that of theory. It is important, however, to notice that Platonism is not just the intellectualizing of a mood; it is an attempt to solve specific problems in a specific way. In Plato's own case, the problems were set by loss of confidence in traditional morality and the emergence of the doctrine that "man is the measure of all things." Plato thought he could counter this doctrine by appeal to another contemporary fact, the rise of science as shown in the development of mathematical knowledge. Mathematics, as he saw it, offered certain truth, although not about the familiar world; the triangle whose properties were investigated by the geometrician was not any particular triangle but the prototype that all particular triangles presuppose. *The* triangle and *the* circle belonged not to the world of the senses but to the world of the intelligence; they were Forms. If this could be said of the objects of mathematical discourse, the same should also be true of the objects of morality. True justice and true goodness were not to be found in popular opinions or human institutions but should be seen as unchanging Forms, eternally existing in a world apart.

Modern philosophers have found much to criticize in this system: as indicated already, they have objected that Forms are not so much existents as abstractions, and they have found the argument from science to morality quite inconclusive because of what they allege to be an absolute dichotomy between fact and value. It may be that nobody today can subscribe to Platonism in precisely the form given it by Plato himself. The general idea, however, has certainly not lost its hold, nor have the moral perplexities to which Plato hoped to find an answer been dissipated by further thought.

ARISTOTELIANISM

For many people, Plato is the type of an other-worldly, Aristotle of a this-worldly philosopher. Plato found reality to lie in things wholly remote from sense; Aristotle took form to be typically embodied in matter and thought it his job as a philosopher to make sense of the here and now. The contrast is to some extent overdrawn for Aristotle, too, believed in pure form (God and the astral intelligences—the intelligent movers of the planets—were supposed to satisfy this description), and Plato was sufficiently concerned with the here and now to want to change human society radically. It remains true, nevertheless, that Aristotelianism is in essentials a form of immanent metaphysics, a theory that instructs men on how to take the world they know rather than one that gives them news of an altogether different world.

Making sense of the here and now

The key concepts in Aristotelianism are substance, form and matter, potentiality and actuality, and cause. Whatever happens involves some substance or substances; unless there were substances, in the sense of concrete existents, nothing could be real whatsoever. Substances, however, are not, as the name might suggest, mere parcels of matter; they are intelligible structures, or forms, embodied in matter. That a thing is of a certain kind means that it has a certain form or structure. But the structure as conceived in Aristotelianism is not merely static. Every substance, in this view, not only has a form but is, as it were, striving to attain its natural form; it is seeking to be in actuality what it is potentially, which is in effect to be a proper specimen of its kind. Because this is so, explanation in this system must be given in teleological rather than mechanical terms. For Aristotle, form is the determining element in the universe, but it operates by drawing things on, so that they become what they have it in themselves to be rather than by acting as a constant efficient cause (*i.e.,* the agent that initiates the process of change). The notion of an efficient cause has a role in Aristotelianism—as Aristotle put it, it takes a man, a developed specimen of his kind, to beget a man; it is, however, a subordinate role and yields pride of place to a different idea, namely, form considered as purpose.

For reasons connected with his astronomy, Aristotle postulated a God. His God, however, had nothing to do with the universe; it was not his creation, and he was, of necessity, indifferent to its vicissitudes (he could not otherwise have been an unmoved mover). It is a mistake to imagine that everything in the Aristotelian universe is trying to fulfill a purpose that God has ordained for it. On the contrary, the teleology of which use is here made is unconscious; although things all tend to an end, they do not in general consciously seek that end. They are like organs in a living body that fulfill a function and yet seemingly have not been put there for that purpose.

As this last remark will suggest, an important source of Aristotelian thought is reflection on natural growth and decay. Aristotle, who was the son of a doctor, was himself a pioneer in natural history, and it is not surprising that he thought in biological terms. What is surprising, and gives his system a continuing interest, is the extent to which he succeeded in applying ideas in fields that are remote from their origin. He was without doubt more successful in some fields than in others: in dealing with the phenomena of social life, for instance, as opposed to those of physical reality. His results overall, however, were impressive enough for his system not only to dominate men's minds for many centuries but to constitute a challenge even today. Men still, on occasions, think like Aristotle, and, as long as that is so, Aristotelianism will remain a live metaphysical option.

THOMISM

Christian metaphysics

The advent of Christianity had important effects in philosophy as in other aspects of human life. Initially Christians were opposed to philosophical claims of any kind; they saw philosophy as an essentially pagan phenomenon and refused to allow the propriety of subjecting Christian dogma to philosophical scrutiny. Christian truth rested on revelation and did not need any certificate of authenticity from mere reason. Later, however, attempts were made to produce a specifically Christian metaphysics, to think out a view of the universe and of man's place in it that did justice to the Christian revelation and nevertheless rested on arguments that might be expected to convince Christians and non-Christians alike. St. Thomas Aquinas was only one of a number of important thinkers in medieval times who produced Christian philosophies; others—such as the philosophers John Duns Scotus in the late 13th century and William of Ockham in the first half of the 14th century—took significantly different views. In selecting the system of Aquinas for summary here, the factor

that has weighed most has been its persistent influence, particularly in postmedieval times. Aquinas was not the only medieval philosopher of distinction, but Thomism is alive as other medieval systems are not.

The central claim of Thomism is that reflection on everyday things and the everyday world reveals it as pointing beyond itself to God as its sustaining cause. Ordinary existents, such as human beings, are in process of constant change. The change, however, is not normally the result of their own efforts, and even when it is, it does not depend on them exclusively. No object in the familiar world can fully account for its own *esse* (*i.e.*, its own act of existing), nor is it wholly self-sufficient; all are affected from without, or at least operate in an environment that is not of their own making. To say this is to say that they are one and all finite. Although finite things can be, and commonly are, stimulated to activity or kept in activity by other finite things, it does not follow that there might be finite things and nothing else. On the contrary, the finite necessarily points beyond itself to the infinite; the system of limited beings, each dependent for its activity on something else of the same kind, demands for its completion the existence of an unlimited being, one that is the source of change in other things but is not subject to change itself. Such a being would be not a cause like any other but a first or ultimate cause; it would be the unconditioned condition of the existence of all other things. Aquinas believed that human reason can produce definitive proofs of the existence of an infinite or perfect being, and he had no hesitation in identifying that being with the Christian God. Because, however, the movement of his thought was from finite to infinite, he claimed to possess only so much philosophical knowledge of the Creator as could be arrived at from study of his creation. Positive knowledge of the divine nature was not available; apart from revelation, man could only say what God is not, or conceive of his attributes by the imperfect method of analogy.

Aquinas worked out his ideas at a time when the philosophy of Aristotle was again becoming familiar in western Europe after a period of being largely forgotten, and many of his detailed theories show Aristotelian influence. He assumed the general truth of the Aristotelian picture of the natural world and the general correctness of Aristotle's way of interpreting natural phenomena. He also took over many of Aristotle's ideas in the fields of ethics and politics. He gave the latter, however, a distinctively different twist by making the final end of man not philosophical contemplation but the attainment of the beatific vision of God; it was Christian rather than Greek ideas that finally shaped his view of the *summum bonum* ("greatest good"). Similarly, his celebrated proofs of God's existence proceeded against a background that is obviously Aristotelian but that need not be presupposed for their central thought to have validity. Thomism can certainly be seen, and historically must be seen, as the system of Aristotle adapted to Christian purposes. It is important, however, to stress that the adaptation resulted in something new, a distinctive way of looking at the world that still has its adherents and still commands the respect of philosophers.

CARTESIANISM

Increased understanding of the physical world

René Descartes worked out his metaphysics at a time of rapid advance in human understanding of the physical world. He adopted from Galileo the view that physical things are not what they are commonly taken to be on the strength of sense experience—namely, possessors of "secondary" properties such as colour, smell, and feel—but are rather objects characterized only by the "primary" qualities of shape, size, mass, and mobility. To understand why a constituent of the physical world behaves as it does, what should be asked is where it is, how large it is, in what direction it is moving, and at what speed; once these questions are answered, its further properties will become intelligible. Descartes held further that all change and movement in the physical world is to be explained in purely mechanical terms. God was needed to give initial impetus to the physical system as a whole, but once it had got going it proceeded of its own accord. To pretend, as the Aristotelians had, to discern purposes in nature was to make the impious claim to insight into God's mind. Descartes applied this theory to the movements of animals as much as to those of inanimate bodies; he thought of both as mere automatons, pushed and pulled about by forces over which they had no control.

Although Descartes thus acquiesced in, indeed emphasized, the mechanistic tendencies of contemporary science, he was far from being a Materialist. Besides material substance there was also thinking substance, and this was in fact wholly different from matter both in kind and in operation. Bodies had as their essence to occupy space; minds were not in space at all. Bodies, again, were determined in their movements; minds were in some sense free, because they possessed will as well as intelligence. Descartes was less explicit on this point than he might have been; the principles on which mental substance is supposed to operate are not made clear, with the result that critics have said that Descartes thought of mental activities in para-mechanical terms. Whether this is true or not, however, there was no reason for Descartes to be in any special difficulty over this point. All he needed to urge was that minds act in the strict sense of the term, which is to say that they take cognizance of their situation and respond more or less intelligently to it. That they can do this differentiates them fundamentally from material things, which are caused to do what they do and are entirely unaffected by rational considerations.

The main crux in Descartes's metaphysics was the difficulty of bringing together the two orders of being, once they were separated. Mention has already been made of the expedient to which later Cartesians were driven in trying to solve this difficulty: in effect, they made the unity of the universe a continuing miracle, dependent upon the grace of God. It is worth mentioning here another move in the same area that many have found instructive. Kant, who was in some respects both a latterday Cartesian and a latter-day Platonist, argued that human activities could be looked at from two points of view. From the theoretical standpoint they were simply a set of happenings, brought about by antecedent events in precisely the same way as occurrences in the natural world. From the standpoint of the agent, however, they must be conceived as the product of rational decision, as acts proper for which the agent could be held responsible. The moment he began to act, a man transferred himself in thought from the phenomenal world of science to an intelligible world of pure spirit; he necessarily acted as if he were not determined by natural forces. The transference, however, was a transference in thought only (to claim any knowledge of the intelligible world was quite unjustified), and because of this the problem of the unity of the universe was dissolved. There was no contradiction in a man's thinking of himself both as a subject for science and as a free originator of action. Contradiction would appear only if he were present in both respects in an identical capacity. But appeal to the doctrine of the two standpoints was thought by Kant to rule this out.

Kantian development

It is only with some hesitation that one can speak of Kant as having put forward a metaphysics. He was in general highly suspicious of claims to metaphysical knowledge, and a principal aim of his philosophy was to expose the confusions into which professing metaphysicians had fallen. Nevertheless, it is clear that Kant had metaphysical convictions, for all his denial of the possibility of metaphysical knowledge; he was committed to the view that men can conceive a non-natural as well as a natural order and must necessarily take the former to be real when they act. The language he used—particularly his talk about man as phenomenon and man as noumenon—is not to the taste of present-day philosophers, but the thought behind it certainly survives. It is in this form, indeed, that Cartesianism may still be said to present a serious intellectual challenge.

IDEALISM

Descartes and Kant were both adherents of metaphysical dualism, though they worked out their dualisms in interestingly different ways. Many thinkers, however, find dualism unsatisfactory in itself; they look for a single prin-

Two solutions to the Cartesian dualism

ciple by which to compass whatever exists. There are two broad steps that are open to the person who confronts a dualism of mind and matter and finds it unsatisfactory: he can either try to show that matter is in some sense reducible to mind, or conversely seek to reduce mind to matter. The first is the solution of Idealism, the second that of Materialism. Idealism has already been treated at length, and it will not be necessary to go into it again here. Only one point about it needs emphasis. As was pointed out, there are various forms of Idealism. In one version, this philosophy maintains that there literally is no such thing as matter; what the common man takes to be material things are, upon closer consideration, nothing but experiences in minds. Nothing exists but minds and their contents; an independently existing material world is strictly no more than an illusion. This was the view taken by Berkeley. In the more sophisticated Idealism of Hegel, however, it is not maintained that mind alone exists; material things are, in one way, taken to be as real as minds. The thesis advanced is rather that the universe must be seen as penetrated by mind, indeed as constituted by it. Spirit, to use Hegel's own word, is the fundamental reality, and everything that exists must accordingly be understood by reference to it, either as being directly explicable in spiritual terms or as prefiguring or pointing forward to spirit. Whatever the merits of this thesis, it is clear that it differs radically from that maintained by Berkeley. Idealism in the form espoused by Berkeley relies largely on arguments drawn from epistemology, though formally its conclusions are ontological, because they take the form of assertions or denials of existence. Hegel, however, had little or nothing to say about epistemology and was not even concerned to put forward an ontology. What he wanted to urge was a doctrine of first principles, a thesis about the terms in which to understand the world. The Hegelian "reduction" of matter to mind was thus reduction in a somewhat attenuated sense. It is important to get this point clear, if only because it has its parallel in the rival doctrine of Materialism.

MATERIALISM

Matter as the only substantial existent

The simplest form of Materialism is found in the claim that only matter exists. Stated thus baldly the claim is absurd, because it is clear that all sorts of things exist that are not of the nature of matter: thoughts and numbers and human institutions would be instances. In the light of these facts, the claim has to be revised to say that matter is the only substantial existent, with appeal being made to distinctions first worked out in Aristotle's doctrine of categories. According to this explanation, many things besides matter exist, but all of them are explicable (or so it is said) as modifications of matter. Thus, human institutions consist in patterns of movement among specific groups of human beings, and human beings in turn are nothing but highly complicated material bodies.

It is clear from these instances that Materialism is a controversial doctrine; it is also clear that its key word, modification, requires further explanation. When, for example, minds are said to be modifications of an underlying material substance, what is meant? A first and relatively easy point is that, like qualities and quantities, they could not exist separately. Unless there were material bodies, there could not be minds, because minds are—to put it crudely—states found in some material bodies. Minds are here equated with mentality, and mentality is clearly an abstraction. To say this, however, is not to remove the whole difficulty. When it is said that mentality is a state of some material body or bodies, is that meant literally or metaphorically? Bodies can often be described from the physical point of view as being in a certain state—for example, as being in a state of internal equilibrium. What is meant here is that the different particles of matter concerned stand in a certain relationship and as a consequence develop certain physical properties. But is mentality to be conceived as a physical property? It sounds extravagant to say so. Yet some such doctrine must be defended if Materialism is to be advanced as a form of ontology with a serious claim for attention. It is interesting in this connection to notice the arguments advanced by scholars like J.J.C. Smart, which purport to identify states of mind with states of the brain. If the two are identical—literally the same thing described from two points of view—thoughts may really be modifications of matter, and Materialism may be tenable in a strong form. If, however, the identity cannot be made out—and very few philosophers are in fact ready to accept it—Materialism can be true at most in a modified form.

Naturalism

This modified form of Materialism is perhaps better described as naturalism. Naturalism holds not that all things consist of matter or its modifications but that whatever exists can be satisfactorily explained in natural terms. To explain something in natural terms is to explain it on scientific lines; naturalism is in fact a proclamation of the omnicompetence, or final competence, of science. It is not essential to this type of view to argue that phenomena can be spoken of in one way only; on this point, as on the point about ontological reducibility, the theory can afford to be liberal. It is, however, vital to make out that the scientific account of a set of happenings takes precedence over any other. Thus, the language in which men commonly speak of action and decision, which may be called for short the language of reasons, must be held to be secondary to the language in which scientists might speak of the same facts. Scientific language is basically causal, and the thesis of this form of Materialism is that causal explanations are fundamental. Naturalism is thus the obverse of Hegelianism; it is a theory of first principles, and it draws its principles from science.

If the question is raised why anyone should take this form of Materialism seriously, the answer lies in a number of significant facts. Physiologists have established correlations between general states of mind and general states of brain activity; their hope is to extend this to the point where particular thoughts and feelings can be shown to have their physiological counterpart. Cyberneticists have produced artifacts that exhibit mindlike behaviour to a remarkable degree; the inference that man is no more than a complicated machine is certainly strengthened by their achievements. Sociologists have shown that, whatever the explicit reasons men give for their beliefs, these are often intelligible in the light of factors of which they themselves take little or no account. The old assumption that human judgments are typically grounded in reason rather than merely caused, is called in question by the results of such investigations, which gain support from findings both in Freudian and in orthodox psychology. None of this evidence is decisive by itself; there are ways in every case of blocking the conclusions that Materialists tend to draw from it. Yet it remains true that, cumulatively, the evidence is impressive. It certainly has enough force to make it necessary to take this type of theory with the greatest seriousness. Metaphysical disputes in the modern world are fundamentally arguments for or against Materialism, and the other types of theory here explored are all seen as alternatives to this compelling, if often unwelcome, view.

Argument, assertion, and method in metaphysics

Attention is now turned from description of the content of particular metaphysical views to more general treatment of the nature of metaphysical claims. The questions that will arise in this section concern such things as the nature and basis of metaphysical assertions, the character of metaphysical arguments and of what are taken to be metaphysical proofs, and the parts played in metaphysical thinking by insight and argument, respectively. They come together in the inquiry as to whether metaphysics can be said to be a science and, if so, what sort of a science it is.

METAPHYSICS AS A SCIENCE

Nature of an a priori science. Sciences are broadly of two kinds, a priori and empirical. In an a priori science such as geometry, a start is made from propositions that are generally taken to be true, and the procedure is to demonstrate with rigorous logic what follows if they are indeed true. It is not necessary that the primary premises of an a priori science should in fact be truths; for the

Hypothetical nature of a priori sciences

purposes of the system they need only be taken as true, or postulated as such. The main interest is not so much in the premises as in their consequences, which the investigator has to set out in due order. The primary premises must, of course, be consistent one with another, and they may be chosen, as in fact happened with Euclidean geometry, because they are thought to have evident application in the real world. This second condition, however, need not be fulfilled; a science of this kind can be and commonly is entirely hypothetical. Its force consists in the demonstration that commitment to the premises necessitates commitment to the conclusions: the first cannot be true if the second are false.

This point about the hypothetical character of a priori sciences has not always been appreciated. In many classical discussions of the subject, the assumption was made that a system of this kind will start from as well as terminate in truths and that necessity will attach to premises and conclusions alike. Aristotle and Descartes both spoke as if this must be the case. It is clear, however, that in this they were mistaken. The form of a typical argument in this field is as follows: (1) p is taken as true or given as true; (2) it is seen that if p, then q; (3) q is deduced as true, given the truth of p. There is no need here for p to be a necessary or self-guaranteeing truth; p can be any proposition whatsoever, provided its truth is granted. The only necessity that needs to be present is that which characterizes the argument form, "If p is true, and p implies q, then q is true," that is $[p \cdot (p \supset q)] \supset q$, in which $\cdot$ symbolizes "and," and $\supset$ means "implies"; and this is a formula that belongs to logic. It is this fact that makes philosophers say, misleadingly, that a priori sciences are one and all analytic. They are not because their premises need not answer this description. They, nevertheless, draw their lifeblood from analytic principles.

Metaphysics as an a priori science. It is clear that metaphysical philosophers have sometimes aspired to present their results in the form of a deductive system, to make metaphysics an a priori science. For this purpose they have taken a deductive system to require not just that the premises entail the conclusions but further that they themselves be necessarily true. Spinoza thus began the first book of his *Ethics* by laying down eight definitions and seven axioms whose truth he took to be self-evident and then proceeding in the body of the text to deduce, as he thought with strict logic, 36 propositions that follow in order from them. He repeated the procedure in the rest of his work. That philosophical conclusions should thus be capable of being set out "in the geometrical manner" was something that Spinoza took as axiomatic; to be worthy of attention at all, philosophy must issue in knowledge as opposed to mere opinion, and knowledge proper had to be exempt from the possibility of doubt, which meant that it must either be intuitively evident or deducible from what was intuitively evident. Spinoza took this conception of knowledge from Descartes, who had himself toyed with the idea of presenting metaphysical arguments in the geometrical manner. Descartes, however, pointed out that, although there was no difficulty in getting agreement to the first principles of geometry, "nothing in metaphysics causes more trouble than the making the perception of its primary notions clear and distinct"; the whole trouble with this discipline is that its students fail to see that they must start from what are in fact the basic truths. Descartes himself spoke as if the problem were no more than pedagogical; it was a question of making people see as self-evident what is in itself self-evident. His own "analytic" approach in the *Meditationes* was chosen to overcome these difficulties; it was, he said, "the best and truest method of teaching." But it may well be that this account is too optimistic. The difficulty with a system such as those of Descartes and Spinoza is that there are persons who cannot be brought to see that the primary propositions of the system are self-evidently true, and this not because they are lacking in attention or insight but because they see the world in a different way. This suggests that in any such system there will necessarily be an element that is arbitrary, or at least noncompulsive. However cogent the links that bind premises to conclusions, the premises themselves will lack a firm foundation. If they do, the interest of the system as a whole must be greatly diminished; it can be admired as an exercise in logic but not valued for more than that.

Deductive systems of Spinoza and Descartes

To avoid this unpalatable conclusion, two expedients are possible. The first is to say that the first premises of a metaphysical system must be not merely self-evident but also self-guaranteeing; they must be such that any attempt to deny them can only result in their reaffirmation. Descartes believed that he could satisfy this requirement by grounding his system in the cogito, though strictly this was the primary truth only from the point of view of subjective exposition and not according to the objective order of things. Aristotle somewhat similarly had argued that the logical principle of noncontradiction, which he took to express a highly general truth about the world, must be accepted as axiomatic on the ground that its correctness is presupposed in any argument directed against it.

Even the Idealists Bradley and Bernard Bosanquet at times spoke as if the first principles of their system were in some way logically compulsive; as Bosanquet put it, one had either to accept them or recognize that one could know nothing. Whatever the position may be about particular metaphysical propositions, however, it seems clear that not all truths that are taken as basic in metaphysics have the characteristic of being self-guaranteeing. A Materialist takes it as fundamental that whatever occurs happens as a result of the operation of natural causes: a theist sees things in the world as finite and thus as pointing beyond themselves to the infinite being who is their ground. No contradiction is involved in denying these positions, though of course for those who accept them the denial necessarily involves commitment to falsehood. It is, however, one thing for a proposition or set of propositions to be false, another altogether for it to be necessarily false. If the first principles of metaphysics were really self-guaranteeing, only one system of metaphysics could be coherent, and it would be true just because it was coherent. The very fact that there is an apparent choice between competing metaphysical systems, which may differ in plausibility but agree in being each internally self-consistent, rules this possibility out.

The alternative is to argue that fundamental metaphysical propositions, though not self-guaranteeing, are nevertheless not arbitrary; they have or, to be more cautious, can have a firm foundation in fact. Metaphysical speculation is not, as some opponents of metaphysics have suggested, essentially idle—that is, the mere working out of the logical consequences of premises that the metaphysician chooses to take as true. Or, rather, it does not necessarily answer this description because a metaphysician can have insight into the true nature of things and can ground his system on that. This second position in fact involves arguing that metaphysics is not an a priori but an empirical science.

Reference to experience

Metaphysics as an empirical science. If metaphysics is an empirical science, the question of whether or not to accept a metaphysical theory must be answerable, in part at any rate, by reference to experience. It will not depend on experience alone, any more than does the acceptability of a scientific theory, because here, as in the scientific case, thinking comes into the reckoning too. A metaphysician can be mistaken in his deductions, just as a scientist can. But even if these are impeccable, he will not necessarily succeed on this view of his undertaking. It may be that he argues correctly from premises that are unacceptable—unacceptable because they lack the necessary foundation in fact. He will then be like a scientist who puts forward a hypothesis and deduces its consequences without mistake only to find that experience fails to confirm the supposition on which he is working.

Scientific hypotheses are refuted, or at least called seriously into question, when predictions based on them fail to come true. As Karl Popper—who has emphasized that there is a unity of method in all generalizing or theoretical sciences—has insisted, every scientific hypothesis must be testable, and the way to test it is to look for circumstances in which it does not hold. To content oneself with favourable evidence is not enough; one must be searching all the time for unfavourable evidence. Further, it must

be possible, if the hypothesis is genuinely scientific, to specify in advance what would count as unfavourable evidence; the circumstances in which the hypothesis needs to be abandoned, or at least modified, must be indicated precisely. In ideal conditions it is possible to devise a crucial experiment that will test a hypothesis definitively; the Michelson–Morely experiment, which disposed of the theory of the luminiferous ether, was such an experiment.

It can be asked, however, what parallels there are to this in metaphysics. The difficulty with testing a metaphysical thesis is twofold. First, metaphysical theories tend to be extremely general and as such highly unspecific. They announce, for example, that every event has some cause or other, or that every change is part of a process that serves some purpose. To find counterexamples to theses of such generality is on any account exceedingly difficult: how can one be sure that all the possibilities have been explored? There is, however, another and still more serious difficulty. The scientist, once he has laid down the conditions that would have to obtain for his hypothesis to prove false, makes no bones about their occurrence; it is, typically, a matter of whether or not a certain pointer reading is registered, and this is a simple question of ascertainable fact. Fact for the metaphysician, however, is altogether more slippery. Different metaphysicians see the world each in his separate way; what they take to be the case is coloured by their metaphysical conceptions. There is no neutral body of facts to which appeal can be made to show that a metaphysical theory falls down, and this being so, the attempt to assimilate metaphysics to science must fail.

That this should be the case is perhaps not surprising. Scientific thinking proceeds within a framework of presuppositions that it is the business of the scientist to use, not to argue for and still less to challenge—presuppositions to the effect, for example, that every change has a natural explanation. No doubt scientists can change their presuppositions, but they seldom do so consciously; their usual practice is to take them for granted. Metaphysicians, however, necessarily take a very different attitude toward presuppositions. It is their business to tell men how to understand the world, and this means that they must, among other things, put forward and argue for a set of interpretative principles. Metaphysicians differ radically in the interpretative principles they accept, and it is this that explains their failure to agree upon what to take as fact. It is naive to suppose that the points at issue between, for example, a Thomist and a Materialist can be settled by observation or even by experiment; the facts to which one might appeal in support of his theory may be seen in a very different light by the other, or perhaps be dismissed as simple illusion. Reflection on the phenomenon of religious experience will illustrate what is meant here. That men undergoing this experience are affected mentally and physically in certain specific ways is perhaps common to both Thomist and Materialist. But the further description of their state is entirely controversial and owes its controversial character to the varying preconceptions that the disputants bring to their task.

INITIAL METAPHYSICAL INSIGHTS

Metaphysics as a matter of vision

Origin. If metaphysics is far from being a simple empirical discipline, however, it does not follow that it is wholly without foundation in fact. The true situation can perhaps be put as follows. Every metaphysic consists in an imaginative view of the world elaborated into a conceptual system. Metaphysics, like poetry, begins by being a matter of vision; a metaphysician sees the scheme of all things in a certain light; for example, as nothing more than a vast mechanism or as God's creation. As a metaphysician, however, he cannot be content to rest in a vision of this sort, as for example the Romantic poet William Wordsworth does in his "Intimations of Immortality." He needs to think out terms in which whatever exists can be described so as to accord with his primary insight; he needs to produce and apply a conceptual system and to argue against possible alternatives. Whatever its origins, metaphysics is strictly intellectual in its development. When the question is raised of the source from which metaphysicians gain their initial insights, the answer that occurs most readily is that they are derived from reflection on certain evident facts. Thus, the source of the Materialist view of the world is undoubtedly the practice of science; the Materialist proposes to give unrestricted validity to ways of thinking that scientists have found effective in a certain restricted sphere. The source of Idealist thought is to be found in the practice of history, or more generally in the interpersonal relations of beings who are at once rational and sensitive; the Idealist philosopher takes concepts that are appropriate in these limited areas to apply to the whole of reality. Every system of metaphysics is grounded in some real experience and owes its initial appeal to that fact. This is not to say, however, that the metaphysician builds on experience as does his scientific colleague. To think that is to take altogether too simple a view of the whole question.

Tests of validity. A question of immense importance is whether there are any means of comparing the validity of initial metaphysical insights. If it has to be answered negatively—if it has to be allowed that, as it were, all candidates in this field start and finish on an equal footing—the argument that each of them has a foundation in fact will be entirely discounted. Whatever respectability their concepts possess in their original homes will be lost once they fall into the hands of the metaphysician, because the procedure of the latter in taking them up and extending them is essentially arbitrary. For example, that one sees the sum of things as a vast machine may be suggested by what goes on in science, but this view can neither claim scientific warrant itself nor draw on scientific prestige, because it seems to spring from nothing better than mere whim. There are, however, two reasons for thinking that initial metaphysical insights are based not on mere whim but on valid grounds.

Insights as limited in number and subject to experience

First, the number of what may be called viable metaphysical insights is in practice limited: there are varying ways of taking the world as a whole, but not an infinite variety. In the outline account of metaphysical theories given above, six different kinds of view were distinguished, each of which may be said to be grounded in one or more areas of experience. It would be possible to extend the list, but probably not very far; further candidates might well turn out to be no more than variations on themes already considered. Thus, Leibniz might be seen as a latter-day Platonist, and Spinoza as offering a different version of the dualism of Descartes, one that is more sympathetic to Materialism than was Descartes himself. If these claims are true, they are certainly important; for the facts here adduced suggest that the experiences or visions on which different metaphysicians build are not peculiar to individual minds but occur commonly and regularly. They are not the product of passing moods, seized on and exploited for no good reason, but connect with thoughts that recur repeatedly in sensitive and intelligent reflection.

Second, there is a sense in which, despite everything said above, metaphysical theories are subject to the test of experience. That metaphysics aspires to give an account of the world as a whole means that each metaphysician claims that his fundamental insight illuminates every department of life. It may be that there are no neutral facts to which a metaphysician can appeal to show the shortcomings of his opponents; metaphysicians pronounce on what is to count as fact, and this puts them in the happy position of being judges in their own case. It remains true, however, that everyone who engages in that type of philosophy has the formal task of accounting for all the facts that he recognizes, and this is something that can be done more or less well. The value of different metaphysical insights is sometimes shown in the success with which they are applied. Furthermore, it is not quite true that the metaphysician need consult no opinion but his own when it comes to working out his views. What might be called public opinion has a part to play as well, though it has no absolute right to a hearing. A metaphysician who chooses to dismiss areas of experience or ways of thinking that are commonly accepted as being in order does so at his peril; he reduces the initial plausibility of his own theories the oftener he finds himself in this position. He could, of course, be right and common opinion wrong; no genuine metaphysician is put off by the thought of such a

conflict. Though he is not put off, however, he has to be wary all the same. He may be able to say what in the end is to count as fact, but if this involves him in dismissing as illusory what instructed opinion generally takes to be real, his triumph may be hollow. Whether he likes it or not, he has to frame a theory that will carry conviction with experts in the different fields concerned, or, if that is going too far, one that will strike them as not wholly implausible. A metaphysician who exercises his veto past that point is simply failing to do his job.

The test of self-consistency of theory

It must be admitted that the tests one can apply to determine the value of a metaphysical theory are at best unsatisfactory. Often one is driven back onto the expedient of asking if the theory is internally self-consistent; a surprisingly large number of philosophical theories are not. To confute a philosopher out of his own mouth is, perhaps, the most effective form of confutation. If this expedient will not apply, however, the questioner is not quite helpless. Whatever the explanation, it is a well-known fact that a philosopher can purchase consistency at the expense of plausibility; he can put forward theories that evade difficulties by simply declaring them nonexistent. In so doing, he turns his back on what instructed opinion generally takes to be fact. His hope is, of course, to persuade others to see the situation as he does, and there is always the possibility that he will succeed. If, however, after a suitable interval he has not, that must surely count against him. It is by this test that one decides, for example, that the metaphysics of Hobbes is not worth prolonged study, despite the enormous ingenuity of its author; there is too much in this system that seems to be sheerly arbitrary. The same comment could be made of certain forms of Idealism, which are so intent on the omnipresence of spirit that they neglect the materiality of the material order. Admittedly, the test is harder to apply when attention is transferred to the major theories in their most persuasive form, because here the question concerns views that have stood the test of time. It is not, however, entirely inapplicable even there. An individual, at least, may feel that this or that view will not do precisely because it achieves comprehensiveness by turning its back on fact; and, though it is unsatisfactory to fall back on personal judgment in this way, there is perhaps no other alternative in this difficult area.

Role of personal or social factors. Some writers on the philosophy of philosophy, such as Dilthey, have suggested that the persistence of a plurality of metaphysical systems is to be explained in terms of personal or social factors. Certain kinds of metaphysical outlook appeal to certain types of human being, or gain currency in social circumstances of this kind or that; to understand why they are accepted, recourse must be had to psychology or sociology or both. In the above account, stress has been laid on the historical background against which a number of famous metaphysical theories got their classical formulations; it is idle to deny that each was originally designed to solve a problem deemed to be urgent at the time. Nevertheless, the problem was, of course, an intellectual problem, and the solution offered claimed to be true, not simply comforting. No doubt wishful thinking is as rife in the field of metaphysics as anywhere; it is all too easy here to confuse what men ought to believe with what they want to believe. Philosophies reveal something about their authors and even about their historical age, as works of literature do; they constitute historical evidence as books on mathematics, perhaps, do not. Yet all this can be admitted without agreeing that metaphysics is merely of psychological or historical importance. Science does not cease to be true because it is shown to be useful. Nor is it true that metaphysical theories always in fact give comfort; there are cases in which men find themselves returning over and over again to possibilities that they would very much like to believe were not realized. A philosopher can commit himself to a view of the world that is not at all to his taste, simply because it seems to him on due consideration that this is how things are. That philosophers are godlike beings able to rise entirely above the limitations of their age seems unlikely. It is equally unlikely, however, that their opinions are determined throughout by nonrational factors, and thus that their thinking can lay no claim to truth.

METAPHYSICAL ARGUMENTS

Classes of metaphysical statements

Logical character of metaphysical statements. Metaphysical statements fall into two main classes: statements about what exists and prescriptions about how to take or understand what exists. It might seem obvious that the first is the more important; the metaphysician first lays down what he takes to exist, and then tells how to interpret it. This would be correct if metaphysics were a departmental inquiry like, for example, botany; but, of course, it is not. Metaphysicians possess no special resources for the detection of unfamiliar entities, and in consequence the realities they accept must all be argued for. The fundamental items that fill the metaphysical world are one and all theoretical; they are not so much palpable realities as artificial constructs. That being so, there is less of a gulf between the two types of metaphysical pronouncement than might at first appear. It could indeed be argued that the two go closely together to constitute what may be called a metaphysical point of view, a standpoint whose primary purpose is to provide understanding. In a metaphysical context, to say what exists is itself a step on the way to understanding; it is not something that antedates theory, but part of a theory itself.

It may be asked whether metaphysical pronouncements are empirical or a priori and, if the latter, whether they are analytic or synthetic. They are certainly not straightforwardly empirical, for reasons just set out, and cannot be merely analytic (*i.e.*, true in virtue of the definitions of their terms and of the laws of logic) if metaphysics is to retain any significance. The conclusion that they must be synthetic a priori (*i.e.* such that, unlike analytic propositions, they convey new knowledge and yet claim complete universality and necessity) seems to follow, and it is just what the opponent of metaphysics wants the metaphysician to adopt. Metaphysics, as he sees it, is a wholly unwarranted attempt to say what the world must be like on the strength of pure thinking, an attempt that is doomed to failure from the start. Before this condemnation is accepted, however, the function that the metaphysician assigns to his principles should be considered. When this is done, it becomes plain that the charge that he claims factual knowledge of a nonempirical sort is false; in one way he recognizes exactly the same facts as anyone else. Where he claims superiority is in knowing how to take facts, and the burden of his message consists in the advocacy of principles that, he alleges, will provide overall understanding. One can describe these principles as synthetic a priori if one chooses. It is probably best, however, to avoid this misleading term and simply say that they are thought of by the metaphysician as applying unequivocally to whatever falls within experience. These metaphysical principles are instructive at least in the sense of having alternatives, and they are certainly treated as being necessary. It is not true, however, that they take the form of statements of fact, even highly general statements of fact; nor is their necessity the same as that which characterizes logical truths. The principles are prescriptions rather than statements, and their necessity arises from the role they play in the constitution of experiential knowledge. It is a necessity that is in one way absolute: nothing that can claim to be real can escape their jurisdiction, because they tell how to take whatever occurs. Nevertheless, in another way the necessity of the principles is merely conditional, for other ways of interpreting the same data can be conceived, and it is admitted that there are circumstances, however hard to specify exactly, in which it would have to be agreed that they do not apply.

Deductive and inductive arguments

Logical form of metaphysical arguments. There is also the question whether metaphysical arguments are inductive or deductive or whether they have some logical form peculiar to themselves. It is obvious that much metaphysical reasoning is, or purports to be, reasoning in the strict sense, which is to say that its form is deductive. Arguments like the first cause argument for God's existence claim to be demonstrations; their exponents believe that anyone who commits himself to the truth of the premises

stands logically committed to the truth of the conclusions. This claim can stand, even if it turns out that the project to set out metaphysical results in the geometrical manner is a mistake. It may be impossible to model metaphysics on mathematics, but that does not make particular metaphysical arguments any less deductive.

As regards inductive arguments, it would be odd to find a metaphysician contending, as, for example, historians regularly do, that p is true and q is true and therefore it is reasonable to conclude that r is true. To assess probabilities in the light of established facts is too cautious for the average metaphysical mind. Yet it would be wrong to deny that metaphysicians are preoccupied with facts. Their objective is to give a reasoned account of what exists or obtains, and for this purpose attention to fact is of course indispensable. It figures in metaphysical thinking at two stages. First, at the beginning, when the metaphysician is concerned to formulate his main thesis; here there is a move from what holds in a restricted sphere (the sphere of physics, for example) to what is supposed to hold generally, a move that is possible only if the theorist concerned has an interest in the sphere in question. To arrive at his own position the metaphysician must extrapolate from what goes on outside metaphysics, and this means that he must be sensitive to significant developments in at least some of the main fields of learning and areas of practical activity. But he needs this extra-philosophical knowledge for a second purpose too: in estimating the success of his own theories. In principle he must show that his interpretation of experience covers the facts in an adequate way, and for this purpose what experts in the different spheres take to be established is of crucial importance. Metaphysics is not an empirical science—the element of speculation it includes is too strong for that—but the metaphysician can no more ride roughshod over facts than the scientist can. At the least he must explain away phenomena that seem to count against his thesis, or indicate how they might be explained away. Whether he explains or explains away, he needs to know what the main phenomena are.

Transcendental argument

Finally, it is sometimes said that metaphysics can make use of a form of argument that is neither deductive nor inductive but transcendental; a transcendental argument is supposed to proceed from a fact to its sole possible condition. A transcendental argument is simply a form of deduction, with the typical pattern: only if p then q; q is true; therefore, p is true. As this form of argument appears in philosophy, the interest, and the difficulty, reside not in the movement from premises to conclusions, which is absolutely routine, but in the setting up of the major premises—in the kinds of things that are taken as starting points. In Kant's case, it was such things as the possibility of pure mathematical knowledge, the possibility of making objectively true statements, the fact that there is a unitary system of time. Kant purported to prove a number of surprising propositions by the use of transcendental arguments; he tried to commend major premises such as his arguments about causality and substance by showing what would result if the protasis (*i.e.*, p) did not hold. What he had to say under this head has attracted particular interest in recent years. It seems clear, however, that from the logical point of view no special significance attaches to this form of argument. Although Kant had been successful in demonstrating that a sufficient is also a necessary condition, he did not make clear why it should be taken as the sole such condition. There is an important gap in his reasoning here, as there is in that of other metaphysical writers.

Criticisms of metaphysics

Metaphysics has many detractors. The man who aspires "to know reality as against mere appearance," to use Bradley's description, is commonly taken to be a dreamer, a dupe, or a charlatan. Reality in this context is, by the metaphysician's own admission, something that is inaccessible to sense; as Plato explained, it can be discovered only by the pure intelligence, and only if the latter can shake itself free of bodily encumbrances. The inference that the metaphysical world is secret and mysterious is natural enough. Metaphysics in this view unlocks the mysteries and lets the ordinary man into the secrets. It is, not to put too fine a point on it, a study of the occult.

Metaphysics as a study of the occult

METAPHYSICS AS KNOWLEDGE OF THE SUPERSENSIBLE

That there are aspects of metaphysics that lend colour to this caricature can scarcely be denied. The language of Plato, in particular, suggests an absolute distinction between the deceitful world of appearances, which can never be an object of knowledge, and the unseen world of Forms, each of which is precisely what it appears to be. Plato urged his readers not to take seriously the things of sense; he told them that everything having to do with the senses, including the natural appetites and the life of the body, is unreal and unimportant. The philosopher, in his view, needs to live an ascetic life, the chief object of which is to cultivate his soul. Only if he does this, and follows a rigorous intellectual training, has he any hope of getting the eye of his soul fixed on true reality and so of understanding why things are what they are.

Yet even this program admits of an innocuous, or relatively innocuous, interpretation. The "dialectician," as Plato called his metaphysical philosopher, is said in one place to be concerned to "give an account," and the only things of which he can give an account are phenomena. Plato's interest, despite first appearances, was not in the unseen for its own sake; he proposed to go behind things visible in order to explain them. He was not so much disdainful of facts as critical of accepted opinions; his attack on the acquiescence in "appearances" was an attack on conventional wisdom. That this was so comes out nowhere more clearly than in the fact that his targets included not just beliefs about what there is but also beliefs about what is good. It is the opinions of the many that need correction and that can happen only if men penetrate behind appearances and lay hold on reality.

Plato is often presented as an enemy of science on the ground that he was bitterly opposed to Empiricism and because he said that, if there was ever to be progress in astronomy, the actual appearances of the starry heavens must be disregarded. He understood by Empiricism, however, the uncritical acceptance of apparent facts, with the attempt to trace regularities in them; it is an attitude that, in his view, is marked by the absence of thought. As for the starry heavens, it is certainly difficult to take Plato quite literally when he compares their function in astronomy to that of a well-drawn diagram in geometry. Yet he was not wrong to suggest that no progress could be made in astronomical inquiries until appearances were seen to be what they were and not taken for absolute realities. The subsequent progress of astronomy has shown this view to be entirely correct.

There are respects in which Plato's attitude to phenomena was precisely the same as that of the modern scientist. The fact remains, nevertheless, that he believed in a realm of unseen realities, and he is of course far from being the only metaphysician to do so. Many, if not quite all, metaphysicians are committed to claiming knowledge of the supersensible, in some degree at least; even Materialists are alleged to make this claim when they say that behind the familiar world of everyday experience there lies material substance that is not accessible to the senses. It has been a commonplace among critics of metaphysics since the early 18th century that no such claims can be justified; the supersensible cannot be known about, or even known of, whether directly or by inference.

SPECIFIC CRITICISMS

Hume. An early but powerful statement of these criticisms is to be found in the writings of David Hume, *A Treatise of Human Nature* (1739–40) and *An Enquiry Concerning Human Understanding* (1748). Hume argued first that every simple idea was derived from some simple impression and that every complex idea was made up of simple ideas; innate ideas, supposed to be native to the mind, were nonexistent. There were eccentricities in Hume's conception of idea (and for that matter in his conception of impression), but these did not destroy the force of his argument that the senses provide the materials

Necessity of sense experience

from which basic concepts are abstracted. A being that lacked sense experience could not have concepts in the normal sense of the term. Next, Hume proceeded to make a sharp distinction between two types of proposition, one knowable by the pure intellect, the other dependent on the occurrence of sense experiences. Propositions concerning matters of fact and existence answer the latter description; they either record what is immediately experienced through the senses or state what is taken to be the case on the basis of such immediate experiences. Such statements about matters of fact and existence are one and all contingent; their contradictories might have been true, though, as a matter of fact, they are not. By contrast, propositions of Hume's other type, which concern relations of ideas, are one and all necessary; reflection on the concepts they contain is enough to show that they must, in logic, be true. Though, in a sense, knowledge of these propositions is arrived at by the exercise of pure reason, no real significance attaches to this fact. It is not the case of some special insight into the nature of things; the truth is rather that these propositions simply make explicit what is implicit in the definitions of the terms they contain. They are thus what Kant was to call analytic propositions, and it is an important part of Hume's case that the only truths to which pure reason can attain are truths of this nature.

Finally, Hume sought to block the argument that, even if the supersensible could not be known directly, or through pure intellectual concepts, its characteristics could, nevertheless, be inferred. His analysis of causality had this as one of its aims. According to Hume, the only means by which men can go beyond the impressions of the memory and the senses and know what lies outside their immediate experience is by employing causal reasoning. Examination of the causal relation, however, shows that it is, among other things, always a relation of types of events in time, one of which invariably precedes the other. Causality is not, as Descartes and others supposed, an intelligible relation involving an internal tie between cause and effect; it is a matter of purely factual connection and reduces on its objective side to nothing more than regular precedence and succession. The importance of this for the present inquiry lies in the consequence that causal relations can hold only between items, or possible items, of experience. According to Hume, if the temporal element is removed from causality, nothing concrete is left; if it is kept, it becomes impossible to argue that one can proceed by causal reasoning from the sensible to the supersensible. Yet it was precisely this that Aristotle, Thomas Aquinas, and Locke had all attempted.

Hume's own explicit pronouncements about metaphysics are ambivalent. There is a famous passage in which he urged men to consign volumes of divinity and "school metaphysics" to the flames, "as containing nothing but sophistry and illusion," but in at least one other place he spoke of the need to "cultivate true metaphysics with some care, in order to destroy the false and adulterate." "True metaphysics," in this connection, meant critical philosophical reflection.

Critical philosophical reflection

Kant. Hume's successor Kant made a sharper distinction between metaphysics and critical philosophy. Much of Kant's philosophical effort was devoted to arguing that metaphysics, understood as knowledge of things supersensible, is an impossibility. Yet metaphysics, as a study of the presuppositions of experience, could be put on "the sure path of science"; it was also possible, and indeed necessary, to hold certain beliefs about God, freedom, and immortality. But however well founded these beliefs might be, they in no sense amounted to knowledge: to know about the intelligible world was entirely beyond human capacity. Kant employed substantially the same arguments as had Hume in seeking to demonstrate this conclusion but introduced interesting variations of his own. One point in his case that is especially important is his distinction between sensibility as a faculty of intuitions and understanding as a faculty of concepts. According to Kant, knowledge demanded both that there be acquaintance with particulars and that these be brought under general descriptions. Acquaintance with particulars was always a matter of the exercise of the senses; only the senses could supply intuitions. Intuitions without concepts, nevertheless, were blind; one could make nothing of particulars unless one could say what they were, and this involved the exercise of a very different faculty, the understanding. Equally, however, the concepts of the understanding were empty when considered in themselves; they were mere forms waiting to be brought to bear on particulars. Kant emphasized that this result held even for what he called "pure" concepts such as cause and substance; the fact that these had a different role in the search for knowledge from the concepts discovered in experience did not give them any intuitive content. In their case, as in that of all other concepts, there could be no valid inference from universal to particulars; to know what particulars there were in the world, it was necessary to do something other than think. Thus is revealed the futility of trying to say what there is on the basis of pure reason alone.

Differences between Hume's and Kant's criticisms

Kant's distinction between analytic and synthetic propositions has peculiarities of its own, but for present purposes it may be treated as substantially identical with Hume's distinction set out above. Similarly, the important differences between Kant and Hume about causality may be ignored, seeing that they agreed on the central point that the concept can be properly applied only within possible experience. If it is asked whether there are substantial differences between the two as critics of metaphysics, the answer must be that there are but that these turn more on temperament and attitude than on explicit doctrine. Hume was more of a genuine iconoclast; he was ready to set aside old beliefs without regret. For Kant, however, the siren song of metaphysics had not lost its charm, despite the harsh words he sometimes permitted himself on the subject. Kant approached philosophy as a strong believer in the powers of reason; he never abandoned his conviction that some of man's concepts are a priori, and he argued at length that the idea of the unconditioned, though lacking constitutive force, had an all-important part to play in regulating the operations of the understanding. His distinction between phenomena and noumena, objects of the senses and objects of the intelligence, is in theory a matter of conceptual possibilities only; he said that, just as one comes to think of things sensible as phenomena, so one can form the idea of a world that is not the object of any kind of sense experience. It seems clear, however, that he went beyond this in his private thinking; the noumenal realm, so far from being a bare possibility invoked as a contrast with the realm that is actually known, was there thought of as a genuine reality that had its effects in the sense world, in the shape of moral scruples and feelings. A comparison of what was said in Kant's early essay *Träume eines Geistersehers erläutert durch Träume der Metaphysik* (1766; *Dreams of a Spirit-Seer*), with the arguments developed in the last part of his *Grundlegung zur Metaphysik der Sitten* (1785; *Fundamental Principles of the Metaphysic of Morals*), would seem to put this judgment beyond serious doubt.

Though Kant remained convinced of the existence of things supersensible, he, nonetheless, maintained throughout his critical writings that there can be no knowledge of them. There can be no science of metaphysics because, to be true to fact, thinking must be grounded in acquaintance with particulars, and the only particulars with which human beings are acquainted are those given in sense. Nor was this all. Attempts to construct metaphysical systems were constantly being made; philosophers repeatedly offered arguments to show that there must be a first cause, that the world must consist of simple parts, that it must have a limit in space, and so on. Kant thought that all such attempts could be ruled out of court once and for all by the simple expedient of showing that for every such proof there was an equally plausible counterproof; each metaphysical thesis, at least in the sphere of cosmology—*i.e.*, the branch of metaphysics that deals with the universe as an orderly system—could be matched with a precise antithesis whose grounds seemed just as secure, thus giving rise to a condition that he called "the antinomy of pure reason." Kant said of this antinomy that "nature itself seems to have arranged it to make reason stop short in its bold pretensions and to compel it to self-examination."

Admittedly, the self-examination led to more than one result: it showed on the one hand that there could be no knowledge of the unconditioned and demonstrated on the other that the familiar world of things in space and time is a mere phenomenon, thus—to Kant—clearing the way to a doctrine of moral belief. Though this doctrine could not be expunged from Kant's philosophy without destroying it altogether, it is quite wrong to present it, as some modern German writers do, as amounting to the advocacy of an alternative metaphysics. What Kant was concerned with here is what must be thought, not what can be known.

Logical Positivists. Despite what has just been said, it must be admitted that Kant's constant talk about the supersensible makes many critics of metaphysics regard him as a dubious ally. This was certainly true in the case of the Logical Positivists, the philosophical school that has attacked metaphysical speculation most sharply in the 20th century. The Positivists derived their name from the "positive" philosophy of Auguste Comte, a 19th-century Frenchman who had represented metaphysical thought as a necessary but now superseded stage in the progression of the human mind from primitive superstition to modern science. Like Comte, the Logical Positivists thought of themselves as advocates of the cause of science; unlike Comte, they took up an attitude toward metaphysics that was uniformly hostile. The external reason for this was to be found in the philosophical atmosphere in the German-speaking world in the years following World War I, an atmosphere that seemed to a group of thinkers known as the Vienna Circle to favour obscurantism and impede rational thought. But there were, of course, internal reasons as well.

According to the Positivists, meaningful statements can be divided into two kinds, those that are analytically true or false and those that express or purport to express matters of material fact. The propositions of logic and mathematics exemplify the first class, those of history and the natural and social sciences the second. To decide whether a sentence that purports to state a fact is meaningful, one must ask what would count for or against its truth; if the answer is "nothing," it cannot have meaning, or at least not in that way. Thus, they adopted the slogan that the meaning of a (nonanalytic) statement is the method of its verification. It was this verification principle that the Positivists used as their main weapon in their attacks on metaphysics. Taking as their examples statements from actual metaphysical texts—statements such as "The Absolute has no history" and "God exists"—they asked first if they were supposed to be analytically or synthetically true, and then, after dismissing the first alternative, asked what could be adduced as evidence in their favour or against them. Many metaphysicians, of course, claimed that there was empirical support for their speculative conclusions; thus, as even Hume said, "the order of the universe proves an omnipotent mind." The very same writers, however, proved strangely reluctant to withdraw their claims in the face of unfavourable evidence; they behaved as if no fact of any kind could count against their contentions. It followed, said the Positivists, that the theses in which they were interested were compatible with any facts whatsoever and thus were entirely lacking in significance. An analytic proposition, such as "It either will or will not rain tomorrow," tells nothing, though there may be a point in giving voice to it. A metaphysical proposition claims to be very different; it purports to reveal an all-important truth about the world. But it is no more informative than a bare tautology, and, if there is a point in putting it forward, it has to do with the emotions rather than the understanding.

The verification principle

In point of fact, the Positivists experienced great difficulty in devising a satisfactory formulation of their verification principle, to say nothing of a satisfactory account of the principle's own status. In the early days of the movement the demand for verifiability was interpreted strictly: only what could be conclusively verified could be significant. This had the effect of showing that statements about the past and propositions of unrestricted generality, to take only two instances, must be without meaning. Later a move was made toward understanding verifiability in a weak sense: a statement was meaningful if any observations bore on its truth. According to A.J. Ayer, an English disciple of the Vienna Circle, writing in 1936,

> It is the mark of a genuine factual proposition, not that it should be equivalent to an experiential proposition, or any finite number of experiential propositions, but simply that some experiential propositions can be deduced from it in conjunction with certain other premises without being deducible from those other premises alone.

As Ayer admitted in his second edition, however, this formulation lets in too much, including the propositions of metaphysics. From "The Absolute has no history" and "If the Absolute has no history, this is red," it follows that "This is red," which is certainly an experiential proposition. Nor were subsequent attempts, by Ayer and others, to tighten up the formulation generally accepted as successful, for in every case it was possible to produce objections of a more or less persuasive kind.

This result may seem paradoxical, for at first glance the Positivist case is extremely impressive. It certainly sounds odd to say that metaphysical sentences are literally without meaning, seeing that, for example, they can be replaced by equivalent sentences in the same or another language. But if the term meaning is taken here in a broad sense and understood to cover significance generally, the contention is by no means implausible. What is now being said is that metaphysical systems have internal meaning only; the terms of which they consist may be interdefinable but perhaps do not relate to anything outside the system. If that were so, metaphysics would in a way make sense but for all that would be essentially idle; it would be a game that might amuse but could hardly instruct. The Positivists confront the metaphysician with the task of showing that this criticism is not correct. Whatever difficulties are involved in formulating a principle of verifiability, the challenge can hardly be ignored.

Moore and Wittgenstein. The Positivists were not the only modern critics of metaphysics. G.E. Moore never argued against metaphysics as such, but nevertheless he produced criticisms of particular metaphysical theses that, if accepted, would make metaphysical speculation difficult, if not impossible. It was characteristic of a certain type of philosopher, according to Moore, to advance claims of a highly paradoxical nature—to say, for instance, that "Time is not real" or that "There are no such things as physical objects." Moore's case for rejecting such claims was that they go against the most central convictions of common sense, convictions that people accept unhesitatingly when they are not doing philosophy. Men constantly say that they did this before that, that things are better or worse than they were; from time to time they put off things until later or remark that tomorrow will be another day. Moore took these facts as definitive proof of the reality of time and definitive disproof of any metaphysical theory that denied it. Supporters of Bradley, the philosopher here criticized, replied that Moore had missed the point. Bradley never denied the truth of temporal propositions as used in the description of appearances; what he questioned was the coherence and ultimate tenability of the whole temporal way of thinking. As Rudolf Carnap, a Logical Positivist, was to put it, he raised an external question and was given an internal answer by Moore. It was an answer, however, that carried considerable conviction. The simple denial of what seem to be obvious facts had always been part of the stock-in-trade of metaphysicians; they make much of the distinction between appearance and reality. Moore may not have demonstrated the impropriety of this insistence, but at least he made it necessary for the metaphysician to be more circumspect, to explain explicitly what he was denying and what he was ready to accept, and so to make his own case sharper and thus easier to confirm or reject.

Common-sense criticisms

Moore's implied criticisms of metaphysics lead on naturally to those of Wittgenstein. Moore took his stand on common sense, whereas Wittgenstein based his on living language. Arguing that men are each involved in a multitude of language games or autonomous linguistic activities, insofar as they are scientific investigators, moral agents, litigants, religious worshipers, and so on, Wittgenstein asked in what language game the claims and questionings of philosophers arose. He replied that there was no genuine

Language criticisms

linguistic context to which they belonged; philosophical puzzlement was essentially idle. Philosophers were preoccupied with highly general questions; they aspired to solve *the* problem of meaning or *the* problem of reality. Against that Wittgenstein argued that words and sentences have meaning as used in particular contexts; there is no single set of conditions that has to be fulfilled if they are to be thought meaningful. Equally, there is no single set of criteria that has to be satisfied by everything one takes to be real. Sticks and stones and men are taken as real in everyday discourse, but so are numbers in the discourse of mathematicians, and so is God in the discourse of religious men. There is simply no warrant for preferring one of these above the others—for saying, for example, with persons of an Empiricist turn of mind, that nothing can be real that does not have existence in space and time.

Wittgenstein's antipathy to metaphysical philosophy was in part based on self-criticism; in his early work the *Tractatus Logico-Philosophicus,* published in 1922, he had himself tried to give a general account of meaning. At least one doctrine of that enigmatic book survived in his later thought: the distinction between saying and showing. Wittgenstein in the *Tractatus* sought to pronounce on "what can be said" and came to the conclusion that only "propositions of natural science" can be. Though at this stage he spoke as if metaphysical statements were senseless, his motives for doing so were very different from those of the Positivists. The latter saw metaphysics as an enemy of science; in their view there was only one way to understand the world, and that was in scientific terms. But Wittgenstein, though agreeing that science alone can be clear, held that scientific thought has its limitations. There are things that cannot be said but can, nonetheless, be shown; the sphere of the mystical is perhaps a case in point. Unlike his Viennese contemporaries, Wittgenstein had no wish to rule out of court the thought that there are more things in heaven and earth than can be compassed in the language of science; writers whom he admired—such as Blaise Pascal, a 17th-century French scientist and writer on religious subjects, and Søren Kierkegaard, a Danish philosopher and theologian who is regarded as the founder of modern Existentialism—had discoursed of such matters in a way that was highly illuminating. They had made clear, however, that, just as one here went beyond the province of science, so also one went beyond that of philosophy. For them the idea that the metaphysician is privy to the most important of all things is absurd. There may be a sense in which men transcend everyday experience in moments of religious feeling or artistic insight, but there is no justification for thinking that when they do they arrive at the metaphysician's Absolute. As Kierkegaard said, the man who looks for speculative proofs in the sphere of religion shows that he does not understand that sphere at all.

Religious philosophers. It is important, in considering current criticisms of metaphysics, to appreciate that this discipline is now under double attack. In the first place, it must face the assault of those who regard it as a rival to science; it is against this assault that sympathizers like R.G. Collingwood, a British philosopher, historian, and archaeologist, seek to defend it. But metaphysics is also in disfavour among many religious philosophers. In earlier days, partisans of religion, and more generally believers in a spiritual order, looked to metaphysics to vindicate their claims against skeptical attack; now they are altogether more reluctant to do so. The continuing controversy about metaphysics has no doubt influenced this development; it scarcely seems sensible to take refuge in a fortress whose walls are so frequently breached. There is, however, another motive that operates here: the feeling that metaphysics is not only dubious but, worse, unnecessary. In an age whose tendencies are antiphilosophical rather than philosophical, there is widespread acceptance of the view that religion and morals, and for that matter science and history, are their own justification; none of them stands in need of a certificate of respectability from philosophy, and any pretense by metaphysicians to supply or refuse such a certificate must be without foundation. Though this view is widespread, it is even so not unchallenged; there are persons who find the fragmentation it involves—belief in God on Sundays, belief in science for the rest of the week—intolerable. For such persons, at least, the search for metaphysical truth and metaphysical answers must retain its fascination. (W.H.W.)

Tendencies in contemporary metaphysics

Background: the thought of Kant and Hegel

Kant's efforts to limit metaphysics opened new lines for its development. He had thought that reason is established by being limited and that some truths are certain independent of anything that can happen in experience because experience is structured by the interpretive categories reflected in these truths. Thus, it is possible to be certain of the world in its general structure but only insofar as it is an experienced, or phenomenal, world—that is, a world known by man, not a world as it is in itself. Hegel, however, argued persistently that knowledge of a thing unknowable in itself is a contradiction and that reason can know all that is real if the mind first accepts the given thing as "always already within experience as other." The mutual implication of knowing mind and reality known is accepted, and a science of self-consciousness that relates all categories and all reality to the knowing subject is envisaged. Thus, Kant's mutual implication of knowing subject and phenomenal thing was given ultimate metaphysical validity by Hegel, and Kant's reformulations of traditional dualisms—*e.g.,* subject–object, appearance–reality, perceptual–categorial, immanent–transcendent, regulative–constitutive—became momentous for metaphysics.

TENDENCIES IN THE UNITED STATES

John Dewey. In this milieu, John Dewey, an American educational reformer and pragmatic philosopher, published his "Kant and Philosophic Method" in 1884 in the journal of a group known as the St. Louis Hegelians. Although Dewey later rejected the full-scale Hegelianism expressed in the article, he did so only after gathering up in a partial synthesis the thought of both Kant and Hegel. In this he sounded the thematic notes of much contemporary American and continental metaphysics. Whether or not this metaphysics is explicitly termed transcendental (that is, concerned with experience as determined by the mind's conceptual and categorial makeup), it does two things: (1) it affirms Kant's insight that physical particulars cannot first be identified and later interrelated by means of the categories, but, to be identified at all, they must be assumed to be already categorized, and reasoning must proceed to expose those categorial structures that make the actuality of knowledge possible; (2) it agrees with Hegel's critique at least to the extent that Kant's idea that the source of sensations is external to the mind in a noumenon is regarded as a transgression of Kant's own doctrine that the categories, particularly that of causation, can be applied only within phenomenal experience. Dewey thought that Kant confused the empirical and transcendental standpoints by mixing analysis of the organism as sensationally responsive with analysis of mind. Kant forgot that it is only because the knowing subject already grasps the world through its categories that it can self-deceivingly regard its sensations as subjective and as caused by something not known. Thus, for Dewey, "The relation between subject and object is not an external one; it is one in a higher unity that is itself constituted by this relation."

In Dewey's extended later thought, metaphysics became the study of "the generic traits of existence." Concern with God and immortality slips nearly from view, and this is typical of much contemporary philosophy. Even so, Dewey's rethinking of the subject–object relation engenders a concept of a democratic and scientific community of persons, bound to each other through common ideals, which has religious overtones. Vague and ambivalent as this concept may be, it helps undermine the whole contrast between immanent and transcendent and leads metaphysics on new paths.

Location of the role of science in knowledge

William James. The work of William James, a leader of the Pragmatic movement, was typical of many contemporary tendencies, one of which was the attempt to locate the role of science in knowledge and culture. Trained in medicine, James hoped to protect the autonomy of psy-

chology as a science by adopting a dualistic view of mind and matter. He "supposes two elements, mind knowing and thing known, and treats them as irreducible. Neither gets out of itself or into the other, neither in any way is the other." He presumed that mental states could be identified independent of a commitment to the metaphysical status of the things known by them and that they could then be correlated to the brain. Ironically, his attempts to identify mental states involved him in commitments to the nature of the world as presented to mind. The only meaning that can be given things is in terms of the anticipated consequences of one's actions upon these things in the world; this anticipation also supplies the meaningfulness of thoughts. This is the basis of the "instrumental" view of thoughts—*i.e.,* reflecting upon thoughts as "tools," or as "plans of action," tells one something about the things known by them, the "tooled"; the converse also occurs.

Each realm of the world is experienced in terms of temporal standards of thought natural to that realm; *e.g.,* standards of mathematics are peculiar because of their ideal, changeless objects. These criteria are not derived from mind alone or from things alone but from their relationship in what is termed experience. This is a "double-barreled" term—that is, an experiencing of experienced things. The mind cannot be specified independent of things that appear to the mind, and things cannot be specified independent of their modes of appearing to the mind. Phenomena regarded abstractly as singular, or "pure," are neutral between mind and matter, which are different contexts of the very same pure experiences—contexts that comprise a single world.

James would not claim that his method is transcendental. Yet the fact remains that for him subject and object cannot be specified independent of each other, and James undercuts dualism and moves toward a transcendental explanation of the conditions of knowledge.

James tried to avoid what can be called logicism, physicalism, and psychologism. The last claimed that, because knowing is a psychical act, all that is known about must be subject to psychological laws. James replied that the known-about, the experienced, has its own autonomy, either as pure experience, a "specific nature" studied by philosophy, as a physical context studied by physics, or, finally, as a psychical context, a human history, studied by psychology. The latter two are both dependent, at least for their ultimate meaningfulness, upon the first. Physicalism attempts to infer the nature of the psychical directly from the physical, thus reducing it to the physical. Most logicisms claimed that pure reason can grasp the real in itself. James agreed that reason entertains ideal objects, the relations between which are fixed independent of the sequence of sensory experience, but he asserted that this experience must decide which necessary truths apply to the world. Although some always do apply, the ascertainment of what is categorial for the world is always incomplete. Just when the world "plays into the hands of logic" is decided in that endless interaction of "worlds" or "orders of experience"—such as the perceptual, the imaginary, the mathematical—occasioned by a thing experienced sifting through the orders trying to find one that can contain it without contradiction; Pegasus, for example, is a mythical creature just because it cannot find a place in the world of real horses. The world of perceptual things, experienced as experienceable by all and as existing simultaneously, serves as a paradigm of reality even though other orders of experience are not reducible to it. Existence is an unusual predicate for James; it means that practical relationship of doing and concern within which things must be able to stand to men if they are to be counted as fundamentally real. James was not giving a subjectivistic account of reality, however, because he included in the fundamentally real all that can be related spatially and temporally to what can stand over against men's bodily selves. This was commonly forgotten by critics of James's popularized theory of truth, Pragmatism, which was thus systematically misunderstood.

James's contemporaries Charles Sanders Peirce and Josiah Royce stood in close dialectical exchange with him on these themes. Differences between them concerned the scope and conditions to be assigned experience. In general, Peirce argued that experience is to be construed more narrowly, in terms of mathematical logic and physics, whereas Royce argued that the understanding of truth, error, and meaning requires the assumption of an absolute knower or experiencer. Peirce was a seminal thinker whose thoughts were often beginnings in the more systematically developed philosophies of the other Americans.

TENDENCIES IN CONTINENTAL EUROPE

Edmund Husserl and Phenomenology. Edmund Husserl, the German philosopher, used the term Phenomenology to name a whole philosophy. In order to rid his transcendental investigation of empirical prejudgments and to discover connections of meaning that are necessary truths underlying both physical and psychological sciences, Husserl bracketed and suspended all judgments of existence and empirical causation. He did not deny them; rather, he no longer simply asserted them. He reflected upon their intended meaning. In reflection he claimed to see that things have meaning in terms of how they appear to men in their pre-reflective life and that awareness is in terms of this "how." In pre-reflective life, however, men are not aware of the "how" as such. By exposing this basic meaning through which men refer to things, he can free their eyes of the "cataracts" of the stereotyped and the obvious and can summon them "back to the things themselves."

Reflection on pre-reflective life

Husserl took traditional metaphysics to be infested with precritical commitments to existence, either physicalistic, psychologistic, or logistic. He used the term ontology, however, to apply to his study of objects of consciousness and even appropriated the Aristotelian term first philosophy. The world appears within the reflective bracket as existentially neutral (that is, as regards whether things have existence in themselves or exist for men) but ontologically ordered because, if various orders of beings exist, then what they are can be nothing but what they are intended to be. And what they are cannot be known until all they are intended to be is known.

Husserl distinguished two types of ontologies: formal ontologies, which are the domain of meanings, or essences, such as "one," "many," "whole," or "part," that are articulated by formal logic and which Husserl referred to as empty; and material ontologies, which discover and map the meaning and structure of sensory experience through transcendental investigation. In material ontology, for example, the essence of any physical thing is discovered by varying in the imagination the object that is given within its strictly correlative mode of perceptual consciousness; the essence is that identical something that continuously maintains itself during the process of variation. It is intuited that the perceived thing cannot vary in the imagination beyond the point of something given perspectively and incompletely to any given perceiving glance; hence, this is the essence of any physical thing. This is a truth of eidetic necessity and comprises a first principle in Husserl's projected philosophical science; *e.g.,* numbers are what they are because of the ways in which they are not like things.

The Existentialists. Husserl had early distinguished the primary task of description of "morphological essences" (those with "floating" spheres of application in the sensory life) from description of essences like those in geometry, which described closed, or definite, manifolds; but the question of the theoretical status of the ordinary perceptual world, or lived world (*Lebenswelt*), became increasingly disputed among Existentialists. They asked whether there can be a philosophical science that has made all its presuppositions transparent to itself. If transcendental elucidation of the *Lebenswelt,* with its historically established sediments of meaning, is really essential to show how theoretical sciences are grounded, then one may reasonably ask how Phenomenology can be sure it has accomplished the elucidation completely because it is itself a theory. The question gained urgency by Husserl's nearly imperceptible slide into what appeared to be an Idealist position regarding the source of all meaning, a commitment to an absolute ego. If this ego is regarded as individual in any

way, the problem arises of how any other individual can be as other because it is constituted in this primal ego.

Husserl's theory of the ego was rejected by French Existentialists such as Jean-Paul Sartre and Maurice Merleau-Ponty. For the latter, the bracketing of meanings can never be completed, for consciousness is not an enclosed individual that could grasp through reflection all its possible motivations to experience and give meaning to a world. Knowers are subjects with bodies, whose perceptual life is articulated only incompletely and discloses the world in progressively surprising ways. More meaning is found in existence than can at any moment be expressed, and even the meaning of existence is not reducible to any definable set of meanings.

Husserl's approach was not nearly radical enough for Martin Heidegger, a German thinker sometimes called an Existentialist. In thinking that he could prescind so neatly from facts and retain the essence of facts, Husserl was still involved to some extent in the prejudgments—the psychologistic, physicalistic, and logistic dualisms—that he inveighed against. For Heidegger there is no realm of consciousness that constitutes meaning, and he does not think that some sharp but harmless line could be drawn between essence and fact. The ambiguity in Husserl's thought between "object" as sense of the particular and as the encountered particular in its bodily presence is not harmless. It is unjustifiable to think that consciousness can finally demarcate the essential sense of a thing. Thus, Heidegger discarded the very concept of consciousness and proposed a "fundamental ontology" of human being (*Dasein*). Man as a subject in the world cannot be made the object of sophisticated theoretical conceptions such as "substance" or "cause"; man, furthermore, finds himself already involved in an ongoing world that cannot as a whole be made the object of such conceptions; yet the structure of this involvement is the transcendental condition of any science of objects. For example, a man can band with other men in philosophical groups and can think about the metaphysical status of other men only because he is already essentially with others. He cannot hope to so purify his own thinking that it becomes that of an impersonal thinker, an absolute ego.

Ontology of *Dasein*

According to Heidegger, to rethink the problem of reality at its roots, it is necessary to rethink the fundamentally temporal, already-given structures of human involvement. Prejudice in the West, which construes reality, or being, on the basis of beings (that is, being as the most general feature of beings), must be overturned, and the problem of the real, the "transcendent," must be rethought on a ground on which distinctions between immanent and transcendent and between perceptual and categorial have been reconstructed. The being of the world transcends any constitution of the meaning of the world and is a condition of experience. Thus, a sense is required of being not as object but as the underlying condition for the reality of the being of all objects.

Heidegger wanted to propose a genuine phenomenology, a study that would presuppose nothing of the traditionally formulated distinctions such as subjective–objective or phenomenal–real. The transcendence of the world can be understood only as it appears; *i.e.,* when they are encountered openly, things appear as appearing in part, as both revealing and concealing themselves. If to the uneducated eye the Sun appears to be smaller than it is, the naive inference can be corrected only by educating the person to interpret appearances—to calculate, for example, the speed and direction of light. The real is given in and through its appearances.

THE THOUGHT OF WHITEHEAD

The thought of Alfred North Whitehead is a distinctive variation on these contemporary themes. Dualisms are undermined by a phenomenology that does not bracket factual assertions. Logical and mathematical deductive schemes must be able to be interpreted in relationships crudely observable in experience, and abstractions of physics and common sense parading as realism (*e.g.,* that things exist separately within their own surfaces) must be revealed for what they are, namely, abstractions. The basic units of reality are organismic unities, "actual occasions," which are spatial and temporal extensions that cannot be exhaustively expressed in terms of distributions of matter at an instant. Their unity is constituted in a perception-like responsiveness to the universe that, though usually lacking consciousness or apprehension, is an appropriation to and for itself of the whole. This appropriation cannot be exhaustively expressed by point-instant mechanics (mechanics that is worked out in connection with the physics of relativity and thus measures not only the distance but also the time intervals between points) but is minimally a "prehension" (a term proper to Whitehead indicating the point-transcending function of perception and consciousness).

Organismic unities

Each enduring object of ordinary perception—tables, chairs, animals—is, for Whitehead, a "society" of actual occasions inheriting, through a process of appropriation and reenactment in a predictable way, characteristics of its predecessors. Human perception is understood as a special case of prehension, in which qualities of the environment are mediated and projected on the basis of organic and affective experience of the perceiver's body, but in such a way that some of this process can be acknowledged by the percipient upon reflection. Because human consciousness is regarded as only a special case of prehensive relations, and because vacuous realisms and notions of transcendence are regarded as "fallacies of misplaced concreteness and simple location," mind–body dualisms are rejected.

Whitehead thought of "the primordial nature of God" as a general ordering of the process of the world, the ultimate basis of all induction and assertion of law, a "conceptual prehension" that functions in the selection of those "eternal objects," or repeatable patterns that are enacted in the world. God, however, does not create actual entities. He provides them with initial impetus, in the form of their subjective aim, to self-creation. Even God is the outcome of creativity, the process by which the events of the world are synthesized into new unities. It is the creative, not fully predictable, advance into novelty of a pluralistic process. The freedom of man and the determinism of nature were regarded by Whitehead as another artificial dualism.

The future of metaphysics is uncertain, not mainly because of 20th-century critics, the Logical Positivists, but because of its own not fully predictable nor controllable dynamisms.

(B.W.W.)

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Works that analyze the thought of specific philosophers include: R.E. AQUILA, "Two Problems of Being and Nonbeing in Sartre's Being and Nothingness," *Philosophy and Phenomenological Research,* 28(2):167–186 (December 1977); SUZANNE BACHELARD, *A Study of Husserl's "Formal and Transcendental Logic"* (1968; originally published in French, 1957); JOHN D. CAPUTO, *The Mystical Elements in Heidegger's Thought* (1978); JACQUES DERRIDA, *Edmund Husserl's "Origin of Geometry": An Introduction* (1978; originally published in French, 2nd rev. ed., 1974); JOSEPH P. FELL, *Heidegger and Sartre* (1979); WOLFGANG WALTER FUCHS, *Phenomenology and the Metaphysics of Presence: An Essay in the Philosophy of Edmund Husserl* (1976); AGNES HELLER (ed.), *Lukács Reappraised* (1983; U.K. title, *Lukács Revalued*); SANG-KI KIM, *The Problem of the Contingency of the World in Husserl's Phenomenology* (1977); A.M. MIRVISH, "Merleau-Ponty and the Nature of Philosophy," *Philosophy and Phenomenological Research,* 43(4):449–476 (June 1983); MARIE-LUISE SCHUBERT KALSI, *Alexius Meinong on Objects of Higher Order and Husserl's Phenomenology* (1978); and ANTHONY THISELTON, *The Two Horizons: New Testament Hermeneutics and Philosophical Description with Special Reference to Heidegger, Bultmann, Gadamer, and Wittgenstein* (1980).

(W.H.W./A.C.G.)

Mexico

Mexico, or the United Mexican States (Spanish: Estados Unidos Mexicanos), is a federal republic located in North America. Sharing a common border throughout its northern extent with the United States, the country is bounded on the west and south by the Pacific Ocean, to the east by the Gulf of Mexico and the Caribbean Sea, and on the southeast by Guatemala and Belize. Roughly triangular in shape, Mexico covers an area of 756,066 square miles (1,958,201 square kilometres). While it is more than 1,850 miles (3,000 kilometres) across the country from northwest to southeast, the width varies from less than 135 miles at the Isthmus of Tehuantepec to more than 1,200 miles in the north.

Mexico has a vast wealth of mineral resources, a limited amount of agricultural land, and a rapidly growing population. More than half of the people live in the central core, while vast areas of the arid north and the tropical south are sparsely settled. The long-held stereotype of Mexico as a country where life is slow-paced and the population consists mostly of subsistence farmers has little truth. Petroleum and tourism have come to dominate the economy, and industrialization is increasing in many parts of the country. Internal migration has caused urban centres to grow dramatically, and more than two-thirds of Mexicans now live in cities; in population, Mexico City, the capital, is the largest city in the world (though the Mexico City metropolitan area ranks third in population when compared to other metropolitan areas). Despite impressive social and economic gains made during the 1960s and '70s, most Mexicans remain poor. Beginning in the 1980s the country was wracked by severe inflation and an enormous foreign debt.

These growing pains of modernization are in sharp counterpoint to the traditional life-styles that prevail in the more isolated rural areas. Small communal villages remain, where Indian peasants live much as did their ancestors. The cultural remnants of great Indian civilizations, such as those at Chichén Itzá or Tulum, provide a contrast to colonial towns like Taxco or Querétaro. In turn, these towns appear as historical relics when compared to the modern metropolis of Mexico City. It is this tremendous cultural and economic diversity, distributed over an enormously complex and varied physical environment, that gives Mexico its character.

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Physical and human geography

THE LAND

Relief. Mexico is located in one of the Earth's most dynamic tectonic areas. It is a part of the circum-Pacific "Ring of Fire," a region of active volcanism and frequent seismic activity. Towering peaks, such as Citlaltépetl (also called Orizaba; 18,701 feet [5,700 metres]) and Popocatépetl (17,883 feet [5,452 metres]), are extremely young in geologic terms (late Tertiary) and are examples of the volcanic forces that built much of the central and southern parts of the country. Mexico is situated on the western, or leading, edge of the huge North American Plate, whose interaction with the Pacific, Cocos, and Caribbean plates has, over geologic time, given rise to the earth-building processes of the area. The complexity found in southern Mexico's physiography is due to the interaction among these tectonic plates, which produces numerous and severe earth movements. It is in this dynamical but often unstable physical environment that the Mexican people have built their nation.

On the basis of geologic history and surface configuration, Mexico can be divided into eight major landform regions. The largest, and most important for human habitation, is the Mexican Plateau. Extending from the Isthmus of Tehuantepec northward to the U.S. border, this region consists of a central plateau and its dissected borders. The central plateau tilts gently upward from the north toward the south. At its northern end the plateau is about 4,000 feet above sea level, and it rises to more than 8,000

The Mexican Plateau

MAP INDEX

Political subdivisions

Aguascalientes . .22 00 N 102 30 W
Baja California
Norte . . . . . .30 00 N 115 00 W
Baja California
Sur . . . . . .25 50 N 111 50 W
Campeche . . . . .19 00 N 90 30 W
Chiapas . . . . . .16 30 N 92 30 W
Chihuahua . . . . .28 30 N 106 00 W
Coahuila . . . . . .27 20 N 104 00 W
Colima . . . . . .19 10 N 104 00 W
Distrito Federal . .19 15 N 99 10 W
Durango . . . . . .24 50 N 104 50 W
Guanajuato . . . . 21 00 N 101 00 W
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Nayarit . . . . . .22 00 N 105 00 W
Nuevo León . . . .25 40 N 100 00 W
Oaxaca . . . . . .17 00 N 96 30 W
Puebla . . . . . .18 50 N 98 00 W
Querétaro . . . . . 21 00 N 99 55 W
Quintana Roo . . .19 40 N 88 30 W
San Luis Potosí . .22 30 N 100 30 W
Sinaloa . . . . . .25 00 N 107 30 W
Sonora . . . . . .29 20 N 110 40 W
Tabasco . . . . . .18 00 N 92 40 W
Tamaulipas . . . .24 00 N 98 45 W
Tlaxcala . . . . . .19 25 N 96 10 W
Veracruz . . . . . .19 20 N 96 40 W
Yucatán . . . . . .20 50 N 89 00 W
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Cities and towns

Acámbaro . . . . .20 02 N 100 44 W
Acapulco . . . . .16 51 N 99 55 W
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Arriaga . . . . . .16 14 N 93 54 W
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Ciudad Guzmán . .19 41 N 103 29 W
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Ciudad Juárez . . .31 44 N 106 29 W
Ciudad Mante . . .22 44 N 98 57 W
Ciudad
Obregón . . . .27 29 N 109 56 W
Ciudad Pemex . . .17 54 N 92 30 W
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Coatzacoalcos . . .18 09 N 94 25 W
Colima . . . . . .19 14 N 103 43 W
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Cosamaloapan . . .18 22 N 95 46 W
Cozumel . . . . . .20 31 N 86 55 W
Cuauhtémoc . . . .28 25 N 106 52 W
Cuernavaca . . . .18 55 N 99 15 W
Culiacán . . . . . .24 48 N 107 24 W
Díaz Gutiérrez . . .22 12 N 100 57 W
Durango . . . . . .24 02 N 104 40 W
El Dorado . . . . . .24 17 N 107 21 W
Ensenada . . . . . .31 52 N 116 37 W
Escuinapa . . . . . .22 51 N 105 48 W
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Gómez Palacio . . .25 34 N 103 30 W
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Guasave . . . . . .25 34 N 108 27 W
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Heroica Nogales .31 20 N 110 56 W
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Independencia . .18 21 N 99 32 W
Irapuato . . . . . .20 41 N 101 21 W
Jalapa . . . . . .19 32 N 96 55 W
Jerez de García
Salinas . . . . . .22 39 N 103 00 W
Jiménez . . . . . .27 08 N 104 55 W
Juchitán . . . . . .16 26 N 95 01 W
La Paz . . . . . .24 10 N 110 18 W
La Piedad
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Las Vacas, see
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Linares . . . . . .24 52 N 99 34 W
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Tuxtla
Macuspana . . . .17 46 N 92 36 W
Manzanillo . . . . .19 03 N 104 20 W
Matamoros . . . .18 36 N 98 28 W
Matamoros . . . .25 53 N 97 30 W
Matehuala . . . . .23 39 N 100 39 W
Mazatlán . . . . . .23 13 N 106 25 W
Mérida . . . . . .20 58 N 89 37 W
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Minatitlán . . . . .17 59 N 94 31 W
Monclova . . . . .26 54 N 101 25 W
Monterrey . . . . .25 40 N 100 19 W
Morelia . . . . . .19 42 N 101 07 W
Mulejé . . . . . .26 53 N 112 01 W
Navojoa . . . . . .27 06 N 109 26 W
Nueva Rosita . . .27 57 N 101 13 W
Nuevo Laredo . . .27 30 N 99 31 W
Oaxaca . . . . . .17 03 N 96 43 W
Orizaba . . . . . .18 51 N 97 06 W
Pachuca . . . . . .20 07 N 98 44 W
Papantla . . . . . .20 27 N 97 19 W
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Piedras Negras . .28 42 N 100 31 W
Poza Rica . . . . .20 33 N 97 27 W
Progreso . . . . . .21 17 N 89 40 W
Puebla . . . . . .19 03 N 98 12 W
Puerto
Escondido . . . .25 48 N 111 20 W
Puerto Vallarta
(Las Penas) . . . .20 37 N 105 15 W
Querétaro . . . . .20 36 N 100 23 W
Reynosa . . . . . .26 07 N 98 18 W
Río Bravo . . . . .25 59 N 98 06 W
Sabinas . . . . . .27 51 N 101 07 W
Salamanca . . . . .20 34 N 101 12 W
Saltillo . . . . . .25 25 N 101 00 W
San Andrés
Tuxtla (Los
Tuxtlas) . . . . .18 27 N 95 13 W
San Cristóbal de
las Casas . . . .16 45 N 92 38 W
San Felipe . . . . .31 00 N 114 52 W
San Francisco
del Rincón . . . .21 01 N 101 51 W
San Ignacio . . . .27 27 N 112 51 W
San Lucas . . . . .22 53 N 109 54 W
San Luis . . . . . .32 29 N 114 48 W
San Luis Potosí . .22 09 N 100 59 W
San Miguel de
Allende . . . . . .20 55 N 100 45 W
San Pedro . . . . .25 45 N 102 59 W
Santa Bárbara . . .26 48 N 105 49 W
Santa Catarina . .25 41 N 100 28 W
Santiago
Papasquiaro . . .25 03 N 105 25 W
Silao . . . . . .20 56 N 101 26 W
Tampico . . . . . .22 13 N 97 51 W
Tapachula . . . . .14 54 N 92 17 W
Taxco . . . . . .18 33 N 99 36 W
Tecomán . . . . . .18 55 N 103 53 W
Tecpan . . . . . .17 15 N 100 41 W
Tehuacán . . . . .18 27 N 97 23 W
Tepic . . . . . .21 30 N 104 54 W
Tequila . . . . . .20 54 N 103 47 W
Tierra Blanca . . .18 27 N 96 21 W
Tijuana . . . . . .32 32 N 117 01 W
Tizimín . . . . . .21 09 N 88 09 W
Tlaquepaque . . . .20 39 N 103 19 W
Tlaxcala . . . . . .19 19 N 98 14 W
Toluca . . . . . .19 17 N 99 40 W
Torreón . . . . . .25 33 N 103 26 W
Tula . . . . . .23 00 N 99 43 W
Tuxpan . . . . . .20 57 N 97 24 W
Tuxpan . . . . . .21 57 N 105 18 W
Tuxtla . . . . . .16 45 N 93 07 W
Uruapan . . . . . .19 25 N 102 04 W
Valles . . . . . .21 59 N 99 01 W
Veracruz . . . . . .19 12 N 96 08 W
Villahermosa . . . .17 59 N 92 55 W
Zacapú . . . . . .19 50 N 101 43 W
Zacatecas . . . . . .22 47 N 102 35 W
Zamora de
Hidalgo . . . . . .19 59 N 102 16 W
Zapopan . . . . . .20 43 N 103 24 W

Physical features and points of interest

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Guarda Island . .29 20 N 113 25 W
Baja California
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California),
peninsula . . . .28 00 N 113 30 W
Balsas, *river* . . . .17 55 N 102 10 W
Basaseachic
Cascades
National Park . . .28 15 N 108 02 W
California, Gulf of
(Cortes, Sea
of) . . . . . .28 00 N 112 00 W
Campeche, Bay
of . . . . . .20 00 N 94 00 W
Catoche, Cape . .21 35 N 87 05 W
Cedros Island . . .28 12 N 115 15 W
Cedros Island
Wildlife
Reserve . . . . .28 12 N 115 15 W
Chapala, Lake . . .20 15 N 103 00 W
Chiapas,
Cordillera de,
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Sierra de
Chichén Itzá,
historical site . . .20 40 N 88 34 W
Citlaltépetl
Volcano
(Orizaba, Pico
de) . . . . . .19 01 N 97 16 W
Conchos, *river* . . .29 35 N 104 25 W
Corrientes,
Cape . . . . . .20 25 N 105 42 W
Cortes, Sea of,
see California,
Gulf of
Costera
Noroiental Plain
(Gulf Coastal
Plain), *region* . .26 00 N 98 00 W
Cozumel Island . .20 25 N 86 55 W
Fuerte, *river* . . . .25 54 N 109 22 W
Gran Desierto
(Sonoran
Desert) . . . . . .32 15 N 114 30 W
Grande de
Santiago
(Santiago),
river . . . . . .21 36 N 105 26 W
Grijalva, *river* . . . .18 36 N 92 39 W
Gulf Coastal
Plain,
see Costera
Noroiental Plain
Isabela Island
National Park . . .21 51 N 105 55 W
Juárez,
Sierra de . . . .32 00 N 115 50 W
La Venta,
historical site . . .17 58 N 94 15 W
Lagunas de
Montebello
National Park . . .16 03 N 91 45 W
Lerma, *river* . . . .20 13 N 102 46 W
Lower California,
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Baja California
Madre,
Laguna . . . . .25 00 N 97 40 W
Madre
Occidental,
Sierra . . . . . .25 00 N 105 00 W
Madre Oriental,
Sierra . . . . . .22 00 N 99 30 W
Madre del Sur,
Sierra . . . . . .17 00 N 100 00 W
Magdalena Bay . .24 35 N 112 00 W
Mapimí Basin,
desert . . . . . .27 30 N 103 30 W
Marías Islands . . .21 25 N 106 28 W
Mayo, *river* . . . .26 45 N 109 47 W
Mexican
Plateau . . . . . .24 00 N 102 00 W
Mexico, Gulf of . .25 00 N 91 00 W
Miguel Alemán
Reservoir . . . . .18 15 N 96 30 W
Moctezuma,
river . . . . . .21 59 N 98 34 W
Monte Albán,
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Nazas, *river* . . . .25 45 N 102 50 W
Norte, Mesa del . .27 00 N 104 00 W
Oaxaca Valley . . .17 00 N 97 00 W
Orizaba, Pico de,
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Volcano
Pacific Coastal
Lowlands . . . .26 00 N 108 00 W
Pacific Ocean . . .18 00 N 110 00 W
Palenque,
historical site . . .17 31 N 91 58 W
Pánuco, *river* . . . .22 16 N 97 47 W
Paricutín
Volcano . . . . .19 28 N 102 15 W
Popocatépetl
Volcano . . . . .19 02 N 98 38 W
Revillagigedo
Islands . . . . . .19 00 N 111 30 W
Río Grande (Río
Bravo) . . . . . .25 55 N 97 09 W
Salado, *river* . . . .26 52 N 99 19 W
San Lucas,
Cape . . . . . .22 52 N 109 53 W
San Pedro Mártir,
Sierra . . . . . .30 45 N 115 13 W
Santiago, see
Grande de
Santiago
Sebastián
Vizcaíno Bay . . .28 00 N 114 30 W
Soconusco,
Sierra de
(Chiapas
Cordillera) . . . .15 30 N 92 35 W
Sonora, *river* . . . .28 48 N 111 49 W
Sonoran Desert,
see Gran
Desierto
Southern
Highlands . . . .18 00 N 100 00 W
Tamiahua,
Laguna de . . . .21 35 N 97 35 W
Tehuantepec,
Gulf of . . . . . .16 00 N 94 50 W
Tehuantepec,
Isthmus of . . . .17 00 N 95 00 W
Términos,
Laguna de . . . .18 37 N 91 33 W
Tiburón Island . . .29 00 N 112 25 W
Toluca, Mount . . .19 08 N 99 44 W
Tula, *historical*
site . . . . . .20 03 N 99 21 W
Tuxpan, *river* . . . .20 59 N 97 18 W
Usumacinta,
river . . . . . .18 24 N 92 38 W
Uxmal, *historical*
site . . . . . .20 22 N 89 46 W
Vicente Guerrero
Reservoir . . . . .23 55 N 98 44 W
Yaqui, *river* . . . .27 37 N 110 39 W
Yucatán
Peninsula . . . . .19 30 N 89 00 W

Scale 1: 13,908,000
1 inch equals approx. 220 miles
0 50 100 150 200 mi
0 100 200 300 km
Key to States (shown by number on map)
1 AGUASCALIENTES
2 QUERÉTARO
3 TLAXCALA
4 MORELOS
5 DISTRITO FEDERAL
Cities over 2,000,000
Cities 500,000 to 2,000,000
Cities 150,000 to 500,000
Cities under 150,000
National capitals
State capitals
PUEBLA State names
International boundaries
Stela boundaries
Intermittent rivers
Dams
Swamps and marshes
Sand areas
National parks
Historical sites
Spot elevations in metres (1 m = 3.28 ft)
Lambert Conformal Conic Projection
UNITED STATES
MEXICO
GUATEMALA
HONDURAS
Gulf of Mexico
PACIFIC OCEAN
Gulf of California
Bay of Campeche
Gulf of Tehuantepec
Tropic of Cancer
REVILLAGIGEDO ISLANDS
SIERRA MADRE OCCIDENTAL
SIERRA MADRE ORIENTAL
MESA DEL NORTE
MEXICAN PLATEAU
COSTERA NOROCCIDENTAL
COSTERA NORORIENTAL
YUCATÁN PENINSULA
CHIHUAHUA
SONORA
COAHUILA
DURANGO
ZACATECAS
NUEVO LEÓN
TAMAULIPAS
SAN LUIS POTOSÍ
AGUASCALIENTES
QUERÉTARO
HIDALGO
TLAXCALA
MORELOS
PUEBLA
VERACRUZ
OAXACA
GUERRERO
MICHOACÁN
JALISCO
COLIMA
NAYARIT
SINALOA
BAJA CALIFORNIA NORTE
BAJA CALIFORNIA SUR
TABASCO
CHIAPAS
CAMPECHE
YUCATÁN
QUINTANA ROO
TAMAULIPAS
Mexico City
Guatemala City
San Salvador
Tegucigalpa
San Diego
Tijuana
Phoenix
Tucson
El Paso
Ciudad Juárez
Chihuahua
Monterrey
Saltillo
Torreón
Durango
Mazatlán
Culiacán
Hermosillo
Guaymas
Nogales
Nuevo Laredo
Reynosa
Matamoros
Corpus Christi
Tampico
Veracruz
Puebla
Acapulco
Oaxaca
Tuxtla Gutiérrez
Villahermosa
Campeche
Mérida
Chetumal
Belize City
Belmopan
Tapachula
Salina Cruz
Coatzacoalco
Minatitlán
Ciudad del Carmen
Progreso
Isla Cozumel
Cabo Catoche
Punta Allen
Laguna Madre
Lake Chapala
Lake Nicaragua
Lake Izabal
Río Grande
Río Bravo
Río Usumacinta
Río Grijalva
Río Motagua
Río Lempa
Río Coatzacoalcos
Río Papaloapan
Río Balsas
Río Pánuco
Río Lerma
Río Santiago
Río Yaqui
Río Mayo
Río Fuerte
Río Sinaloa
Río Culiacán
Río Colorado
Río Conchos
Río Nazas
Río Aguanaval
Río Sabinas
Río Salado
Río Soto la Marina
Río Tamesí
Río Tuxpan
Río Cazones
Río Tecolutla
Río Nautla
Río Jamapa
Río Papagayo
Río Verde
Río Ameca
Río Grande de Santiago
Río Culiacán
Río Mocorito
Río Sinaloa
Río Fuerte
Río Mayo
Río Yaqui
Río Sonora
Río Concepción
Río Magdalena
Río Altar
Río Santa Cruz
Río Gila
Río Salado
Río Colorado
Río Hondo

feet south of Mexico City. Throughout the plateau, flat-tish intermontane basins and *bolsones* (ephemeral interior drainage basins) are interrupted by mountainous outcrops.

The central plateau is divided into two major parts. The Mesa del Norte begins near the U.S. border and ends near San Luis Potosí. In this arid, lower part of the Mexican Plateau, interior drainage (that is, without outlet to the ocean) predominates, and there are few permanent streams. The Mesa Central stretches from San Luis Potosí to just south of Mexico City. Formed largely by volcanic action, the surface of the Mesa Central is higher (7,000 to 9,000 feet above sea level), moister, and generally flatter than the Mesa del Norte. The Mesa Central is divided into a series of fairly level intermontane basins separated by eroded volcanic peaks. The largest valleys, such as those of Mexico, Puebla, and Guadalajara, rarely exceed 100 square miles in area, while many others are quite small. The basins are generally fertile; the traditional breadbasket of the country, the Guanajuato Basin, is located in the northern part of the Mesa Central. Many of the basins were sites of major lakes that were drained to facilitate European settlement. Around Mexico City the weak, structurally unstable soils that remain have caused buildings to shift on their foundations and over many years to sink slowly into the ground.

The Mexican Plateau is flanked by dissected mountainous borders. To the west is the largely volcanic Sierra Madre Occidental, with an average height of 8,000 to 9,000 feet. It has been highly incised by westward-flowing streams that eroded a series of deep canyons, or *barrancas,* the most spectacular of which is the Barranca del Cobre ("Copper Canyon"), Mexico's Grand Canyon. The Sierra Madre Oriental, a range of folded mountains formed of shales and limestones, is situated on the eastern side of the Mexican Plateau. With average elevations similar to those of the Sierra Madre Occidental, this highly dissected highland region has peaks exceeding 12,000 feet. The Neo-Volcánica Cordillera (also called the Transverse Volcanic Axis), with spectacular snowcapped peaks such as Popocatépetl, Iztaccíhuatl (17,342 feet [5,286 metres]), and Toluca (14,954 feet [4,558 metres]), forms the southern boundary of the Mexican Plateau.

Coastal lowlands

East and west of the Mexican Plateau lie the country's coastal lowlands. The Gulf Coastal Plain extends some 900 miles along the Gulf of Mexico from the Texas border to the Yucatán Peninsula. Characterized by lagoons and low-lying swampy areas east of the abrupt escarpment formed by the Sierra Madre Oriental, the triangular northern portion of the plain is more than 100 miles wide near the U.S. border but tapers toward the south. North of Tampico, an outlier of the Sierra Madre Oriental reaches the sea and interrupts the continuity of the Gulf Coastal Plain. South from there the plain is narrow and irregular, widening at the northern end of the Isthmus of Tehuantepec and then encompassing the horizontal limestone formations that underlie the Yucatán Peninsula.

The Pacific Coastal Lowlands, much narrower and less well defined than their east coast counterpart, begin near the Mexicali Valley in the north and terminate near Tuxpan, some 900 miles to the south; despite their name, for most of this distance, the lowlands face the Gulf of California. Bounded on the east by the steep-sided Sierra Madre Occidental, the Pacific Coastal Lowlands are a series of coastal terraces, mesas, and small basins interspersed with riverine deltas and restricted coastal strips. Parts of this arid region have become important sites of irrigated agricultural production.

Baja California

An isolated strip of extremely arid land, the Baja California Peninsula is nearly 800 miles long but seldom more than 100 miles wide. The central core of the peninsula is a huge granitic fault block with peaks of more than 9,000 feet above sea level in the San Pedro Martír and Sierra de Juárez. The gently sloping western side of these mountain ranges is in contrast to the steep eastern escarpment, which makes access from the Gulf of California extremely difficult.

The Balsas Depression, which takes its name from the major river draining the region, lies immediately south of the Mexican Plateau. The depression is formed of small, irregular basins interrupted by hilly outcrops, which gives this hot, dry area a distinctive physical landscape.

The Southern Highlands are a series of highly dissected mountain ranges and plateaus. On their southwestern side, approximately from Puerto Vallarta to the Gulf of Tehuantepec, are a series of ranges known collectively as the Sierra Madre del Sur. These relatively low (7,000 to 8,000 feet above sea level) crystalline mountains often reach the sea to create a rugged coastal margin, part of which is known as the Mexican Riviera. Picturesque coastal sites, such as Ixtapa-Zihuatanejo, Acapulco, and Puerto Escondido, are favourite tourist destinations, while the less hospitable inland basins provide a difficult environment for traditional peasant farmers. Farther northeast is the Mesa del Sur, with numerous stream-eroded ridges and small, isolated valleys some 4,000 to 5,000 feet above sea level. The Oaxaca Valley is the largest and most densely settled of these valleys. With its predominantly Indian population, it is one of the most picturesque yet poorest parts of Mexico.

A low-lying, narrow constriction of land, the Isthmus of Tehuantepec reaches an elevation of less than 900 feet. Its hilly central area is bordered on either side by narrow coastal plains.

The Chiapas Highlands, an extension of the mountain ranges of Central America, are composed of a series of fault block mountains surrounding a high rift valley. The low, crystalline Sierra de Soconusco range lies along the Pacific coast. To the northwest and paralleling the coast is the rift valley of the Grijalva River. A group of highly dissected, folded, and faulted mountains is located between the valley and the Tabasco Plain, a southeastern extension of the Gulf Coastal Plain.

To the northeast of the Tabasco Plain and extending into the Gulf of Mexico is the Yucatán Peninsula. The peninsula's limestone terrain is generally flat to rolling and seldom exceeds 500 feet in elevation. There is little surface drainage, and subterranean erosion has produced caverns and sinkholes, the latter being formed when cavern roofs collapse. The islands of Cozumel and Mujeres lie off the peninsula's northeastern tip.

Drainage. Because of its climatic characteristics and arrangement of landforms, Mexico has few major rivers or natural lakes. The largest are found in the central part of the country. The Lerma River has its headwaters in the Toluca Basin, west of Mexico City, and flows westward to form Lake Chapala, the country's largest natural lake. The Santiago River then flows out of the lake to the northwest, crossing the Sierra Madre Occidental on its way to the Pacific. The eastward-flowing Moctezuma-Pánuco river system, which drains much of the eastern portion of the Mesa Central, has carved gorges through the Sierra Madre Oriental to reach the Gulf of Mexico. Lakes Pátzcuaro and Cuitzeo, west of Mexico City, are remnants of the numerous lakes that once were found in the Mesa Central.

The Balsas River and its tributaries drain the Balsas Depression as well as much of the southern portion of the Mesa Central. Dammed where it crosses the Sierra Madre del Sur, the Balsas is a major source of hydroelectric power. Farther southeast, the Grijalva-Usumacinta river system drains most of the humid Chiapas Highlands. Together with the Papaloapan River, which enters the Gulf of Mexico south of Veracruz, the Grijalva and Usumacinta account for about 40 percent of the total volume of Mexico's rivers.

In the north, aridity and interior drainage limit the size and number of rivers. By far the most important stream in this part of the country is the Río Bravo del Norte (Rio Grande in the United States), which forms part of the international border. The Conchos River, a tributary of the Río Bravo, drains much of the Mesa del Norte. Because the Sierra Madre Occidental and the Sierra Madre Oriental originate close to the coastal margins, streams on the west and east coasts are short and steep. Along the Pacific Coastal Lowlands the Yaqui, Fuerte, and Culiacán rivers have been dammed and support major irrigated acreages. Aridity in Baja California and the porous limestones that underlie the Yucatán Peninsula cause these regions to be virtually devoid of permanent surface streams.

Soils. In the tropical areas of southern Mexico, lateritic soils predominate. Throughout southeastern Mexico, leaching produces infertile reddish or yellow soils high in iron oxides and aluminum hydroxides. The richest soils in the country are the chenozem-like volcanic soils found in the Mesa Central. Deep, easily crumbled, and rich in base minerals, these dark soils have been, in some areas, farmed continuously for several centuries. Because of their excellent drainage and good structural properties, they can be used for crops even on extremely steep slopes, but overuse has caused serious sheet erosion and exposure of tepetate (a lime hardpan) in many areas. In the arid north, gray-brown desert soils occupy the largest expanses. High in lime and soluble salts, these soils can be extremely productive when irrigated, but salt buildup is sometimes a serious problem.

Volcanic soils

Climate. Because of its topographic diversity and latitudinal range, Mexico has a wide array of climatic conditions, often occurring over short distances. More than half of the country lies south of the Tropic of Cancer. In these areas, tropical maritime air masses from the Gulf of Mexico, the Caribbean, and the Pacific, which are attracted by the relatively low pressures that occur over the land, are the main sources of precipitation that is heaviest during the period from May through August. Tropical hurricanes, which are spawned in oceans on both sides of the country, are common in the coastal lowland areas during the months of August through October. The climates in northern Mexico, situated latitudinally within one of the world's great desert regions, are strongly influenced by the semipermanent Pacific subtropical anticyclone, which minimizes precipitation.

Within the tropics temperature variations from season to season are small, often only about 10° F (5° C) between the warmest and coldest months. In these areas winter is defined as the rainy rather than the cold season. Because elevation rather than latitude is the primary climatic influence in southern Mexico, several vertical climatic zones are recognized. In the Mexican tropics, from sea level to just over 3,000 feet, is the *tierra caliente* ("hot land"), with uniformly high temperatures. Veracruz, located on the Gulf of Mexico, for example, has an average daily temperature of approximately 77° F (25° C). The *tierra templada* ("temperate land") extends to about 6,000 feet. Located at an elevation of more than 4,600 feet, Jalapa has an average daily temperature of 66° F (19° C). *Tierra fria* ("cold land") extends as high as 11,000 feet. Pachuca, at just under 8,000 feet, has an average annual temperature of 59° F (15° C). Above the *tierra fria* are the *paramos,* or alpine pastures, while the *tierra helada* ("frozen land"), or permanent snow line, in central Mexico is found between 13,000 and 14,000 feet.

North of the tropics, temperature ranges increase substantially and are greatest in the north central portion of the Mesa del Norte. In the northern interior, summer and winter temperatures are extreme. The highest temperatures in the country, exceeding 110° F (43° C), occur in July and August in central Baja California and in the northern Sonoran and Chihuahuan deserts. Outside of the high mountainous areas of northern Mexico and the north central portion of the Mesa del Norte, the lowest temperatures normally do not descend below 32° F (0° C).

Rainfall

Most of Mexico lacks adequate precipitation at least during a part of the year. With the exception of the highland areas of the Sierra Madre Occidental, the Sierra Madre Oriental, and the Gulf Coastal Plain, all of the area north of the Tropic of Cancer generally receives less than 20 inches (500 millimetres) of precipitation annually and is classified climatically as either tropical desert or tropical steppe. Nearly all of Baja California, much of Sonora state, and large parts of Chihuahua state receive less than 10 inches of rainfall yearly. Much of central and southern Mexico receives less than 40 inches of precipitation annually, most from May through August, and is classified as having tropical savanna or highland savanna climates. Only the Gulf Coastal Plain and the adjacent mountains, from roughly Tampico southward to Villahermosa, the Chiapas Highlands, and the southern part of the Yucatán Peninsula receive abundant rainfall year-round. In combination with uniformly high temperatures, this creates a tropical rain forest climate in these areas.

Plant and animal life. The tropical deserts of Baja California, Sonora, and north central Mexico are characterized by sparse desert scrub vegetation. On the higher portions of the Sonoran and Chihuahuan steppes, as well as in much of Coahuila and Tamulipas, there have evolved distinctive ecosystems composed of short grasses, scattered shrubs, and a variety of cacti and other succulents. Sonora and Chihuahua are the archetypes for flora groups that bear their names. The boojum tree is unique to a limited portion of Sonora and central Baja California.

Most of the Sierra Madre Occidental and large parts of the Mesa Central, including its dissected borders, originally were covered by forests of coniferous, evergreen deciduous, and deciduous trees. Similar forests extended southward into the Southern Highlands. Long periods of human occupation in these regions have decimated most of the natural vegetation. Major areas of coniferous forests are found at higher elevations in the Sierra Madre Occidental. The semiarid Balsas Depression has a tropical scrub vegetation composed of shrubs, low deciduous trees, and scattered cacti.

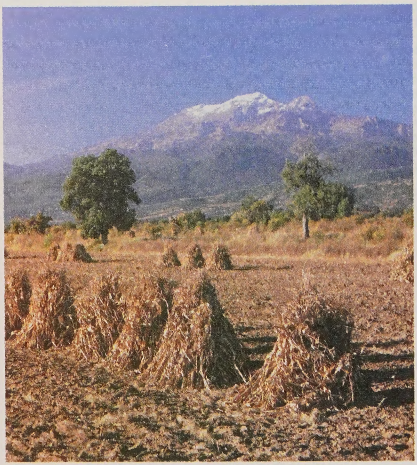
The high-precipitation zones of the Gulf Coastal Plain, the adjacent east-facing mountain slopes, the Chiapas Highlands, and the southern part of the Yucatán Peninsula are dominated by tropical rain forest, or selva, vegetation. These dense stands of broadleaf evergreen trees of varying heights are among the most luxuriant and diversified in the world. Valuable tropical hardwoods, as well as ferns, epiphytes, and a variety of palms, make these selva areas of particular interest. A large portion of the Pacific coastal area, from Mazatlán to the Guatemalan border, is covered by tropical deciduous or semi-deciduous forests, which lack the variety and density of tropical rain forests.

Mexico sits astride the commonly accepted boundary dividing North and Middle American animal species and, therefore, has a diverse array of fauna, especially in the selva regions of the south. The rain forests of the Gulf Coast and Chiapas Highlands and the semi-deciduous forests of the Pacific coast still provide a largely undisturbed habitat for monkeys, parrots, jaguars, tapirs, anteaters, and other tropical species. In contrast, the natural wildlife of northern Mexico was severely affected by the introduction of European grazing animals more than 400 years ago. While rabbits, snakes, and armadillos abound in the deserts and steppes, larger animals such as deer, pumas, and coyotes are found mainly in isolated or mountainous areas. Countless ducks and geese migrate into the northern part of the Sierra Madre Occidental to winter. A millennium of human habitation has brought about the decimation of natural fauna throughout much of the Mesa Central and parts of the Southern Highlands, especially in the Oaxaca Valley.

Settlement patterns. *Traditional regions.* Because of distinctive differences in physical environment, ethnic and racial characteristics, and settlement histories, specific cultural areas have evolved. Mexico traditionally has been divided between the Spanish-mestizo north and the Indian-mestizo south. This corresponds roughly to the pre-Columbian boundary that separated the highly developed Indian cultures of the Mesa Central and the south from the more primitive groups to the north.

Northern Mexico is a sparsely populated area with isolated clusters of settlement; it can be divided into four separate cultural regions. The largest region is the North, which closely corresponds in area to the Mesa del Norte. Mining and ranching were introduced there by the Spanish in the 16th and 18th centuries, respectively, and these industries have continued to characterize the region, though modern irrigation projects and industrialization programs along the border with the United States have diversified the economy.

The Northeast stretches from Tampico to the U.S. border and inland to the Sierra Madre Oriental. The Indian population of the area was eliminated by early European settlers, who established farms and ranches in the area. Although it was long one of the country's poorest regions, the emerging petroleum and steel industries and the develop-



Volcanic peak of Iztaccíhuatl overlooking a field of corn shocks in the agricultural region of Puebla state in the Mesa Central of Mexico.
Chip and Rosa María de la Cueva Peterson

ment of irrigation projects along the Río Bravo del Norte have greatly improved the region's economic condition.

The Northwest is an extensive region lying west of the crest of the Sierra Madre Occidental and stretching southward from the U.S. border to northern Nayarit state. This physiographically complex area had a substantial Indian population before the Spanish conquest, and the Tarahumara and Seri are among the Indian peoples still found in isolated parts of the region. As in the North, mineral resources originally attracted the Spanish, but agriculture, especially ranching, now characterizes the region.

Baja California, historically one of the more isolated parts of Mexico, is largely a desert, with major concentrations of settlement in urban areas at both ends of the peninsula. The original Indian population, scattered and culturally poorly developed, was decimated by diseases introduced by missionaries in the late 18th century. Europeans and mestizos established themselves in farming communities at oases, originally at sites such as San Ignacio and Mulejé.

Southern Mexico was much more strongly influenced by its Indian heritage than was the northern part of the country. The cultural core of the nation has been the Central region, which includes the central and eastern portions of the Mesa Central and its surrounding highlands. This was the centre of the Aztec Empire as well as numerous other Indian homelands. It became the core of New Spain and the political and economic capital of Mexico. In addition to being the primary centre of urbanization, this is also one of the nation's most important agricultural areas. Numerous basins, such as those of Mexico, Toluca, Puebla, and Morelos, are densely settled. Racial mixing has been intense in this region, but Indian groups are still found in the more isolated portions of Michoacán, Mezquital, Puebla, and Toluca. Nowhere is the contrast between modern urban Mexico and traditional rural Indian lifestyles sharper than in this region.

The Central region

The West region is centred on the city of Guadalajara and encompasses the state of Jalisco along with portions of Colima, Nayarit, Aguascalientes, Zacatecas, and Guanajuato states. With its relatively high rural population, fertile basins, and access to the Pacific, it was historically the most important agricultural region in the nation. The Guanajuato Basin has long been called the "breadbasket of Mexico." Despite its agricultural prominence, a large number of small urban centres, such as Querétaro, Salamanca, Irapuato, and León, are developing industrially, while Manzanillo has become the most important port on the Pacific. Many of the things often thought of as distinctively Mexican—such as tequila, mariachi music, and the ornate embroidered sombrero and charro costume—originated in the West.

The Balsas cultural region, which closely corresponds to the physiographic area of the same name, is arid, hot, and sparsely settled. Cattle ranching has been the mainstay of the economy, although subsistence-level slash-and-burn agriculture is widely practiced by impoverished peasant farmers.

The Southern Highlands, encompassing much of the states of Michoacán, Guerrero, and Oaxaca, is poverty-stricken. This region has the highest concentration of Indians in the country; and the Zapotec, Mixtec, and other Indian groups farm *minifundia* (small plots of land), using traditional methods. The picturesque, "crazy-quilt" landscape that results belies the widespread poverty. Modern coastal tourist centres, such as Acapulco and the more recently developed Puerto Escondido, are a marked contrast to the traditional rural life-styles of the region.

The Gulf Coast region includes the coastal zones of Veracruz and Tabasco as well as the adjacent east-facing slopes of the Sierra Madre Oriental. The population of the coastal area is overwhelmingly mestizo, but Indian groups are found in the mountains north of Veracruz. Veracruz, the cultural centre of this region, has long been the country's major nonpetroleum port. Cattle ranching and commercial agriculture are important components of the rural economy. The southern parts of the region were disease-infested, swampy, and nearly devoid of settlement until the Papaloapan and Grijalva-Usumacinta river projects allowed commercial exploitation of the rich alluvial soils.

Most of the Chiapas region is relatively isolated from the rest of Mexico. Commercial agriculture, particularly cotton production, is practiced on the Soconusco (Pacific) coast, while livestock grazing and subsistence agriculture are important elsewhere. Indian peoples are the majority in the northern highlands around San Cristóbal de las Casas, but mestizos are the dominant population in the southern half of the region.

The Yucatán

The centre of the lowland Maya civilization, the Yucatán has a predominantly Indian rural population. This low-lying area is known for its archaeological sites, such as Chichén Itzá, Uxmal, and Tulum. Mérida, the only major city in the region, was the centre for the production of henequen (a type of *Agave*), which led to a regional economic boom in the late 1800s. In the tropical rain forests to the south, the sparse population depends on subsistence agriculture or hunting and gathering.

Rural settlement. Before the arrival of Europeans, the indigenous population was highly concentrated in the Central, West, and Southern Highland regions. The Spanish settled in existing Indian communities in order to exploit their labour in agriculture and mining. As a result, these areas have remained the most densely populated throughout Mexico's history.

Away from this central core, settlement was sparse and was attracted to specific opportunities, such as mines, mission sites, or military outposts. Mining had the largest impact on population redistribution. Silver-mining towns, such as Durango, San Luis Potosí, Aguascalientes, Pachuca, and Zacatecas, were founded in the middle to late 1500s and represented the first settlements outside the central core. By contrast, it was not until the mid-1800s that large-scale ranching was introduced into northern Mexico. This clustered pattern of settlement, with large areas effectively devoid of population, has characterized the nation's rural settlement pattern.

Urban settlement. Urbanization is taking place at a rapid pace in Mexico. While the largest urban places are growing the most rapidly in absolute numbers, small- and intermediate-sized cities have the highest percentage increases. By the mid-1980s the country had more than 100 urban centres with 50,000 or more people. The major axis

of urbanization stretches as a narrow band across central Mexico from Puebla to Guadalajara, but the growth of the northern border cities has been the most spectacular.

Major cities

Within the hierarchy of Mexican urban places, Mexico City is the undisputed primary city. It is the political, economic, social, educational, and industrial capital of the nation. With a population of almost 10,000,000 in the mid-1980s, it is the largest city in the world (see MEXICO CITY).

Guadalajara is the nation's second largest urban area. It is a much more traditional city in structure and appearance than is Mexico City. As the regional capital of Jalisco and much of the West, Guadalajara is a major market centre and has developed a substantial industrial base. With a well-respected university and medical school, it is also a major educational and cultural centre.

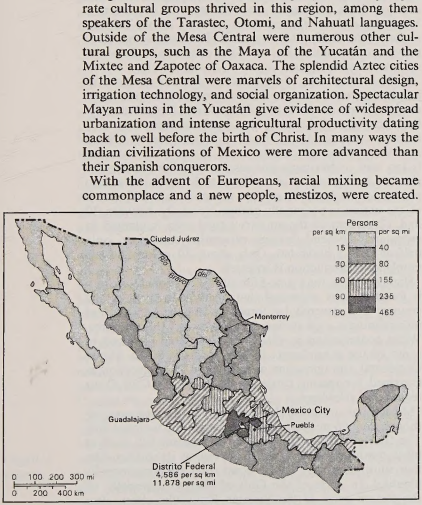
Monterrey developed as the iron and steel centre of the nation. Because the modern city dates only to the beginning of the 20th century, and because much of its growth is recent, it is singularly unremarkable in appearance, and the arid Mesa del Norte provides a stark, somewhat barren setting. High-grade coal from the nearby Sabinas fields was a major consideration in siting the steel industry in Monterrey. A number of heavy industries also have been located in the urban area. As the centre of the National Action Party (PAN), Monterrey is a stronghold of political conservatism.

THE PEOPLE

Ethnic composition. Mexico's population is composed of many ethnic groups. At the time of European arrival in the early 1500s, the country was inhabited by people who are thought to have migrated into the New World from Asia some 40,000 to 60,000 years ago by crossing a former land bridge in the Bering Strait. After their arrival into what is now Mexico, centuries of isolation allowed the evolution of unique cultural traits among the many separate clusters. Highly organized civilizations occupied various regions for at least 2,000 years before European discovery.

By far the greatest number of people lived in the Mesa Central. At the time of European arrival, most lived under the general rule of the Aztec Empire, but many separate cultural groups thrived in this region, among them speakers of the Tarastec, Otomi, and Nahuatl languages. Outside of the Mesa Central were numerous other cultural groups, such as the Maya of the Yucatán and the Mixtec and Zapotec of Oaxaca. The splendid Aztec cities of the Mesa Central were marvels of architectural design, irrigation technology, and social organization. Spectacular Mayan ruins in the Yucatán give evidence of widespread urbanization and intense agricultural productivity dating back to well before the birth of Christ. In many ways the Indian civilizations of Mexico were more advanced than their Spanish conquerors.

With the advent of Europeans, racial mixing became commonplace and a new people, mestizos, were created.



Population density of Mexico.

Over the past four centuries mestizos have become the dominant racial group in Mexico, accounting for at least half of the total population. Northern Mexico is overwhelmingly mestizo in both urban and rural areas. Because the number of Europeans in the total population has been small, the Indian contribution to the mestizo racial group has been relatively large. Indian racial characteristics therefore predominate in many Mexican mestizos. Europeans, including those who immigrated during the 20th century, account for about 15 percent of the population and are largely concentrated in urban areas, especially Mexico City, and in the West.

Although mestizos form the bulk of the population throughout the country, there are several areas where Indian speakers still represent the dominant population group. Maya speakers are the majority ethnic group in the rural Yucatán and the Chiapas Highlands. In the Southern Highlands, especially the Oaxaca Valley and remoter parts of the Sierra Madre del Sur, Indian (primarily Zapotec) communities abound. Despite their decreasing numbers, enclaves of Indians are still significant in isolated mountain areas on the eastern margin of the Mesa Central.

Linguistic composition. Spanish, which is the official national language and the language of instruction in schools, is spoken by more than 95 percent of the population. Although Indians are thought to represent about a quarter of the population, less than 10 percent of them speak an Indian language. There are, however, more than 50 Indian languages spoken by more than 100,000 people, including Maya in the Yucatán; Huastec in northern Veracruz; Nahuatl, Tarastec, Totonac, Otomi, and Mazahua mainly on the Mesa Central; Zapotec, Mixtec, and Mazatec in Oaxaca; and Tzeltal and Tzotzil in Chiapas.

Religion. There is no official religion in Mexico, as the constitution guarantees separation of church and state. However, Roman Catholicism is practiced by more than 95 percent of the population. The shrine of the Virgin of Guadalupe, the nation's patron saint, is located in Mexico City and is the site of annual pilgrimage for hundreds of thousands of people, many of them peasants. A significant proportion of Indians retain traditional religious beliefs and practices, despite their adherence to Roman Catholicism. Protestant missionaries are active in the country and have been especially successful in converting the urban poor.

Demographic trends. One of the most important characteristics of Mexico's population since 1940 has been the rapid rate of natural increase. Even though the rate slowed during the 1980s, the population is still growing about 50 percent faster than the world average and three times as rapidly as that of the United States. This growth rate is a reflection of the improved health care standards that were introduced beginning in 1940. There have been drastic declines in the death rate, and infant mortality, although still quite high in comparison to more developed countries, has been significantly reduced. The crude death rate, a gross measure of deaths within the population, has declined by as much as 50 percent since 1960.

Given the rapid growth, the population is disproportionately young; about 40 percent of the population is under 15 years of age. Life expectancy at birth has nearly doubled since 1930 and, at 70 years, is close to that in more developed countries.

The total population has increased more than 500 percent since 1915. Such growth has severely taxed the ability of the Mexican government to provide basic social services and economic opportunities for the people. Although the government traditionally has opposed limiting population growth, the position was modified in the late 1970s because of recurring economic difficulties.

Internal migration has altered the distribution of the population. Large numbers of peasants from rural areas and small towns have moved to cities since mid-century. An estimated 70 percent of Mexicans live in cities, 50 percent in cities of more than 50,000. This represents a substantial proportional decline in rural population, which accounted for half of all residents in 1960, although their absolute numbers have remained fairly constant. A lack of agricultural land, limited job opportunities, and the availability

of few social amenities push people from the rural areas.

The perception of increased chances for social and economic mobility as well as the dynamic character of urban places attracts rural people to the cities. Many internal migrants go to large regional centres such as Guadalajara, Puebla, and Monterrey, but Mexico City is the principal destination. Because of favourable employment prospects, increasing numbers of migrants have moved to cities on the U.S. border. As a result, Ciudad Juárez, Mexicali, and Tijuana are among the fastest growing cities in the nation.

Emigration

In addition to internal migration, the number of people who have emigrated from Mexico to the United States has grown sharply since the late 1970s. Estimates are highly inaccurate and vary drastically, but it is believed that somewhere between 4,000,000 and 8,000,000 Mexicans relocated illegally to the United States between 1970 and 1985. While a large proportion of these emigrants have low educational levels and limited technical skills, an increasing number of highly qualified technicians and professionals have found their way north, causing a "brain drain" for the country.

Illegal migration has acted as a safety valve in that it eases the social and economic problems associated with overly rapid population growth. The nation's resources would be stressed even further if large-scale emigration had not occurred. Remission of income earned outside of the country also represents a significant part of the nation's economy.

THE ECONOMY

Since the Revolution of 1910, Mexico's most notable economic achievement has been the sharp reduction of foreign ownership of the means of production while maintaining overall national growth. The economy is a combination of private, state, and mixed-capital enterprises. The state regulates the operation of private concerns in a number of ways, including the issuance of import licenses, the establishment of production quotas, and the control of prices on some products. In addition, private capital is barred from investment in certain activities. Private capital interests, with a majority of shares owned by Mexican nationals, control most industrial manufacturing activities, while semiautonomous state corporations operate the petroleum industry, generate and distribute electricity, run the banks, and oversee the telephone and telegraph systems. The government also controls foreign capital investment, usually by prohibiting it from certain industries, such as insurance, petroleum, and forestry, or by limiting it to a minority interest in others, such as mining, transportation, broadcasting, and soft-drink production.

State regulation of commerce

Mexico is a developing nation economically. Nonetheless, in constant pesos, the gross domestic product per capita increased more than one and a half times between 1960 and 1980. Given very rapid population growth during the same period, the nation's economic growth has been impressive, with an average annual rate of nearly 7 percent. Services account for almost 50 percent of the total gross domestic product, manufacturing about 25 percent, and agriculture about 10 percent.

The nation's active labour force is equivalent to about one-third of the total population. The service sector accounts for the largest proportion of workers, about 30 percent. Slightly more than 25 percent of workers are employed in agriculture and about 12 percent in manufacturing. Nearly half of the nonagricultural labour force is unionized. The largest and most powerful union, the Confederation of Mexican Workers, is closely related to the ruling political party, the Institutional Revolutionary Party.

The economic boom that began in the 1970s was sustained by petroleum exports and spurred substantial capital investment from both the public and private sectors. The increase in capital created jobs and expanded the market for goods and services. Much of this development, however, was financed through loans from private banks and international lending institutions. The resulting debt, coupled with plummeting petroleum prices on the world market in the early 1980s, precipitated an economic crisis unparalleled in Mexico's history.

Resources. *Mineral resources.* Minerals have been an important part of the economy throughout Mexico's history, and some 40 are now extracted in commercial quantities. Silver was long the most valuable product mined in the country, and Mexico continues to be the world's leading producer of that commodity. The major mining area during the colonial period was the so-called Silver Belt, a region that extended from Guanajuato and Zacatecas in the Mesa Central to Chihuahua in the Mesa del Norte, with outposts such as San Luis Potosí farther east.

The Silver Belt

The Silver Belt is still the primary region of nonfuel mineral production in the country, although now both industrial and precious minerals are sought. Silver is still taken from the older centres of Guanajuato, Pachuca, and Zacatecas, but zinc, lead, gold, mercury, cadmium, and such trace minerals as antimony and manganese are more important in total value. Iron ore deposits have been worked near Durango since the early 1900s and have provided the raw materials used in iron and steel production at Monterrey. Coking-quality coal is mined at the Sabinas fields to the north of Monterrey. Rich copper deposits were discovered in the late 1800s near Santa Rosalía in Baja California, but these deposits have been largely depleted. The country's largest deposits of copper are located at Cananea and La Caridad in northern Sonora state.

Since the mid-1970s, petroleum products have been Mexico's primary economic asset. Nearly 70 percent of the nation's foreign exchange earnings is derived from the sale of oil, the overwhelming majority of which is exported to the United States. The country's first commercially productive oil fields were discovered about 1900 off of Tampico on the Gulf Coast. Shortly thereafter additional producing zones were found farther south, near the Isthmus of Tehuantepec. Foreign capital was invested in the exploitation of petroleum, and most oil was exported until the industry was nationalized in 1938 with the creation of Petróleos Mexicanos (Pemex), a semiautonomous governmental agency charged with the exploration, production, and marketing of oil and natural gas.

Petroleum products

Several major oil-producing fields are now in operation in the Gulf of Mexico and along its coast; the main fields include the Poza Rica (near Tuxpan), the Tampico-Misantla basin, and the Chiapas-Tabasco sites. Major natural gas fields are located near Reynosa in northeastern Mexico and near Veracruz and in the Chiapas-Tabasco region of the Gulf of Mexico coast. The country has huge proven and potential reserves of petroleum and substantial reserves of natural gas.

Biologic resources. Largely because of the diversity of its physical environment, Mexico produces a wide array of agricultural products in different areas. Despite the fact that farming and ranching have been the basic economic activities throughout its history, Mexico has a limited amount of good agricultural land. Much of the country is too arid or too mountainous for crops or grazing. Irrigation is required in many areas to bring the land into production. It is estimated that no more than 20 percent of the nation is potentially arable. Normally, between 10 and 12 percent of the country's total area is planted to crops annually, and, because of weather conditions, only half of that is harvested. Only about 20 percent of the cropland in production is irrigated.

Slightly more than one-fifth of the national territory is forested. It is estimated that nearly two-thirds of the country was covered by forests in the mid-1500s, but indiscriminate exploitation has decimated this resource. While conservation methods are now being practiced in some of the pine forests in the northern Sierra Madre Occidental, the uprooting of rain forest for conversion to grassland for rearing cattle continues in the Gulf Coast region and elsewhere.

Mexico has a bountiful supply of marine resources, although they do not form a major part of the national diet. The Gulf of California is known for its game fish, such as black marlin and other billfish, as well as its shrimp. Farther south along the Pacific coast tuna are commercially plentiful. In parts of the Gulf of Mexico, especially off the eastern coast of the Yucatán Peninsula, clean, clear waters teem with tropical fish. Large shrimping grounds

are found in the northern part of the Gulf of Mexico as well as in the south near Campeche.

Hydroelectric resources. Oil and natural gas account for more than three-fourths of the fuels used by Mexican industry, but this represents a recent change brought about by abundant new supplies. In the 1940s and '50s hydroelectric power was seen as vital for the nation. Because of their proximity to major population clusters, most of the early projects were located on the streams exiting the eastern and southern escarpments of the Mesa Central. Better transmission technologies have permitted newer projects to be located farther away, such as the Malpaso Project on the Grijalva River on the margins of the Chiapas Highlands.

Agriculture, forestry, and fishing. *Agriculture.* About one-tenth of the gross domestic product is derived from agriculture, which employs one-fourth of the total work force. A significant proportion of Mexican agriculture still relies on traditional farming methods, especially in the regions having predominantly Indian populations. In these areas intensive subsistence agriculture based on corn (maize), beans, and squash is practiced on small plots of land, often as parts of communal village holdings. The system is highly labour-intensive and has low per capita productivity, which limits the opportunities for economic advancement.

The ejido system

While not its major objective, one of the legacies of the Revolution of 1910 was land reform, which produced the ejido system. At the time of the revolution, the rural peasantry was virtually landless and worked under a debt peonage system on haciendas (large estates). The Constitution of 1917 contained a statute limiting the amount of land that a person could own and, through the concept of social utility, legalized the federal government's expropriation and redistribution of land. Initially, small parcels were granted to communal groups whose members worked holdings individually (usually cropland) or in common (usually pasture or woodland). Later modifications brought about cooperative ejidos. By the end of the 1930s haciendas had all but disappeared from the Mesa Central, Balsas Depression, and Southern Highlands. Land redistribution produced a large number of small holdings, from 10 to 20 acres (four to eight hectares) in size. These small farms are barely viable as economic units, but although much of what is grown is used for subsistence, a considerable proportion of what they produce enters into commercial markets to supply the towns and cities of central and southern Mexico. Corn is the staple crop in most areas, but many crops and animal products are produced.

Commercial agricultural products come from three major regions of the country—the tropical regions of the Gulf Coast and Chiapas Highlands, the irrigated lands of the North and Northwest, and the Guanajuato Basin in the Mesa Central. Tropical crops have been grown on the Gulf Coastal Plain and its adjacent highlands since the early colonial period. Production now extends southeastward from near Tampico to the Chiapas Highlands and inland to the eastern slopes of the Sierra Madre Oriental. Coffee and sugarcane are the most important crops in value and acreage. They are produced in quantities sufficient to meet the country's internal demands as well as to provide sizable amounts for export. Coffee is Mexico's most valuable export crop. Increased local demand for sugar, however, has caused exports of that commodity to drop since the late 1970s. Bananas, pineapples, papayas, mangos, cacao, and rice are grown primarily for the domestic market. Mexico is one of the world's leading producers of vanilla, which is also grown in these areas. Smaller areas of cacao, coffee, and sugar production are found in western Chiapas. Cotton has become a major crop along the Pacific Coastal Plain near the Guatemalan border.

Irrigation projects

Irrigated agriculture has brought large-scale commercial production to the North and Northwest. Cotton has become the major crop in the areas developed by irrigation projects since the 1930s. The Laguna Project near Torreón was the nation's first attempt at providing water to the arid North, and huge cooperative ejidos were formed to farm cotton using modern mechanized methods. This was followed by the Las Delicias Project near Chihuahua, which also featured cotton but later brought substantial acreages of wheat into production. Much of the region's wheat is grown from drought-resistant hybrids. Despite its new producing areas, rapid population growth has made Mexico a net importer of grain since 1980.

Several new areas in the Northwest have been brought into production since the 1940s. The largest of the saline land reclamation projects are in the Fuerte and Yaqui river valleys, but a series of projects extends from Hermosillo in the north to Culiacán in the south. Much of the land is worked by cooperative ejidos, though significant areas of private land are also farmed there. Wheat, especially north of Sinaloa, is the most important crop in the region, which is now the country's centre of grain production. Cotton, vegetables, and oilseeds also make important contributions to the area's agricultural economy. Winter vegetables, especially tomatoes and lettuce, are grown mainly for markets in the United States. Cotton is the major crop of the Mexicali Valley.

Within the Mesa Central, the Guanajuato Basin traditionally has been considered the "breadbasket" of Mexico. Wheat, corn, vegetables, peanuts (groundnuts), strawberries, and beans are produced on small holdings. While still a major producing region with the advantage of proximity to major urban markets, the Guanajuato Basin has been eclipsed in agricultural preeminence by the Northwest.

Livestock ranching has been concentrated in the North since Mexico gained independence. Open-range cattle operations, frequently exceeding 250,000 acres in size, were created in the 1800s, and a number of large holdings persist despite agrarian reform. Because of the arid conditions and limited natural vegetation, the region's capacity for grazing animals is low. Nonetheless, a significant proportion of livestock is raised on relatively small ranches. In combination, these ranches have provided meat for the domestic market as well as substantial quantities for export.

Since the 1960s major improvements have been made in the ranching industry in the North. Many of the criollo cattle, descendants of stock introduced from Spain in the 1500s, have been replaced by Herefords, Brahman, and other breeds, while open-range methods are giving way to rotational grazing systems. Some natural pastures are being improved by means of irrigation, top-seeding, and fertilization. Supplemental feeding of stock has also become more common.

Cattle are also raised commercially for the domestic market in tropical areas, mainly in the Northeast, Gulf Coast, and Chiapas regions. In these areas Brahman, or Zebu, cattle are favoured because of their tolerance of heat and high humidity. Luxuriant vegetation and ample moisture make the animal-carrying capacity of the land much higher than in the North. Rain forests are being cleared and planted with imported African grasses to facilitate grazing.

Mexico produces two specialized crops that are rarely grown elsewhere. Henequen, a member of the genus *Agave,* yields a fibre used in furniture manufacturing and cordage. The plant was introduced into the northern Yucatán in the 1880s, and for many years this area was the sole source of henequen. Extensive plantations survived until the mid-1930s, when land reform led to their demise. Still an important export crop for the region, henequen is now grown on small farms and by cooperatives.

Maguey, also of the genus *Agave,* is planted in many parts of the Mesa Central. Originally used in making pulque, an inexpensive alcoholic beverage, maguey was a crop grown by many small farmers because it could be planted on infertile, rocky soils. Tequila, Mexico's national liquor, also is derived from maguey. Tequila takes its name from the town of Tequila in the state of Jalisco, the centre for its production and distilling. Yet another alcoholic drink derived from an agave is mescal, which is produced primarily in Oaxaca.

Forestry. By far the largest part of the forest area is located in the tropical east and south of the country. These tropical forests yield a wide variety of valuable products, including hardwoods, such as oaks and mahogany, and an assortment of fragrant woods, such as cedar and rosewood. In addition, the rain forests of Chiapas and the southern

Yucatán contain sapodilla trees, which are the principal source for chicle, the latex used in the manufacture of chewing gum. Softwoods are found in the Sierra Madre Oriental and the Sierra Madre Occidental above 6,000 feet. Stands of ponderosa, lodgepole, and other pines are especially well developed in the Sierra Madre Occidental, especially in the states of Chihuahua and Durango.

Fishing. Two shrimping areas of the Gulf Coast, from Tampico north to the U.S. border and from Veracruz south to Campeche, have been fished commercially since the 1940s. The Gulf of California shrimping grounds, first exploited on a large scale in the late 1950s, are now the most important in the nation. Deepwater fish abound off the Pacific coast of Baja California. Since the formation of a commercial fishing fleet in the 1960s, this area has become the country's main fishing ground, producing most of the total commercial catch. Sardines, anchovies, and tuna are the leading species taken. In the near-shore zone of the Pacific coast of Baja California, lobster and abalone are captured in commercial quantities. The rest of the commercial marine catch comes from the Gulf of Mexico, especially off the Campeche Bank north of the Yucatán Peninsula.

Industry. Mexico is one of the most industrialized countries in Latin America. Industry accounts for one-fourth of the gross domestic product and provides jobs for one-tenth of the total work force. A disproportionate share of manufacturing is located in the Mexico City metropolitan area, largely because of its huge market and superior infrastructure. An impressive array of industries has located there, including agricultural processing, automotive assembly, electronics manufacturing, iron and steel production, and the manufacture of a wide variety of consumer goods. The efforts of the federal government to disperse industry to sites outside the capital have had only modest success. In fact, much of the industrialization so dispersed has been to neighbouring cities of the Central region. One exception has been the growth in important border cities, spurred by the *maquiladora,* or "twin plant," program. This arrangement allows duty-free importation and exportation between the United States and Mexico of raw materials or parts made within a narrow border zone. The overwhelming majority of the plants are foreign-owned and have been located in Mexico to take advantage of low labour costs.

Mineral production and processing

Most of the mining of metals, industrial raw materials, and coal is found in the North, while oil and natural gas production is concentrated in the Northeast and Gulf Coast regions. Open-pit mining is used for extracting copper at Cananea and La Caridad, coal at Sabinas, and iron ore at Las Truchas and Monclova. The government-operated steel mills north of Mexico City were shut down in the late 1980s.

Pemex, Latin America's largest oil company, produces several hundred billion barrels of oil annually. A system of oil and gas pipelines has been constructed to move these products to major cities in the Mesa Central and to the U.S. border, where they formerly linked up with pipelines in the United States. Large, new oil refineries have been built near the Gulf of Mexico at Minatitlán and Reynosa to augment the older productive capacity of those at Ciudad Madero near Tampico. Additional refineries are located at Salamanca, Tula and Atzcapotzalco near Mexico City, Poza Rica, and Salina Cruz. Sulfur is found in conjunction with petroleum in many of the Gulf fields and is used in the manufacture of a wide variety of products. Petrochemical plants have been built in Veracruz state at Coatzacoalcos, the major export centre for sulfur products, and at Ciudad Pemex in Tabasco. Both are located in formerly unpopulated rain forest regions. A number of petrochemical sites are also found near refineries in the Mesa Central.

Manufacturing

The mechanical engineering sector is engaged in the production of automobiles and trucks. Auto assembly plants have been established in Puebla, Toluca, and Hermosillo in the Northwest. Textile production was traditionally more dispersed, with older centres located in Puebla and Guadalajara and newer ones in Torreón and Ciudad Juárez. The border industrialization program has seen a growing concentration of "high-tech" industries such as electronics assembly, including television and computer components, and other manufacturing in cities such as Tijuana and Ciudad Juárez.

Before the economic slowdown of the early 1980s, public-works projects such as housing and transportation infrastructure accounted for as much as half of the construction activity in the nation. Such programs were subsequently reduced, and privately financed construction was essentially curtailed because of high interest and inflation rates. A massive rebuilding program is needed to repair damage caused by the 1985 Mexico City earthquake.

The Federal Commission of Electricity operates the electrical power network for the country. Thermal generation, using oil and natural gas, has replaced hydroelectric power as the main source of electricity.

Tourism

Tourism is a major growth industry and Mexico's second largest economic asset after petroleum. Tourists once traveled mainly to Mexico City and the surrounding colonial towns of the Mesa Central or to the Mayan ruins of the Yucatán. More recently, tourists have discovered the country's beaches, and the government has invested heavily in this sector. The world-famous resorts of Acapulco, Puerto Vallarta, Ixtapa-Zihuatanejo, Cancún, Cozumel, Mazatlán, and Cabo San Lucas have been developed or significantly improved since the 1960s through the construction of new hotels, airports, and other tourist facilities. Given an exotic cultural diversity, tropical settings, relatively low prices, and easy accessibility, Mexico exerts a strong attraction on American tourists, who now represent most of its visitors.

Foreign debt

Finance. Mexico accumulated more than two-thirds of its foreign debt after the mid-1970s, largely in conjunction with the decline in international prices for petroleum. The country had to renegotiate its obligations to foreign lenders in the 1980s in order to meet debt service payments, and additional loans were secured to pay interest on the debt as well as to restructure payments. Many of the nation's most basic economic dilemmas stemmed from the foreign debt problem. To solve this problem the government embarked upon an austerity program, which included limiting federal spending and controlling prices and wages.

As a result of internal financial problems, there was a major outflow of capital to money markets in other countries, especially the United States. A general lack of confidence in the government's ability to overcome the debt problem stymied economic recovery, and foreign investment, except in *maquiladora* operations, was drastically reduced.

Banking structure

Until 1982 Mexico had a dual banking structure consisting of governmental financial institutions and private banks that were owned by commercial and industrial groups. The private banking sector was nationalized in an effort to reduce the perceived manipulation and exploitation of the financial markets by private capital. The Bank of Mexico has the sole right to issue bank notes; it also enforces credit controls, fixes reserve requirements, and sells gold to the public. There are other state financial institutions, the most important being the National Development Bank. It is one of the primary financial institutions through which foreign funds are channeled into industrial development projects.

The nation's stock exchange plays only a minor role in providing capital. Most funds are secured through government bonds or bank securities.

Trade. Mexican imports increased rapidly in the 1970s, especially capital goods and agricultural products. The value of exports during this time also increased substantially because of high petroleum prices on the world market. Since the early 1980s, however, the value of oil exports has been substantially reduced.

The United States is Mexico's major trading partner. Almost two-thirds of all exports go to the United States, mainly in the form of petroleum, while more than two-thirds of all imports are from the United States.

Transportation. Because of its physical diversity and developing economy, Mexico has had a difficult time creating an integrated transportation network. It was one of the first countries in Latin America to promote railway development, but the extensive state-owned railway sys-

tem remains inefficient. Major rail routes extend outward from Mexico City northwestward along the Pacific coast to Mexicali, northward through the Central Plateau to El Paso and Laredo, Texas, eastward via the Gulf Coastal Plain to the Yucatán Peninsula, and southeastward to Oaxaca. Rail traffic, for both passengers and freight, is slow and unreliable.

Highways

As a result, highways are the major mode of transporting passengers and goods. Cross-country trucking accounts for most freight movement within the nation, and interstate buses carry most of the passengers. While they have been improved tremendously since the late 20th century, Mexico's highways are barely adequate to serve the national need. As with rails, all major roads lead to Mexico City. Several highways link northern border cities to the capital. Similar highways connect the Yucatán Peninsula and the Guatemalan border with the Mesa Central. The 1,250-mile Pan-American Highway runs from Ciudad Cuauhtémoc, on the border with Guatemala, to Nuevo Laredo, on the border with the United States, passing through Mexico City. Several parts of the country lack good rail and road connections, especially from east to west across northern Mexico. In addition, many secondary roads are in poor condition.

Air travel has become a major mode of transportation within Mexico. Two national airlines, Aeroméxico and Mexicana, serve all tourist locations and medium-sized urban centres within the country as well as many international destinations.

ADMINISTRATION AND SOCIAL CONDITIONS

Government. Mexico is a federal republic composed of 31 states and the Federal District. Governmental powers are divided between executive, legislative, and judicial branches, but in practice the president has strong control. The Constitution of 1917 guarantees personal freedoms and civil liberties and also establishes economic and political principles for the country. Suffrage is universal for those over 18 years of age, and voting is mandatory.

The legislative branch has a Senate of 128 members, four from each state and the Federal District, as well as a Chamber of Deputies with 500 members. Senators serve six-year terms and deputies three-year terms; members of the legislature cannot be reelected for the immediately succeeding term. Three-fifths of the deputies are elected directly by popular vote while the remainder are selected in proportion to the votes received by each political party. The legislature ratifies elections and thus has been able to declare candidates elected, regardless of vote totals. Although it has the right to verify presidential elections, pass the budget, and initiate tax bills, the legislature seldom does so and thus has lost much of its power and prestige.

The president of Mexico is popularly elected and can serve only one six-year term. The president is empowered to select a Cabinet, the attorney general, diplomats, high-ranking military officers, and supreme court justices (who serve life terms) and traditionally approves legislative and state gubernatorial candidates. The president also has the right to issue *reglamentos,* or basic rules that have the effect of law.

During the period 1929–2000 the president, as leader of the Institutional Revolutionary Party (Partido Revolucionario Institucional; PRI), typically selected the party's next presidential candidate—thus effectively choosing his own successor, because the PRI was the dominant political party and had never lost a presidential election. Ernesto Zedillo broke from that tradition in 1999, causing the PRI to hold a primary election to choose a candidate; Zedillo also instituted other electoral reforms. In 2000 the PRI's presidential candidate was defeated by Vicente Fox of the conservative National Action Party (Partido Acción Nacional; PAN), marking the end of 71 years of continuous rule by the PRI. The PRI also lost a large number of legislative seats to PAN, the leftist Party of the Democratic Revolution (Partido de la Revolución Democrática; PRD), and other smaller parties.

Defeat of the PRI

At the state and local levels, governors, unicameral legislatures, and mayors are elected by popular vote. Governors serve for six years, deputies for three. States can levy taxes and have all powers not delegated to the federal government, but in fact they have relatively little revenue-generating potential or political power.

The courts are responsible for the administration of justice. The Supreme Court of Justice is the highest tribunal, and there are state superior courts as well as civil and criminal courts. The constitution protects the rights of the accused and guarantees a free trial with due process.

The military has long been an apolitical force in the country, but its high-ranking officers are appointed by the president. Conscripts serve a year's compulsory service. The military's primary role is maintenance of internal order, and for this reason about three-fourths of military personnel are in the army.

Education. Mexico has made significant efforts to improve educational opportunities for its people. School attendance is required for children aged six to 14. The number of schools for children has been increased, and adult literacy programs have been promoted vigorously since the 1970s. By the mid-1990s Mexico's literacy rate was estimated to be approximately 90 percent, up nearly 20 percent since 1970.

Public schools in Mexico are funded by the federal government. Although nearly three-fourths of all primary public schools are located in rural areas, such schools are the least well-developed in the nation and often do not cover the primary cycle. Many internal migrants move to cities because of the availability of better schools for their children. In rural areas, as well as in many low-income urban areas, teachers need only a secondary education to be certified to teach. Despite increases in the numbers of schoolrooms, teachers, and educational supplies, about one-seventh of all school-age children do not attend school.

Secondary schools are virtually nonexistent in rural areas, and universities are found only in the largest cities. As with primary education, private secondary schools are considered vastly superior to public ones, and families who can afford it send their children to private schools. This helps to maintain the socioeconomic imbalance that greatly favours the middle and upper classes.

Universities

Of the more than 50 universities in the country, one-fifth are located in Mexico City, and a high proportion of all university students study there. The National Autonomous University of Mexico, the College of Mexico, and the Monterrey Institute of Technology and Higher Education are among the most prestigious institutions of higher education in the country. A college degree is a passport to social mobility in Mexico.

Health and welfare. Federally subsidized medical and hospital care is available to all Mexican citizens. Several government institutions, including the Mexican Social Security Institute and the Security and Social Services Institute for Government Workers, operate hospitals. Public medicine, like public education, is considered inferior to private care, however, and those who can afford it avail themselves of private physicians and hospitals.

Clinics, though sometimes attended only by a nurse, are found throughout the country. Anything more than the most basic medical needs, however, must be handled in the cities. The quality of medical service varies throughout the country, with Mexico City by far the principal centre for specialized treatment. The overall quality of medical care in Mexico lags behind that available in the United States and Europe, and many Mexicans travel outside the country for more sophisticated surgical procedures or treatments.

There are strong differences in health conditions from region to region within Mexico. In general, rural areas have much higher mortality and morbidity levels than do urban areas. Regions with large Indian populations, such as Chiapas, Oaxaca, and portions of Guerrero, as well as isolated mountainous sections of the Mesa Central, have especially low health standards and high death rates. There also are great differences in health conditions among social classes in cities.

Housing. A lack of adequate housing is one of Mexico's most serious problems. Although substandard housing is more visible in urban areas, living conditions are probably

worse in rural areas. Within the cities, the federal government has built multiunit housing projects. The problem has increased more rapidly than new units can be constructed, however, and economic difficulties have reduced the funds available for new construction.

Economic and social divisions. Mexican society is sharply divided by income and educational level. Although a middle class is developing in the cities, the principal division is between the wealthy, well-educated elite and the urban and rural poor.

Widespread rural poverty is a serious problem. Agrarian reform in the central and southern parts of the country has institutionalized much of the rural peasantry, *ejidatarios* and *minifundistas,* into barely more than subsistence agriculturalists, with limited opportunities for economic or social advancement. An increasing proportion of the rural population is landless and depends on day labour, often at less than minimum wages, for survival. In many areas, but particularly in the northern half of the country, large landholders form an agricultural elite. Controlling extensive holdings and often using modern mechanized farming methods, they control nearly half of the income generated by agriculture. A rural middle class has evolved, but it represents only a small percentage of total agriculturalists.

Widespread poverty

By far the largest segment of the urban population is in the lowest socioeconomic class. It is estimated that at least 40 percent of city dwellers have incomes below the official poverty level, including a significant percentage of workers who are government employees. Extensive squatter settlements, often lacking basic services, are a common element of all Mexican cities. As an example, Nezahualcóyotl, on the eastern side of Mexico City, has more than 1,000,000 residents living in substandard housing and unsanitary conditions. In contrast, the relatively affluent middle- and upper-income groups enjoy the amenities of urban life and control most of the social, political, and economic activity of the country.

Wages and cost of living. Minimum wage laws have been in effect since 1934. Wages are determined by the type of work and the cost of living in specific regions. Urban job classifications pay higher minimum wages than rural categories, and the highest minimum wages are paid in Mexico City and the border cities of Tijuana, Mexicali, and Ciudad Juárez. Wage rates are theoretically adjusted every two years, but they have been changed more frequently since the 1970s.

Until about 1980 Mexico's inflation rate was relatively modest for a developing nation. The cost of living rose by less than 3 percent annually between 1960 and 1970, increasing to between 10 and 20 percent in the 1970s. Inflation rose to triple digits during the late 1980s.

CULTURAL LIFE

Because of its ethnic and regional diversity, as well as the socioeconomic divisions within the population, Mexico is culturally heterogeneous. Among rural peoples there are strong regional affinities and allegiances, often referred to as *patria chica* ("small homeland"), which help to perpetuate cultural diversity. The large number of Indian languages and customs still extant, especially in the south, also accentuate cultural differences. In an attempt to unite the nation culturally by identifying a uniquely Mexican culture, the government has supported indigenous folk arts and crafts as well as the European-inspired classical arts. Since the 1930s, *indigenismo,* or pride in the Indian heritage, has been a major unifying theme of the country.

The arts. Mexican writers and artists have received worldwide acclaim for their creativity and innovativeness. Within their work both a folk and classical tradition have been strong.

The country's best-known writers have gained their reputations by dealing with questions of universal significance, as did Samuel Ramos, whose philosophical speculations on man and culture in Mexico influenced post-1945 writers in several genres. The prolific critic and cultural analyst Octavio Paz is considered by many to be the foremost poet of Latin America. The novels of Carlos Fuentes are honoured throughout the world, Gustavo Sainz is a leader in Spanish-language literature, and Juan José Arreola's fantasies are widely admired. Among dramatists, Rodolfo Usigli has been extremely influential, and Luisa Josefina Hernández and Emilio Carballido have made important contributions.

Perhaps the most widely recognized Mexican art form is the mural, and the Mexican Muralist school counted among its members the most powerful figures of the genre. The murals created by Diego Rivera and David Alfaro Siqueiros, depicting aspects of the Mexican Revolution, the nation's modernization, and class struggle, have become legendary, and, among others, Rufino Tamayo and Juan Soriano have achieved stature. Perhaps the most popular of Mexico's folk artists is José Clemente Orozco, whose animated plaster-of-paris skeleton characters are both satirical and lifelike.

Mexican popular music, especially ranchero and mariachi music, has attracted a wide following throughout the Spanish-speaking world, and Mexico City has become one of the major recording centres for the Americas. The country's motion-picture and television industries are among the largest in Latin America, producing films and programs that circulate throughout the region.

Cultural institutions. To encourage and help disseminate Mexican art in all its forms, the federal government sponsors the National Institute of Fine Arts. Under its auspices are the programs of the National Symphony Orchestra, the Ballet Folklorico, and the Modern and Classical Ballet, all of which perform nationally and internationally to promote Mexican culture. Folk and popular culture also receive support through government bodies, among them the Native Institute, which seeks to preserve and stimulate traditional craftsmanship.

A number of internationally acclaimed museums, including the National Museum of Anthropology and the Museum of Folk Art, are supported by the Secretariat of Public Education. The National Autonomous University of Mexico, College of Mexico, and Cultural Seminary are important institutions contributing to the arts and humanities.

Recreation. Bullfighting is the country's national sport, and the Plaza México in Mexico City is one of the great venues for this spectacle. Soccer is still the most popular participatory sport, but baseball has attracted increasing numbers of spectators and players at both the professional and the amateur level. Mexico has produced a number of world champions in the lighter weight classes in professional boxing.

Bullfighting

Press and broadcasting. Mexico City has a large number of daily newspapers, some of which are respected for their objectivity and relative independence. Although newspapers are guaranteed freedom of the press under the constitution and there is no official censorship, nearly all are muted in their criticism of the president and his policies. There are regional tabloids outside the capital, but they have little national impact. In publishing, Mexico City is now one of the leading centres for Spanish-language books and magazines.

For statistical data on the land and people of Mexico, see the *Britannica World Data* section in the BRITANNICA BOOK OF THE YEAR. (E.C.G.)

History

PRE-COLUMBIAN MEXICO

Early Hunting Period. It is assumed that the first inhabitants of Middle America were early American Indians, of Asian and Mongoloid derivation, who migrated into the area at some time during the final stage of the Pleistocene Epoch. The date of their arrival in central Mexico remains speculative. The assertions of some archaeologists that early man resided in Mexico 30,000 to 40,000 years ago, before developing technology for big-game hunting, are rejected by most scholars. More generally accepted claims for early man in Mexico pertain to a somewhat later period and to hunters of large herd animals such as the mammoth. Human artifacts and mammoth bones dated to approximately 9000 BC have been found together in the same geologic strata in the Valley of Mexico at Santa Isabel Ixtapan.

Food-Collecting and Incipient Cultivation Period. With the increased dryness and change of fauna following the glacial retreat of the last Wisconsin substage (approximately 7500 BC), the inhabitants of Middle America were forced to turn from big-game hunting to other means of subsistence. These were the hunting of small game and the collecting of wild food plants. This mode of existence is best seen in the archaeological discoveries made in the Tehuacán Valley of Puebla.

In the earlier El Riego (7000–5000 BC) and Coxcatlán (5000–3400 BC) phases of this sequence the inhabitants of the Tehuacán Valley were seasonal nomads who divided their time between small hunting encampments and larger temporary villages, which were used as bases for collecting plants such as various grasses and maguey and cactus fruits. Maize (*Zea mays*), a wild grass, first came under cultivation in this time, probably as early as 5000 BC. Avocados, chili peppers, amaranth, zapotes, tepary beans, and squashes were also primitive cultigens. During the Abejas phase (3400–2300 BC) use of cultivated plants increased at the expense of wild plants and, probably, at the expense of hunting. A hybrid maize, crossed with the wild grass teosinte, appeared for the first time, and pumpkins and the common bean were introduced. Toward the end of the phase, settlement assumed a more permanent form in what appear to have been year-round pit-house villages. In the Purron phase (2300–1500 BC) the first pottery was produced in vessel forms that duplicate earlier stone vessels.

Cultivation of maize

Early Formative Period. By 2000 BC some village communities in Middle America were sustained largely or wholly by agriculture. Because these villages are located largely in southern Mesoamerica, it is likely that agriculture originated there. It soon spread to other areas. During the Early Formative Period the Middle American agricultural plant complex was assembled and improved by hybridization and more sophisticated cultivation techniques.

Middle Formative Period. The Middle Formative Period was a time of transition from the simple agricultural village to more complex societies organized around politico-religious capitals or nuclei. This trend had probably begun in the latter part of the Early Formative, but the first large ceremonial centres and the first monumental stone sculpture occur at about 1000 BC in southern Veracruz and Tabasco. The sites in question, San Lorenzo and La Venta, are locations of characteristic Olmec art. This art is amazingly sophisticated, with consummate control of both full round and bas-relief forms. The human theme predominates, although humans are frequently depicted with jaguar mouths and nostrils. The Olmec artists made great stone heads, altars, and stelae, and they also worked as lapidaries in exquisite jade figurines and other small objects. Olmec stylistic influence reached to Oaxaca, Chiapas, Guatemala, El Salvador, and the Valley of Mexico.

Olmec art

Late Formative Period. The Late Formative Period saw the spread of complex societies throughout much of Middle America. Hieroglyphics and complex calendrical calculations appeared. These elements of civilization are first noted in association with the Tres Zapotes, Izapan, and early Oaxacan art styles. The true city or urban centre also came into being during this period. One of the earliest manifestations of densely settled city life occurred in the Valley of Mexico at Teotihuacán, where the Late Formative urban zone covered some two square kilometres.

Classic Period. The characteristic Middle American aesthetic and religious patterns that began in the Late Formative crystallized in the Classic Period. In the Maya Lowlands polychrome ceramics, the use of the corbeled vault in temple construction, the foreshadowings of typical Maya art, and the probable beginnings of Initial Series calendrics all belong to the end of the Late Formative Period (100 BC–AD 300). The full Maya artistic, architectural, and calendric-hieroglyphic traditions were then ushered in during an Early Classic sub-period (AD 300–600). Tikal, Uaxactún, and Copán all attained their first glories in these centuries. In the Late Classic sub-period, between AD 600 and 900, ceremonial centres in the Maya Lowlands proliferated in number, as did the carving and erection of the inscribed and dated stelae and monuments.

The breakdown of the Classic Period civilizations began with the destruction of the city of Teotihuacán in about AD 700. This commercial, political, and religious metropolis appears to have fallen before the warlike Toltec, peoples of Uto-Aztecan speech who invaded central Mexico from the north and who established their capital at Tula.

Postclassic Period. Four trends characterized the Postclassic Period. First, there was a completion of the breakup of the old regional Classic Period cultures, with their distinctive art and architectural styles and religious traditions. Second, the new Postclassic cultures displayed more secular orientation. Third, fortifications and an increase of warlike themes in art bespoke a more militaristic attitude throughout much of Middle America. Fourth, the urban-type community, which first appeared in the Late Formative and was known through the Classic Period, was emphasized even more than previously.

In the later Postclassic Period Tenochtitlán, the Aztec capital, located where Mexico City now stands, became the dominant force in Middle America. An Aztec empire reached from coast to coast through central and southern Mexico; however, many tributary nations were held by the Aztecs in rather loose bonds, and when Cortés marched from Veracruz to Tenochtitlán he was aided by tribes anxious to free themselves from the Aztec yoke. In the Maya Lowlands the Toltec-controlled centre of Chichén Itzá lost its position of leadership in about AD 1200. Thereafter, there seems to have been something of a Maya resurgence, with the Yucatecan capital being eventually established at the walled city of Mayapán. (G.R.W./M.C.M.)

The Aztecs. The word Azteca is derived from Aztlán ("White Land"), where, according to Aztec tradition, their tribe originated. Aztlán probably is merely a general reference to the northwestern region of Mexico. The Aztecs are also known as Tenochca, a name derived from a legendary patriarch called Tenoch. Tenoch, or Tenochca, gave the name to Tenochtitlán ("Stone Rising in the Water"), a city founded by the Aztecs on an island in Lake Texcoco, in the Valley of Mexico. The Aztecs were also known as Mexica. The name Mexica came to be applied not only to the ancient city of Tenochtitlán but also to the modern Mexican nation and its inhabitants (Mexico, Mexicans).

The language of the Aztecs was Nahuatl, part of the Uto-Aztecan linguistic family which, at the time of the early explorations of America by Europeans, was making its influence felt intermittently in western North America from the Yellowstone River to Panama. Once the Aztecs achieved political ascendancy, their language gained currency in an area almost as large as present-day Mexico.

The Nahuatl language

The empire the Aztecs established was equaled in the New World only by that of the Incas of Peru, and the brilliance of their civilization is comparable to that of other great ancient cultures of America and the Old World. From their legendary land of Aztlán, the Aztecs came into contact with the highly developed Toltec civilization located in central Mexico and having as its capital the city of Tula. The appearance of the Aztecs is linked, however, not to the splendour of Tula and of the Toltec but to their decline. For reasons not fully known but having to do with internal social, political, and religious conflicts, a tremendous cultural catastrophe, which has been compared to the fall of the Roman Empire, occurred at the beginning of the 12th century AD. The city of Tula was attacked and destroyed, as were other important Toltec centres. Tribes of less-developed cultures—hunters and gatherers—took advantage of the situation and added to the chaos, traveling from the arid plateau of northern Mexico toward the fertile, civilized central zone. In their legends the Aztecs portray themselves as part of that wave of barbarian invaders known by the general term Chichimec ("Sons of the Dog").

The decline of the Toltec

From the beginning of the 12th century to the beginning of the 13th, the Aztecs wandered in search of a new place to settle. During that time a group of Chichimec, under the leadership of Xólotl, succeeded in gaining power in the Valley of Mexico, establishing their centre first in Tenayuca and later in Texcoco. Xólotl's Chichimec joined forces with the remaining Toltec, who were firmly entrenched in Culhuacán. The combination of strong

Chichimec power in rapid process of assimilating a higher culture and the restoration of Toltec power in Culhuacán led to a period of relative peace and cultural progress in the Valley of Mexico. The stabilization of this new situation attracted immigrants from all parts of the disturbed country, among them the Aztecs, who by then had established a precarious home near the ruins of Tula.

During their stay in Tula the Aztecs perfected their technological knowledge, especially with regard to agriculture. According to their traditions, it was there that they undertook irrigation cultivation and built *chinampas* (the famous, but misnamed, "floating gardens"). Aztec religion took definite form, centring on the god Huitzilopochtli ("Hummingbird-on-the-Left"), sun worship, and human sacrifice. Aztec tradition has it that Huitzilopochtli ordered them to take leave again in search of a permanent home.

Their long pilgrimage ended in the year of "two house," according to their calendar (AD 1325), when the wanderers found the land spoken of in their prophecies. On a small island in Lake Texcoco, the elder members of the tribe spotted an eagle, symbol of the sun and of Huitzilopochtli, resting on a nopal cactus. There they built the temple of their tribal god and, around it, the first dwellings of what was to become the powerful city of Tenochtitlán, the capital of the Aztec empire, of the viceroyalty of New Spain, and of the modern Mexican nation.

The founding of Tenochtitlán

The swamp-surrounded island on which the Aztecs were forced to take refuge was so uninviting that none of the powers in the Valley of Mexico had claimed it. Tenochtitlán was thus located at the edge of the lands occupied by the valley's three powers: the Chichimec of Texcoco, the Toltec of Culhuacán, and the Tepanec of Atzcapotzalco. It was not long before the Aztecs used their strategic position to advantage, placing their military forces at the service of the Tepanec, who were waging war against the Toltec and the Chichimec. It was in this capacity that the Aztecs began to form their notions about empire building. Under a succession of ambitious kings they established a dominion that eventually stretched over most of present-day Mexico.

The task of attempting to organize the empire along lines other than mere Aztec military strength was left to Montezuma II, the ninth Aztec king (1502–20). It was Montezuma's reign that produced the codices in which Aztec officials recorded the organization of the empire into provinces and the payment of tribute according to the production of each region. A gigantic political, military, and religious bureaucracy was built up, with governors, tax collectors, courts of justice, military garrisons, mail and messenger services, and other civil offices. Despite their feverish efforts at political organization, the Aztecs still had the strength to subjugate their allies, Texcoco and Tacuba, and to undertake new campaigns. It is probable that in this period Aztec troops pushed as far south as Central America.

The demise of Aztec hegemony

But the days of the Aztecs' greatest glory were also their last. Since 1517, Spanish expeditions led by Francisco Hernández de Córdoba, Juan de Grijalva, and Hernán Cortés had been exploring the coasts along the Gulf of Mexico. Rumours of ships as large as houses reached Tenochtitlán, and to them were added prophecies of the imminent return of the benign deity and cultural hero Quetzalcóatl; they could mean only disaster for the Aztecs and their god Huitzilopochtli. Cortés' bold march against Tenochtitlán set the stage for the final scene of the Aztec Empire. Spanish might, combined with a general revolt of the peoples under Tenochtitlán domination, proved superior to the Aztecs' strength. Under the last two Aztec kings, Cuitláhuac and Cuauhtémoc, Tenochtitlán was besieged and destroyed after a heroic Aztec defense. Over the still-smoldering ruins of Tenochtitlán a new city began to rise. Symbolizing the future Mexico, a Christian cathedral was erected on the stones of Huitzilopochtli's temple.

The almost incredible story of a small wandering tribe that was able to build an empire in one century (from the beginning of the 14th century to the beginning of the 15th) can be largely explained by three main factors: Aztec religion, the economy of the Valley of Mexico, and Aztec sociopolitical organization.

Aztec religion centred around the cult of Huitzilopochtli, a young warrior and symbol of the sun who died every evening to be born anew the following day. At dawn Huitzilopochtli began his daily struggle against the stars and the moon, driving them away with a shaft of light. At sunset he died and returned to the bosom of the earth, his mother (Coatlicue), where he renewed his strength in order to take up the fight against darkness. In order to guarantee human existence, Huitzilopochtli had to be well-nourished; his sustenance was human blood. The Aztecs were people of the sun, chosen by Huitzilopochtli to provide him nourishment. War was, therefore, not only their favourite occupation but also, more importantly, a religious obligation in which captured enemies were sacrificed to the sun. As Aztec power grew, the number of human sacrifices increased. Prisoners from all parts of the country were put to death in Tenochtitlán so that the universe and man might survive.

The economic basis of the Aztec hegemony was the Valley of Mexico's agriculture, characterized by *chinampas* and irrigation systems. It was mainly from the Toltec that the Aztecs had learned these techniques. Nevertheless, these methods date even further back in Mexican history; almost certainly they were in existence in the 6th century BC. The high productivity of the systems resulted in a heavy density of population in the Valley of Mexico and the development of large urban centres. In the early 16th century the population of the valley fluctuated around 2,000,000, with some cities approaching or exceeding 100,000. Because of this enormous concentration of population and economic resources, the Valley of Mexico became the pivotal key to power in the central part of the country. The group successful in uniting the valley under a single authority could go on to conquer the neighbouring valleys of Morelos, Mexico, Puebla, and Hidalgo, and, thence, the rest of the country.

From very early times, another factor contributed to the strategic importance of the Valley of Mexico: a system of lakes (Texcoco, Chalco, Xochimilco, Xaltoca, and Zumpango) that were connected naturally and by means of artificial canals. Extensive water transportation on the lakes compensated for the lack of the wheel and of domesticated animals and, in no small measure, furthered the early economic and political unification of the valley.

All these factors served as powerful stimuli to trade. Probably in keeping with an ancient tradition, the merchants (*pochteca*) of Aztec society were organized in powerful guilds, which even started wars on their own and sent trading expeditions to remote places. It was on the basis of the geographic data collected by their merchants that the Aztecs drew up maps not only of what is now Mexico but also of Central America. It is virtually impossible to separate the Aztecs' trade policy from their military and expansionist policy.

The third essential factor in Aztec imperialism was the sociopolitical organization of the tribe. Aztec society in the early 16th century displayed many features described as "primitive," together with manifestations of a highly advanced civilization. For example, the division of the tribe into *calpulli* ("big houses"), pseudo-family units established in Tenochtitlán, has sometimes been interpreted as proof of an egalitarian organization. Yet, evidence of social stratification is indisputable.

Aztec society has also been interpreted as "feudal." This assertion is based on the existence of an Aztec hereditary "nobility," behind which was a group of knighted commoners with access to land rights. Nevertheless, the relation of these noble groups to the Aztec kings, to the rest of society, and to land ownership cannot be compared with Old World feudalism. At the time it came into contact with the Spaniards, Aztec society was characterized by an Oriental-type political organization, in which the king was absolute. Particularly during the reign of Montezuma II, Aztec society and the empire itself were vigorously reorganized. A gigantic bureaucracy, completely dominated by the king, was charged with administering the immense empire and gradually absorbed the old social groups of nobles, knights, and merchants. (An.Pa./M.C.M.)

For fuller treatment of Maya, Aztec, and other Mid-

dle American civilizations, see the article PRE-COLUMBIAN CIVILIZATIONS.

CONQUEST OF MEXICO

Diego Velázquez, governor of Cuba, laid the foundation for the conquest of Mexico. In 1517 and 1518 Velázquez sent out expeditions headed by Francisco Hernández de Córdoba and Juan de Grijalva that explored the coasts of Yucatán and the Mexican Gulf. Velázquez commissioned Hernán Cortés to outfit an expedition to investigate their tales of great wealth in the area. Spending his own fortune and a goodly portion of Velázquez', Cortés left Havana in November 1518, following a break in relations with Velázquez. Cortés landed in Mexico and then freed himself from Velázquez' overlordship by founding the city of Veracruz and establishing a town council (*cabildo*) that in turn empowered him to conquer Mexico in the name of Charles I of Spain. Divining that Mexico was a fabulously wealthy realm held together by sheer force and that the Aztec ruler Montezuma held him in superstitious awe, Cortés pushed into central Mexico with only about 500 Europeans and several thousand Indian allies. In an incredible campaign lasting two years, Cortés took the capital city of Tenochtitlán on Aug. 13, 1521. His success was the result of a combination of factors: the hatred of the conquered tribes for the Aztec overlords; Montezuma's belief that Cortés was a returning god; Cortés' personal qualities of leadership and diplomacy; European arms—crossbows, muskets, and steel swords—and horses; disease; and the aid of Cortés' interpreter-mistress, Malinche.

(M.D.B./M.C.M.)

EXPANSION OF SPANISH RULE

After taking possession of the Aztec Empire, the Spaniards quickly subjugated most of the other Indian tribes in southern Mexico, and by 1525 Spanish rule had been extended as far south as Guatemala and Honduras. The only area in southern Mexico of effective Indian resistance was Yucatán, inhabited by the Maya tribes. Francisco de Montejo undertook the conquest of this region in 1526, but, because Maya bands were so dispersed, it was nearly 20 years before the Spaniards won control of the northern end of the peninsula. Some Indians in the interior remained independent for another century and a half.

The occupation of northern Mexico, which was thinly populated and largely arid, proceeded more slowly than did that of central and southern Mexico. Spanish expansion in this area was motivated chiefly by the hope of discovering precious metals, the need for defense against nomadic Indian raiders, and the desire to forestall incursions by the British and French.

Between 1530 and 1536 Jalisco and other Pacific coast regions were conquered by Nuño de Guzmán. The Indians of Jalisco rebelled in 1541 but were suppressed after hard fighting; this episode became known as the Mixton War. In order to complete the subjugation of the Indians, the Spaniards began to move into Zacatecas, where in 1546 they discovered immensely valuable silver mines. Similar discoveries in Guanajuato and San Luis Potosí and the occupation of most of this north central region quickly followed. Meanwhile Álvar Núñez Cabeza de Vaca, shipwrecked on the coast of Texas in 1528, had spent eight years making his way across northern Mexico before reaching a Spanish settlement on the Pacific coast and had brought back stories of rich Indian civilizations that supposedly existed somewhere in the north. During the years 1540–42 Francisco Vázquez de Coronado led an expedition to search for these mythical kingdoms, exploring as far as Kansas before turning back in disappointment. The effective occupation of northern Mexico occurred later in the century and involved prolonged fighting with nomadic Indian tribes. Throughout much of the north, the first Spanish settlers were Franciscans and Jesuits who established Indian missions. At the same time that exploration and settlement were bringing new areas under effective control, an administrative bureaucracy was being put into place. New Spain was organized as a viceroyalty governed by a viceroy appointed by the king.

Near the end of the 16th century, the northern frontier of New Spain in most areas was close to the present Mexican–U.S. boundary line. Within the area that is now the United States, a settlement had been made in Florida in 1565. In 1598 Juan de Oñate began the conquest of New Mexico, though the Indians of the region rebelled in 1680 and were not reconquered until 1694. Later northern expansion was undertaken mainly to check rival European powers. After the French had established colonies in Louisiana, Spanish settlements were made in Texas in 1716, while on the Pacific coast the threat of Russian expansion caused the Spaniards in 1769 to begin the occupation of Upper California. Throughout the 18th century there were incessant boundary disputes between Spain, Britain, France, and subsequently the United States, and some territories changed hands several times. Florida was ceded to Britain in 1763, restored to Spain in 1783, and sold to the United States in 1819. Louisiana became Spanish in 1763 but was regained by France in 1800 and sold to the United States three years later. The northern boundary of New Spain remained largely indeterminate until the Adams–Onís Treaty of 1819, by which the United States acquired Florida but recognized Spanish sovereignty over Texas, New Mexico, and California.

(H.B.P./M.C.M.)

COLONIAL PERIOD, 1701–1821

A fundamental shift in the governance of New Spain occurred as a result of the War of the Spanish Succession (1701–13), when Bourbons replaced Habsburgs on the Spanish throne. Ruling by divine right, the Bourbon kings were enlightened despots whose major interests lay in increasing the economic returns from the Spanish Empire; they introduced many French practices and ideas into overseas administration.

Among the notable administrative reforms undertaken by Charles III in 1784 was the creation of 18 intendancies. In place of the numerous *alcaldías mayores* and *corregimientos,* which were abolished, *partidos* of about the same size were created within each intendancy. Headed by the intendancy of Mexico, each intendant was given considerable autonomy in increasing economic production within his sphere, developing useful arts and sciences, and bettering education and social conditions, all of the latter less for altruistic than for economic reasons.

Fed by currents of rationalism from England and Europe, the Enlightenment in Spain and Mexico spurred the spread of new scientific knowledge and, especially, its application to mining and agriculture. Political liberalism became a factor when the American and French revolutions called into question the divine right of kings. A later development was the proliferation of the military establishment under the impact of British and Russian pressures on the frontiers of New Spain. Having strung a series of missionforts across northern Mexico, authorities in Madrid and Mexico augmented the few regular Spanish troops that could be spared from the peninsula by fostering a local militia with special exemptions (*fueros*) granted to Creole (Mexican-born) officers. Thus, an explosive combination resulted from the almost simultaneous appearances of new ideas, guns, and administrative confusion between the old Habsburg and the new Bourbon administrative systems.

The turmoil of Napoleonic Europe was the immediate background of the move for Mexican independence. Napoleon Bonaparte occupied Spain in 1808, imprisoned King Ferdinand VII, and attempted unsuccessfully to impose his brother Joseph Bonaparte as monarch. Rebelling, the Spanish resurrected their long-defunct Cortes (representative assembly) to govern as regent in the absence of the legitimate king, and, with representation from the overseas realms, the Cortes in 1812 promulgated a liberal constitution in the King's name. The document provided for a constitutional monarch, popular suffrage, a representative government, and other features taken from the French and U.S. constitutions. Continental events stimulated rivalries in Mexico as contradictory commands were being received from the mother country. The viceregal establishment put down sporadic rebellions by those who professed loyalty to the imprisoned king but who demanded some form of self-government.

Factionalism and rebellion

The most important local revolt was sparked by Miguel Hidalgo y Costilla, a parish priest in Dolores. On Sept. 16, 1810, Hidalgo issued the "Grito de Dolores" ("Cry of Dolores"), calling for the end of rule by Spanish peninsulars, for equality of races, and for redistribution of land. Mexican Independence Day commemorates this event.

Warning that the Spaniards would deliver Mexico to the godless French, Hidalgo exhorted his followers to fight and die for the Mexican Virgin, Our Lady of Guadalupe. When Hidalgo left his tiny village, he marched with his followers into Guanajuato, a major colonial mining centre peopled by Spaniards and Creoles. There the leading citizens barricaded themselves in a warehouse. Hidalgo captured the warehouse on September 28, but he quickly lost control of his rebel army. Most of the Creole elite were massacred, and the town was pillaged.

The Guanajuato massacre swung moderate and undecided support behind the viceroy's efforts to crush the Hidalgo rebellion, lest a full-scale caste war ensue. Royalist forces defeated Hidalgo at the Bridge of Calderón on Jan. 18, 1811. On March 19 he was captured along with other major insurgent leaders. On July 31 Hidalgo was executed, ending the first of the political civil wars that were to wrack Mexico for three-quarters of a century.

The Hidalgo cause was taken up by his associate José María Morelos y Pavón, another parish priest, who won control of substantial sections of southern Mexico. The constituent congresses, which Morelos called at Chilpancingo in 1813, issued at Apatzingán in 1814 formal declarations of independence and drafted republican constitutions for the areas under his military control.

At about the same time Napoleonic troops were withdrawing from Spain, and in 1814 Ferdinand VII returned from involuntary exile. One of his first acts was to nullify Spain's liberal 1812 constitution drawn up by the Cortes. The departure of the French freed Spanish troops needed to crush the Morelos revolution. Captured and defrocked, Morelos was shot as a heretic and revolutionary on Dec. 22, 1815. Scattered but dwindling guerrilla bands kept alive the populist, republican, nationalist tradition of Hidalgo and Morelos.

Mexican independence came about almost by accident when constitutionalists in Spain led a rebellion that, in 1820, forced Ferdinand VII to reinstate the liberal constitution of 1812. Conservatives in Mexico, alarmed that anticlerical liberals would threaten their religious, economic, and social privileges, saw independence from Spain as a method of sparing New Spain from such changes. They found a spokesman and able leader in Agustín de Iturbide, a first-generation Creole. Iturbide, who had served as a loyal royalist officer against Hidalgo and others, had been given command of royal troops with which he was to snuff out remnants of the republican movement, then headed by the future president Vicente Guerrero.

The Plan de Iguala

While ostensibly fighting Guerrero, however, Iturbide was in fact negotiating with him to join a new independence movement. In 1821 they issued the so-called Plan de Iguala, a conservative document that declared that the Mexican nation was to be independent, that its religion was to be Roman Catholicism, and that its inhabitants were to be united, without distinction between Mexican and European. It stipulated further that Mexico would become a constitutional monarchy under Ferdinand VII, that he or some Spanish prince would occupy the throne in Mexico City, and that an interim junta would draw up regulations for the election of deputies to a congress, which would write a constitution for the monarchy.

United as the Army of the Three Guarantees (independence, union, preservation of Roman Catholicism), the combined troops of Iturbide and Guerrero gained control of most of Mexico by the time Juan O'Donojú, appointed Spanish captain general, arrived in the viceregal capital. Without money, provisions, or troops, O'Donojú felt himself compelled to sign the Treaty of Córdoba on Aug. 24, 1821, thus officially ending New Spain's dependence on Old Spain. The convention provided that the Mexican nation, thenceforth to be styled the Mexican Empire, was to be recognized as independent. Under the treaty, the new empire's congress was to elect an emperor if no suitable European prince could be found. In one of the ironies of history a conservative Mexico had gained independence from a temporarily liberal Spain.

INDEPENDENCE

Although Spain at first disavowed O'Donojú's recognition of Mexican independence, the date now recognized as that of separation of New Spain from Old Spain is in fact Aug. 24, 1821.

The Mexican Empire, 1821–23. The first Mexican Empire spanned only a short transitional period from colony to republic. Independence had been the point on which republicans and conservatives alike could agree. The new constitutional monarchy shielded the conservatives from a Spanish government that had suppressed religious orders, tried clerical cases in civil courts, and decreed that the church could not acquire real property. Such a government was also palatable to the insurgents, whose major objective was independence.

Iturbide became president of a council of regents, which convoked a Sovereign Constituent Congress. Deputies to the congress represented the intendancies, the name they retained during the empire. When representatives from the Central American intendancies, part of the old viceroyalty of New Spain, decided that their areas did not wish to remain part of the Mexican Empire, they were allowed to withdraw and to organize their own independent governments.

On the evening of May 18, 1822, military groups proclaimed Iturbide Emperor Agustín I, and on the next day a majority in congress ratified the "people's choice" and recommended that the monarchy be hereditary, not elective. Agustín I was crowned in a long ceremony on July 21. The empire was recognized by the United States on Dec. 12, 1822, when the Mexican minister was officially received in Washington, D.C. But even then Agustín's power and prestige were already ebbing, and conflict soon developed between the military hero Iturbide and the primarily civilian congress. On Oct. 31, 1822, the Emperor dismissed congress and ruled through an appointed 45-man junta. The act, which was condemned by many as arbitrary, provided discontented military men with a pretext to revolt. Among their leaders was General Antonio López de Santa Anna, whom Agustín had first promoted for services in the Army of the Three Guarantees. In Veracruz, Santa Anna proclaimed a Mexican Republic on Dec. 2, 1823, and was supported by old guerrillas. Other military men had similar plans. Agustín was forced to reconvene congress and to abdicate. In 1824 he returned from European exile but was arrested and shot. This first epoch of independent Mexican national life thus foreshadowed many problems of the succeeding republic.

Troubles of the new republic

The early republic. When a republican constitution was adopted in 1824, the Mexican people had had little or no previous experience in self-government. Their economy was precarious; mining, a mainstay in colonial times, had declined during the many years of fighting, and widespread anti-Spanish feelings had caused an exodus of Spaniards, depleting both the nation's capital reserves and its pool of trained people. Political instability made borrowing abroad expensive, and nearly all public revenues had to come from customs receipts, which were pledged well in advance. As Mexico's national debt mounted, so did its problems. A vicious, seemingly unbreakable cycle marked the first half century of Mexican national life. Whenever public monies were insufficient to pay the army, its officers revolted, captured the government, and negotiated international loans. The high interest payments on such loans reduced available funds for education and other social and cultural improvements, which many Mexican leaders thought were urgent requirements.

The constitution of 1824 provided for a federal republic, consisting of 19 states, four territories, and a federal district; it also set a number of goals, toward which the nation subsequently inched its way. Although the monarchical idea survived for nearly half a century more, Mexico remained a republic. The constitution abolished slavery, which was never a major issue, and enfranchised all male inhabitants; Indians thus lost their special colonial status,

and accompanying protections, as wards of the government. In many ways they were worse off during the 19th century than they had been under the paternalism of the Spanish crown. Restrictive state legislation excluded the great mass of peasantry from the political process.

Under various labels, two factions contended for control. Generally conservative, the Centralists favoured a strong central government in the viceregal tradition, a paid national army, and Roman Catholicism as the exclusive religion. Opposed to them were the Federalists, who favoured limited central government, local militia, and nearly autonomous states; they tended to be anticlerical and opposed the continuance of colonial *fueros,* which gave special status to ecclesiastics and the military and exempted them from various civil obligations.

The pendulum of power swung back and forth between the two groups. In 1824 Guadalupe Victoria, a Federalist and a leader in the independence movement, was elected president. Centralists replaced Federalists in 1828. A Federalist revolt in 1829 put Vicente Guerrero in the presidential chair, but he was soon overthrown by the Centralists, who held power until 1832. In 1833 another change placed Federalists in power until 1836, when Centralists again regained control and held it for nearly a decade.

The age of Santa Anna: Texas and the Mexican War. After the downfall of Iturbide, Mexican politics revolved for some time about the enigmatic personality of Antonio López de Santa Anna, a charismatic general with seemingly few fixed ideological or political beliefs. Allied with the Federalists, Santa Anna was first chosen president in 1833, but, rather than serve, he placed the liberal vice president Valentín Gómez Farías at the head of the government until Farías and his group in 1834 attacked the privileges of the clergy. Then Santa Anna assumed his presidential post and nullified the anticlerical legislation.

Problems over Texas

Santa Anna was president when difficulties over Texas first began to mount. Under favourable terms, some 30,000 U.S. immigrants had populated that previously desolate area. Fearful that their growing numbers posed a threat, the Mexican government in 1830 closed the border to further immigration and imposed on the Texans oppressive restrictions that contravened the Mexican constitution. When Santa Anna adopted a new constitution in 1836, and in the process eliminated all vestiges of states' rights, Texas declared itself an independent republic. Santa Anna quickly gathered an army to crush the revolt. He met with initial success when he trapped a small Texas garrison at the Alamo and totally eliminated it, but he was defeated and captured by Texas forces in April 1836 and subsequently freed. Though Mexico made no further efforts to reconquer Texas, it refused to recognize its independence.

At that time a doctrine now known as Manifest Destiny was at its height in the United States. It expressed a belief that it was the destiny of the United States to occupy all the North American continent and perhaps all of Mexico. The United States annexed the Republic of Texas in 1845, a move that caused the Mexican government to break off diplomatic relations. Santa Anna was overthrown for his apparent willingness to negotiate with the United States.

Although the United States claimed that the southern boundary of Texas was the Rio Grande, the boundary had always been the Nueces River. Shortly after his election in March 1845, U.S. President James K. Polk tried to secure an agreement on the Rio Grande boundary and to purchase California, but the Mexican government refused to discuss either matter. Polk ordered U.S. troops to occupy the disputed territory between the rivers. When Mexican and U.S. patrols clashed in April 1846, Polk asserted that American blood had been shed on American soil—an outrage that required action. Less warlike politicians, such as the Illinois congressman Abraham Lincoln, to no avail submitted resolutions asking Polk to point out the precise location of this outrage. Polk's congressional majority formally declared war on Mexico in April.

War with the United States

Without major difficulty, U.S. troops captured New Mexico and Upper California (now the state of California). General Zachary Taylor led the main U.S. force to quick victories in northeastern Mexico. At that juncture the government of Mexican president Mariano Paredes y Arrillaga was overthrown, and Santa Anna reemerged as president in September 1846. Almost immediately, Santa Anna mobilized Mexican forces and marched northward, boasting that the superior numbers and courage of his men meant that he would sign a peace treaty in Washington. Although Taylor and Santa Anna fought a close battle at Buena Vista, Santa Anna was beaten and forced to retreat on Feb. 23, 1847. Both sides sustained heavy losses.

A change in U.S. strategy left Taylor holding ground in northern Mexico; it was decided that Mexico could be beaten only by capturing Mexico City, via Veracruz. General Winfield Scott was given command of the expedition. On April 18, 1847, he defeated Santa Anna in the critical battle at Cerro Gordo. Though Mexican resistance continued to be formidable, Scott captured Mexico City on Sept. 14, 1847. Santa Anna went into voluntary exile while a new Mexican government negotiated peace.

Dated Feb. 2, 1848, the Treaty of Guadalupe Hidalgo terminated the war. Under its terms Mexico ceded all territory north of an irregular line of the Rio Grande and the Gila River across the Colorado to the Pacific. The United States paid Mexico $15,000,000 and assumed $3,250,000 in claims held by U.S. citizens against Mexico.

After the war Santa Anna figured in one more major episode before the political scene changed. In 1853 conservatives seized power and invited him to become dictator. Among other things, on Dec. 16, 1853, Santa Anna decreed that the dictatorship should be prolonged indefinitely and that he should be addressed as "His Most Serene Highness." To raise funds for an expanded army, he sold territory south of the Gila River to the United States for $10,000,000; this Gadsden Purchase, as it is now called, was the last significant boundary change of the Mexican Republic.

The Reform. Since independence a new generation of Mexicans had been born; appalled at the easy victory the United States had won, the more thoughtful among them felt that Mexico's survival as an independent nation depended on fundamental reform. Among the new faces was Benito Juárez, a Zapotec Indian educated as a middle-class liberal, who had moved to New Orleans and had discussed and planned Mexico's future with fellow expatriates. With no military force to implement their plans, they bided time until their opportunity came, in 1854, when Juan Álvarez, a surviving hero of independence, and Ignacio Comonfort, a political moderate, proclaimed a liberal rebellion against Santa Anna and forced him out of the presidency.

Neither Álvarez, who served a short term as president, nor Comonfort, who succeeded him, had any clearly defined program. The role of the returned expatriates was to act as a brain trust to carry out La Reforma ("The Reform"). Its aims were to abolish remnants of colonialism by removing special ecclesiastical and military privileges; to separate church and state by secularizing education, marriages, and burials; to reduce the economic power of the church by forcing it to sell its properties; to foster an economic development that envisaged Mexico as a country of yeoman farmers and small industrialists; and, above all, to establish a single standard of legal justice.

Juárez was made minister of justice. Among his first reforms was the so-called Ley Juárez (Nov. 23, 1855), which abolished *fueros* and the use of special military and ecclesiastical courts in civil cases. The minister of finance, Miguel Lerdo de Tejada, sponsored the Ley Lerdo (June 25, 1856), which restricted the right of ecclesiastical and civil corporations to own lands by decreeing that church lands not directly used for religious purposes must be sold and lands held in common by Indian communities (*ejidos*) be distributed to individual villagers.

Constitution of 1857

The reformers called a convention to draft a new constitution, which would provide a legal base for the reform. It was promulgated on Feb. 12, 1857, but did not become effective until the following September 16, the 47th anniversary of the "Grito de Dolores." The Constitution of 1857 prohibited slavery and abridgments of freedom of speech or press; it abolished special courts and prohibited civil and ecclesiastical corporations from owning property, except buildings in use; it eliminated monopolies; it

prescribed that Mexico was to be a representative, democratic, republican nation; and it defined the states and their responsibilities. This constitution, which remained in force until it was modified in 1917, increased the power of the central executive.

Neither the religious community nor the military accepted the 1857 constitution, and both inveighed against the reform, calling for retention of "religion and *fueros*." The church excommunicated all civil officials who swore to support the constitution. When civil war erupted, Comonfort went into exile after his efforts at compromise had failed; Juárez automatically succeeded him as constitutional president. The conservatives captured Mexico City and set up a competing regime. Juárez and his government moved to Veracruz, where they controlled the customs receipts.

Foreign powers became involved in the Mexican struggle. On April 6, 1859, the United States recognized the Juárez government; President James Buchanan permitted war matériel to be shipped to Juárez' forces. Americans were encouraged to serve the liberal cause as volunteers; Spain and France generally favoured the conservatives, as did Great Britain.

In July 1859 Juárez issued a series of decrees: all church property except buildings used for worship was to be confiscated without compensation; all marriages apart from civil were declared annulled; the formal separation of church and state was proclaimed; cemeteries were declared public property, and burial fees were abolished. Moneys from the sale of confiscated church property, though less than anticipated, speeded the end of the civil war. On Dec. 22, 1860, the liberals won a critical battle, and, when the conservative president, Miguel Miramón, fled, the conservative cause collapsed. The victorious liberal army of about 25,000 men entered Mexico City on New Year's Day, 1861. On his return (January 11) Juárez was greeted by an enthusiastic populace who welcomed the end of the long and devastating civil war and the reestablishment of government under the constitution of 1857.

French intervention. Exiled Mexican conservatives, who continued to intrigue, enlisted the help of a powerful ally, the French ruler Napoleon III, who wanted to create a Latin league that would include the Mediterranean lands and the former possessions of Spain and Portugal in the New World as well. (The term Latin America dates from this time and concept.) With its strategic position and its economic potential, Mexico seemed especially attractive to the Napoleonic imperial scheme. A French bastion in Mexico would check the Manifest Destiny of the United States and provide a base from which Central and South American protectorates could be added. The fact that the United States was engaged in a civil war (1861–65) was a determining element. In 1861 Napoleon III was willing to believe the Mexican conservatives' assertions that the masses of Mexican people would support his intervention to restore religion and set up a monarchy.

Ambitions of Napoleon III

Mexico's chaotic economic situation afforded Napoleon III the perfect opportunity to implement his scheme. The government of Benito Juárez had a huge foreign debt, and in 1861 the Mexican government suspended all payments to Spain, Britain, and France. The three European powers prepared to send a punitive expedition to Mexico. The intervention was spearheaded by Spain, the forces of which landed at Veracruz on Dec. 14, 1861, and were followed soon after by French and British contingents. When the allies fell into dispute over the $15,000,000 French claim for payment of certain questionable bonds, both Spain and Great Britain disengaged from the joint venture.

The French expeditionary force began its march toward Mexico City. When the Mexican army made a stand at Puebla on May 5, 1862, the French retreated to await reinforcements. Napoleon dispatched 30,000 more troops under the command of the French general Élie-Frédéric Forey. The Mexicans could not withstand French might, and on June 10, 1863, Forey rode as conqueror into Mexico City. The French rapidly secured much of central Mexico, forcing Juárez and his government to keep constantly on the move in the north.

Napoleon III had already identified a pair of puppets to place on the Mexican throne: Maximilian of the House of Habsburg and his wife, Charlotte (Carlota), daughter of the King of Belgium. Assured of Napoleon's continued military support and the economic backing of the British, Maximilian and Charlotte arrived in Veracruz on May 28, 1864, having passed through Rome to confer with the Pope before they embarked. On June 12 Emperor Maximilian was welcomed in Mexico City.

Emperor Maximilian

Maximilian attempted to follow a policy of national conciliation, hoping to unite Mexican factions and interests. But he proved too much a Habsburg to be an effective tool of Napoleon's schemes, too much a liberal to please the conservatives who had engineered his coronation, and too tainted by conservative sponsorship to win republican support.

Maximilian was perhaps less naive than he has been pictured. Not fully convinced that a majority of Mexicans welcomed him as emperor nor sure that he should place full reliance on French troops, he tried to create a Mexican rural guard and a separate imperial army around a nucleus of Austrian and Belgian volunteers. His proposal to reduce the number of regular Mexican army generals to 18 brought early disillusionment to the army, a mainstay of conservatism, which had expected Maximilian to be a puppet. The Mexican officers became further irritated when, with Maximilian's approval, French officers outranked them. At this time the Habsburg emperor and the French commander, Achille-François Bazaine, were following conflicting army policies, Napoleon having ordered Bazaine to Mexicanize the army to cut time and costs of occupation.

At the same time, clerical groups, eager to reap rewards for their efforts on the Emperor's behalf, pressed him to reverse the Reform. A papal nuncio from Rome arrived with a message asking that Maximilian revoke the anticlerical laws, establish Roman Catholicism as the exclusive religion, restore the religious orders, remove the church from its dependence on civil authorities, turn education over to ecclesiastics, and return properties confiscated and sold by the republicans. Replying that he, not outsiders, would decide such matters, Maximilian issued decrees establishing religious toleration, with Roman Catholicism favoured but still dependent on the state. He confirmed that the previous sales of church property under the Reform laws were legal and that revenues the church had received from property Juárez had nationalized were to be ceded to the state. Thus, Maximilian's conservative support further dwindled because the clergy and their followers felt betrayed.

In September 1864 Maximilian took what amounted to a guided tour of the cities that supported his empire. The warm welcomes he received from the people led him to conclude that a majority of Mexicans wanted peace and justice, which the activities of the republican guerrillas threatened. He therefore decreed on November 4 that, thenceforth, republicans would be considered bandits and brigands, subject to extreme penalties; this negated Maximilian's attempts to woo their supporters by inviting them into his council of state.

In 1865 French troops chased Juárez to, but not over, the U.S. border. Believing that the Mexican president had left national territory and that republicanism had therefore collapsed, Maximilian on October 2 issued a strong decree, ordering that all guerrillas be court-martialed and shot within 24 hours; the same penalties were to apply to persons who hid, aided, or otherwise helped them. Juárez had earlier issued a parallel decree (January 1862) against those who aided the French interventionists and imperialists.

French troops, though they were effective in keeping republicans on the outskirts of major productive areas, were also costly. Napoleon's Mexican adventure came under heavy press and parliamentary fire in France as costs in men and money mounted without economic or political advantages to compensate for the expenditures. There was criticism from overseas as well; with its civil war ended, the United States turned to the international scene. William H. Seward, the U.S. secretary of state, brought mounting diplomatic pressure on Napoleon to withdraw

Withdrawal of foreign troops

French troops; in February 1866 Napoleon agreed to clear foreign troops from Mexico by November 1867. A U.S. request to the Austrian government to stop enrollment of volunteers for the Mexican imperial army also brought an affirmative response.

In liquidating his Mexican venture, Napoleon said that, since Maximilian had not carried out his part of the pact to bring peace and orderly government to Mexico, the French were relieved of their obligations for military and financial support. Stunned, Maximilian sought to have the decision reversed. The empress Charlotte tried without success to persuade the French ruler to honour his solemn pledge. From Paris she traveled to Rome to plead with the Pope; there she went mad and was taken to Belgium, where she lingered insane until her death in 1927. Bazaine, ordered to withdraw all French troops immediately, auctioned off military material not worth shipping to France—including horses and saddles—and destroyed large supplies of powder and projectiles rather than turn them over to Maximilian. In February 1867 Bazaine left Mexico City, and by March 12 all 28,690 men had embarked. Napoleon made Bazaine the scapegoat of the Mexican fiasco, blaming its high costs and lack of results on his mismanagement, and implied personal dishonesty.

As French power withdrew, republican forces reconquered Mexico, and Maximilian was left with only a regiment of Austrian hussars, a battalion of infantry, and a small army of relatively untrained Mexican draftees. After first considering abdication, Maximilian decided to defend his imperial status and his honour as a Habsburg by making as strong a stand as possible, though planning, in the event of defeat, to negotiate an honourable exile. With these resolves he concentrated most of his troops—9,000 men—at Querétaro, a city loyal to the imperial cause. On May 5, 1867, the republican forces laid siege, initially with 32,000 men, later with an additional 10,000. By May 14 the starving imperialist force, reduced to about 5,000, had decided to withdraw and take a stand in the mountains. A disaffected imperial officer, in return for a promise that Maximilian be spared, placed republican soldiers, whom he passed off as relief troops, at strategic places in Querétaro. The siege ended the next day when Maximilian and his generals surrendered.

Under Juárez' decrees of 1862, Maximilian and his two leading generals were court-martialed and sentenced to death by firing squad. President Juárez refused to be swayed by the petitions for mercy that poured in from foreign governments. He wanted to demonstrate that Mexico could act independently; that, as the Reform contended, all men were equal under law; that foreign monarchical adventures in Mexico were futile; and that the honour of the Mexican dead would be redeemed. Maximilian and the generals were executed on June 19, 1867, terminating a bizarre interlude of Mexican history.

The restored republic. At least 50,000 persons lost their lives in the struggles between republic and empire, and when Juárez reentered Mexico City on July 15, 1867, his immediate task was to abate the rancors of civil war. The vindicated Juárez regime took few major reprisals—principal imperialists were fined, some were imprisoned for short terms, and a few were exiled. One of Juárez' first acts was to start rebuilding the shattered economy. In an era of goodwill engendered by the sympathy and aid the United States had extended to the Mexican cause, the claims of the two countries against each other were settled by peaceful arbitration. Diplomatic relations were gradually reestablished with Europe.

Rebuilding the republic

In December 1867 Juárez was reelected president. Apart from trying to foster political tranquillity, his main aims were to improve public education and to put the economy on a sound footing. To avoid the problems of dogma and religious opinion that had divided Mexicans, Juárez entrusted the development of a national educational system to Gabino Barreda, a follower of the French thinker Auguste Comte, who had said that the human mind and society passed through three successive stages—religious, metaphysical, and positive. Known as positivists, Barreda and his followers contended that the Reform, by displacing the church and militarism, had done away with the earlier two stages and that Mexico was in the third, or positivist, stage. The public-education law for the Federal District, which was to serve as the national model, stressed the secular state as the inculcator of scientific ethical norms, with "Liberty, Order, and Progress" as the means, base, and product of the system.

The chief architect of economic rehabilitation was Matías Romero, who had been Juárez' minister in Washington and who believed that Mexico's development was dependent on three basic elements: immigration, communication networks, and the exploitation of natural resources. In 1867 and '68 the government renewed concessions to British capitalists for the completion of the Veracruz–Mexico City railway and issued concessions for others; it authorized the opening of new roads and the extension of the telegraph system. Work was begun on reforming the tax systems and tariff schedules.

The reelection of Juárez in 1871 was contested more heatedly than that of 1867 had been. Thereafter, despite formidable opposition in congress, tariff reform was approved, as was Mexico's adoption of the metric system, which ended the chaotic colonial system of weights and measures.

After a short illness, Juárez died suddenly on July 18, 1872, his death closing one era and opening another. Behind him lay Mexico's long colonial history and its partial survivals through the early 19th century. The notion of a Mexican monarchy had been forever buried with Maximilian. Under Juárez, Mexicans had begun to modernize the economy and some of the social institutions, to expand rail, road, and telegraph networks, and to develop secular education.

Juárez' death also brought temporary political peace. Without incident, Sebastián Lerdo de Tejada, the president of the supreme court, and next in line of succession, was sworn in as acting president on July 19. Congress immediately began to lavish posthumous honours on Juárez, who by his innate abilities and great strength of character had led his people through unprecedented travail. He remains a major figure in the history of Mexico.

Temporary political peace

A national election placed Lerdo in the presidential chair in his own right on Nov. 16, 1872. The course Juárez had charted remained unchanged. On New Year's Day, 1873, the Veracruz–Mexico City railway was inaugurated. Other works were commissioned. Congress and the executive branch of government continued to dole out railway and telegraph concessions. To safeguard the nation against future bloodshed, congress on May 31 added specific reform laws to the constitution of 1857—church and state were explicitly declared independent of one another; freedom of religion was proclaimed; church acquisition of real estate was abolished; religious oaths were banned in civil courts; forced labour was forbidden; and liberty of man in respect to labour, education, and religion was declared inviolable. The degree to which the Reform had triumphed was evidenced by the fact that no national movement developed against these additions to the organic laws. The Lerdo government in 1874 renewed diplomatic relations with France, Spain, and Prussia.

The age of Porfirio Díaz. From 35 years, from 1876 until a political revolution unseated him in 1911, the personality of Porfirio Díaz dominated the history of his country. Like Juárez, Díaz was a poor Indian from Oaxaca but of Mixtec rather than Zapotec heritage. Educated locally, he had chosen a military career and had become an outstanding general in the republican cause against the French intervention and empire. Although he vied for the presidency against Juárez in 1867 and again in 1871, their ideological differences were not great. When in 1875 Lerdo ran for reelection, Díaz led a successful revolt and assumed the presidency in November 1876.

Díaz took the blueprint for Mexico's future that Juárez and Lerdo had elaborated and implemented it. While clearing out pockets of political resistance, he turned the presidency over to Manuel González, a companion in arms. Díaz won the election again in 1884 and was regularly returned to that office through 1908. During his long regime he scrupulously kept democratic and constitutional forms intact, partly in the conviction that it was

the president's duty to train the unready Mexican people to use them properly.

The *científicos*

Around him Díaz gathered many intellectuals (the *científicos*). They were positivists who stressed the need for rational planning and development. The emphasis was on economic development to assure social progress. How such development was to be achieved was translated into one of Díaz' political slogans, "*pan o palo*" ("bread or the club"), meaning that acquiescence to official policies would ensure livelihood, even wealth, but failure to agree would bring sure reprisals—harassment, imprisonment, death. Another slogan was "few politics, much administration." Liberty was dropped from the earlier positivist triad of liberty, order, and progress. It was the price the Mexican people were expected to pay for the benefits the *científicos* policies would provide.

Capital, though badly needed, could not be attracted until Mexico had tidied up its international and national fiscal affairs. Mexican finances were placed on a solid base, and a stable currency was established. With guarantees of political and social tranquillity, foreign investment was encouraged and obtained. European and U.S. funds built some 15,000 miles of railways, provided electricity and streetcars for the cities, created industrial complexes, rehabilitated port facilities, and developed the mining of industrial metals. Early petroleum concessions to foreigners laid the groundwork for serious problems later, when world navies shifted from coal to oil and when automobiles were mass-produced.

A complex mechanism in which all major and most minor decisions rested in the hands of the president evolved during the first two decades of the Díaz regime, or Porfiriato. The success of the practice rested on self-interest; Díaz made it worthwhile for everyone to support the system. For the most part, the small body of intellectuals was absorbed into the expanding bureaucracy or the subsidized press. The army and the church were made handmaidens of the regime rather than its adversaries; generals were encouraged to become entrepreneurs. While retaining the Reform laws on the books, Díaz was purposely conciliatory toward the church and allowed it to regain some of its former economic power without letting it develop significant political influence.

The Porfiriato

The regime also perfected instruments of repression and control, though for many years it used them sparingly. Forced military conscription lay in the hands of the president's appointees. Troublesome elements such as the Yaqui Indians were inducted en masse and shipped as cheap labour to the sisal plantations of Yucatán or the tobacco fields of Oaxaca. Governors were personal appointees of the president. Their actions were monitored by *jefes políticos* ("political chiefs"), who reported directly to the president and on his authorization intervened in municipal and state affairs. An elite constabulary, the *rurales*, like the Texas Rangers and Canadian Mounted Police, created a myth of ubiquity that eliminated the brigandage and banditry characteristic of earlier 19th-century Mexican countrysides.

In an era in which material success was highly regarded, Díaz' accomplishments were praised, but his popularity began to decline, perhaps about 1895. Prosperity had been preempted by a relatively small group, many of whom were foreigners. The Mexican economic and social elite self-consciously aped European (especially French) modes of dress, education, and even language. Between the affluent and the growing urban and rural proletariat there was an expanding middle-class body. Meanwhile, a new generation, which could recall none of the chaos of the days before Porfirio Díaz took charge, began to question the system. As criticism increased, so did repression. It was from this interaction that the Mexican Revolution resulted.

PRECURSORS OF THE REVOLUTION

The Regeneration group

Shortly after 1900 many Mexicans began to question the nation's apathetic acceptance of the Porfirian peace. The earliest and most vocal critics were Mexican radical groups, perhaps the most important of which called itself Regeneration. Its members were anarchists who adapted their dogmas to the Mexican scene. While always small in numbers and often ineffective in actions, this group had great influence. Many of the reforms and programs it advocated were embodied in the Mexican constitution of 1917.

The leader of the Regeneration group was Ricardo Flores Magón, who had been born in Oaxaca of an Indian mother and a mestizo father and had been sent for further education to Mexico City, where he had turned to idealistic student activism. For leading a small demonstration against the reelection of Porfirio Díaz in 1892, he was jailed for the first of many times. The group's movement took form in 1900, when Camilo Arriaga, a well-to-do engineer in San Luis Potosí, organized first a club and then a small party to restore the liberalism of Juárez. Arriaga called a national meeting of liberal clubs in 1901, and a short time later most of the small band were jailed, and their newspaper, *Regeneracion,* which Flores Magón edited, was suppressed. After they had served their prison sentences the young radicals fled north to the United States and Canada, settling for a while in St. Louis, Mo., where they formally organized the Mexican Liberal Party. Although its name suggests the earlier Reform, in fact it was anarcho-syndicalist, dedicated to the overthrow of the Mexican government and the total renovation of Mexican society.

In 1906 the Regeneration group published a comprehensive program in the form of a manifesto that had wide, if clandestine, circulation in Mexico. It advocated a one-term presidency, guarantees of civil liberties, breaking the hold of the Roman Catholic Church, vast expansion of free public education, and land reform. It asked that Mexican citizenship be a prerequisite to property ownership and that unused land be distributed to the landless. The manifesto proposed confiscation of the wealth that Díaz and the *científicos* had illegally acquired, the abolition of child labour, guaranteed minimum wages, and bettered working conditions for workers. In muted tones it criticized capitalism as a system of exploitation. The Regeneration group drew its main lines of thought from Mikhail Bakunin, a Russian revolutionary writer who believed that the power of any institution, including government, that exercised controls over individuals should be reduced.

Many charges by the Regeneration and similar groups were borne out when the Díaz troops, in bloody fashion, broke strikes in the textile region of Veracruz and the copper-mining regions of the northwest state of Sonora. Several of these strikes had been fomented by Regeneration organizers at the same time that U.S. muckrakers were exposing the evils of corrupt government, big business, and other aspects of life in the United States and abroad. Possibly to refute their unfavourable reports, Díaz gave an interview in 1908 to an American reporter, James Creelman, that became a milestone in prerevolutionary history. To blunt charges of one-man rule, Díaz very carefully but clearly said that in his view the time had come for Mexico to advance toward democracy, that he would welcome an opposition party in the 1910 presidential election, that he would be most happy to sustain and guide the opposition party, and that to inaugurate a democratic government in Mexico he would forget himself. This fell like a bombsheli in Mexico, where most readers failed to note that he had not specified a time. It was widely believed that this implied he would not run for the presidency in 1910. Mexican newspapers not only reprinted the interview but also began openly to discuss Mexican political questions, long forbidden by the regime. Pamphlets and then books added to the political rumblings.

Political opposition to Díaz

Two main opposition groups soon emerged. One backed General Bernardo Reyes as vice presidential candidate over Díaz' handpicked candidate. Reyes forthrightly opposed *científico* theories and practices and, as governor of the progressive northern state of Nuevo León, had initiated a state workman's compensation law.

The other main party, anti-reelectionist, had been created largely through the efforts of Francisco I. Madero, then a political unknown, whose efforts elevated him to the highest place in the revolutionary pantheon as the "Apostle of Democracy." Born into one of the 10 richest

families in Mexico, whose agricultural enterprises spread over much of northern Mexico, Madero was educated in the United States and France. In his own right he became an enlightened entrepreneur and amassed a considerable personal fortune.

Madero became concerned with how badly Mexico was faring in comparison to the rest of the world. Mexican food prices were rising, and rural and urban standards of living were dropping. He attributed Mexico's retrograde position to the prolonged political dictatorship. He helped journalists to expose these matters and provided considerable early financial support to the Regeneration group, but he disassociated from them after about 1907, when it became clearer that they intended to destroy, not reform, the system.

Madero, setting about to organize a national party to compete in the 1910 elections, published *La sucesión presidencial en 1910* ("The Presidential Succession in 1910") as a campaign document, two-thirds of which dealt with the history of Mexico and the corrupting influences of absolute power and the rest with his program to revive the democratic usages that had atrophied for so long. The initial aim was to win the vice presidency.

Despite harassment, Madero carried on a vigorous and wearying campaign in the summer of 1909. During an interview with Díaz, he was surprised by the dictator's advanced old age and his remoteness from current issues. Díaz' condition and the enthusiasm of Madero's crowds led the anti-reelectionists to modify their goals. Rather than accept Díaz as the inevitable president in 1910, they decided to try for the presidency themselves.

On June 14 Madero was arrested and jailed and thus became the martyr and victim of the system he was trying peacefully to change. Since it was perfectly clear that Díaz was not going to permit free and honest elections, Madero and his followers decided that the only hope of improving Mexico was through armed revolt. On Oct. 4, 1910, the Chamber of Deputies, which had assembled as the electoral college, declared that Díaz had been reelected. On October 5 Madero managed to escape from the San Luis Potosí jail. He arrived on October 7 in San Antonio, Texas, where with aides he prepared and issued, as of the day of his escape, the Plan of San Luis Potosí, which proclaimed the principles of "effective suffrage, no reelection." Madero declared that Díaz was illegally president of Mexico. Designating Sunday, November 20, as the day when citizens should take up arms against the government of Porfirio Díaz, he promised that a successful revolution would institute political reforms.

The Plan of San Luis Potosí

But on November 20, the official birthday of the Mexican Revolution, no mass uprisings took place. Small bands of guerrillas, most of them in northern Mexico, kept the rebellion alive while Madero used his family fortune to supply them with arms from Texas. Under the leadership of Pascual Orozco and Pancho Villa, the northern rebels began to defeat Federalist forces, who held most of the strategic rail lines, especially those emanating from Ciudad Juárez, on the U.S. border, where the Federalist troops had consolidated. Until the revolutionists laid siege to that city, no more than 2,500 armed men were engaged in the Madero revolution.

THE MEXICAN REVOLUTION AND ITS AFTERMATH, 1910–40

When armed outbreaks initiated the Mexican Revolution in 1910, the immediate object was to replace Díaz as president. What began as a relatively simple political movement broadened into a major economic and social upheaval that gave Mexico many unique characteristics. During the long struggle, the Mexican people developed a sense of identity and purpose, unmatched by any Latin-American republic. Many reforms had been established by 1940, when the goals of the revolution were institutionalized as guidelines for future Mexican policies.

The military revolution. On Feb. 14, 1911, Madero crossed into Mexico near Ciudad Juárez to head his forces. In the next few months the rebels learned how debilitated the Díaz army had become; led by aged generals, the Federalist troops lacked discipline, cohesion, unity of command, and effectiveness. Under these circumstances, the revolution gained ground and momentum. On May 10 the Federal commander surrendered at Ciudad Juárez, which marked the beginning of the end. An agreement negotiated with the Díaz regime provided that Díaz would resign, that an interim president, Francisco León de la Barra, would call general elections, and that revolutionary forces would be discharged. On May 25 Díaz resigned and sailed for Paris. Several revolutionary bands, including that of Emiliano Zapata, resisted being disarmed by the Federal army.

In the heated political atmosphere, congress on November 2 declared that Madero had won the presidency in an election held the previous month. The new government was able to withstand constant attacks from the right and left for only 15 months. A series of unsuccessful counterrevolutionary revolts culminated in a successful plot in February 1913. Following 10 days of cannonading the heart of Mexico City, with high civilian casualties, Victoriano Huerta, commandant of government forces, betrayed Madero and arranged for his arrest and that of his vice president, José María Pino Suárez, so that Huerta could assume the presidency himself. These plans were made with the knowledge, if not the connivance, of the U.S. ambassador, Henry Lane Wilson, who was thus defying President William H. Taft's instructions to remain aloof from domestic Mexican politics.

Shortly thereafter, presumably on Huerta's orders, Madero and Pino Suárez were shot while being transferred from one prison to another. Their deaths rekindled revolutionary fires. In northern Mexico, Venustiano Carranza, refusing to recognize Huerta as president, demanded that the office be elective, as specified in the constitution. He called his new movement the Constitutionalist Revolution. Former chieftains such as Pancho Villa made loose alliances with Carranza. The revived revolution took on highly local and regional aspects.

The new president of the United States, Woodrow Wilson, was determined to oust Huerta and, on flimsy pretexts, landed U.S. troops at Veracruz and occupied it. All of the revolutionary leaders except Villa rejected this external intervention in a national struggle. The combined revolutionary forces unseated Huerta in 1914 but then split over who was to exercise presidential power. Zapata in Morelos and Villa in the north joined to fight the revolutionary groups under Carranza, the most important of which was headed by General Álvaro Obregón. Obregón won a decisive victory over Villa at Celaya in April 1915 but failed to bring the civil war to an immediate end. Sporadic fighting continued for the next five years.

Split among revolutionary groups

The constitution of 1917. With most of central and southern Mexico under constitutionalist control, Carranza in 1916 convoked a constituent congress in Querétaro to revise and update the constitution of 1857.. In the course of fighting, the economic and social demands of the radical precursors had become common slogans as contending revolutionary bands bid for popular support. The constitution of 1917 incorporated the aspirations of those groups involved in the revolution. A major concern of Zapata's followers was land reform. Carranza's advisers had prepared a draft document that included not only most of the revolutionary decrees about land reform but also the most advanced European social legislation.

The constitution of 1917 specifically incorporated the major features of the 1824 and 1857 charters regarding territorial organization, civil liberties, democratic forms, and anticlerical and antimonopoly clauses. The constitution completely reversed the concept widely held in Mexico that government should take only a limited, passive role. Its philosophy was that the national government had an obligation to take an active role in promoting the social, economic, and cultural well-being of its citizens. Article 3 sketched a vast plan of secular, free, compulsory public education. Article 14 reaffirmed the sanctity of private property and contracts, but article 27 interjected concepts of social utility and national benefit to limit the untrammeled use of private property. The most important new concepts came in Articles 27 and 123. The former reasserted national ownership of subsoil resources and outlined alternative land-reform and agrarian programs.

The latter, the magna carta of labour and social welfare, was set apart to highlight its importance; in addition to guaranteeing minimum wages and the right to organize and strike, it gave labour social status and destroyed the concept of it as an economic commodity to be bought at the lowest rates to maximize profits. Article 123 also outlined a comprehensive system of social security, including public health and welfare programs. Reflecting the nationalistic feelings of the revolutionaries, foreigners and foreign interests were placed under limitations. Article 33, for instance, permitted the president to deport foreigners at will.

The constitution of 1917 set the goals toward which presidents were to work. As expected, Carranza was elected president and given de jure recognition by the United States. When Zapata was betrayed and killed in 1919, the last organized opposition to the Carranza-Obregón reorganization dissolved. Pancho Villa retired from active campaigning after his raids across the border, especially one in Columbus, N.M. (March 9, 1916), had failed to embroil the United States in conflict with Carranza. Villa was ambushed and shot by political enemies in 1923.

The northern dynasty: Obregón and Calles. When Carranza failed to move toward immediate social reforms, General Obregón enlisted two other powerful north Mexican chieftains, Plutarco Elías Calles and Adolfo de La Huerta, to join him in an almost bloodless coup; together they formed the northern dynasty. Carranza was killed as he fled from Mexico City, and Obregón took office as president Dec. 1, 1920. The dynasty agreed that peace was needed to rehabilitate Mexico from the devastations of nearly a decade of civil upheaval. Using a combination of force and political incentives, Obregón placated many ambitious military leaders.

Overthrow of Carranza

Obregón began to implement the ideals set forth in the constitution. Administrative machinery was set up to distribute land to the landless and to restore communal holdings (ejidos) to villages. The government supported the Regional Confederation of Mexican Labour (Confederación Regional de Obreros Mexicanos; CROM). José Vasconcelos, who was named minister of education, was to implement the program of rural education. He sponsored a cultural program that brought Mexico worldwide fame and importance. Radical mural painters such as Rivera, Orozco, and Siqueiros, who were commissioned to portray Mexican and especially revolutionary history on public buildings, exalted the Indian past, as did creative writers.

At the end of his term, Obregón stepped aside for Calles. Calles' presidency followed the same general lines as had Obregón's. Land distribution was stepped up, an irrigation program was begun, and in 1925 renewed pressure was put on the petroleum companies to exchange for leases the titles they had obtained from Díaz. Problems with the church developed when Calles instituted vigorously anticlerical measures; in retaliation, the church suspended all religious ceremonies and approved and possibly sponsored a rebellion in western Mexico known as the Cristeros. Mediation of the church–state controversy was unofficially accomplished by Dwight W. Morrow, the U.S. ambassador to Mexico, whose sympathetic and skillful diplomacy also eased tensions between the two countries.

In 1928 the presidential term was extended from four to six years, and the doctrine of "no reelection" was modified to mean "no successive reelection." Obregón was the successful presidential candidate, but, before he could take office, he was assassinated by José de León Toral, a religious fanatic. With Calles unable to succeed himself, a peculiarly Mexican single-party system came into being.

Single-party system

Calles formed the National Revolutionary Party, a coalition of regional and local military bosses and labour and peasant leaders. To safeguard the gains of the revolution, he excluded the church and other possible reactionary elements. With Calles as chief, the official party governed in the name of the revolution. A congress, drawn from party ranks, named successive, short-term presidents to fill out the Obregón term.

In the period 1928–34 a worldwide depression and increasing personal vested interests caused many of the older, now conservative revolutionaries, including Calles, to go slowly in implementing the reform mandates of the constitution. The ruling clique continued to be militantly anticlerical, but government support was withdrawn from CROM, which disintegrated. Land distribution slowed down, and educational programs were curtailed. On the positive side, the Calles years saw the beginnings of an irrigation and road-building program.

Resurgence under Cárdenas. Within the revolutionary family, General Lázaro Cárdenas was a respected if not outstanding revolutionary. Having quietly and faithfully worked his way up the ladder of politico-military power during the Obregón and Calles years, he seemed a safe candidate in the 1934 elections. He was also acceptable to a powerful group within the party, which drafted a six-year plan incorporating extended revolutionary reforms.

With his election to the presidency for a six-year term beginning in 1934, Cárdenas strengthened the labour movement and took other steps that defied Calles. When the inevitable test of power came, Cárdenas won, and Calles fled into temporary exile, after which Cárdenas renamed and reorganized the party on a functional national basis—the agrarians formed one sector; labour another; the military yet another; and bureaucrats, teachers, and miscellaneous groups made up the popular sector. The four sectors agreed to support the slate of candidates the party designated. The local, state, and national representatives made party policy and ratified the president's choice of candidates.

With massive popular support and with the power elites under control, Cárdenas tirelessly pushed toward revolutionary goals. He and his advisers elaborated the land-reform programs; using land expropriated from private owners, they created communal cooperatives and gave them ejido status. By the end of his term about 40 percent of the rural working force was under the ejido program. Cárdenas also nationalized railways and placed them under the management of labour.

Perhaps Cárdenas' single most spectacular action was the expropriation of foreign petroleum companies following a labour dispute in which unions demanded not only wage increases but also participation in what management considered its exclusive role. A series of court cases and special boards found in favour of the workers. When the companies refused to accept the decisions, Cárdenas on March 18, 1938, decreed expropriation of their holdings, thus nationalizing the petroleum industry. Petróleos Mexicanos (Pemex), then a small agency, was designated to administer the industry for the nation. The British government, whose nationals had a far larger stake than U.S. firms, immediately broke diplomatic relations. After a short delay U.S. President Franklin D. Roosevelt indicated that, if Mexico would make prompt and fair payments, he would not intervene diplomatically on behalf of the oil companies. This sympathetic reaction was based largely on the advice of the U.S. ambassador, Josephus Daniels, who as secretary of the navy had ordered the occupation of Veracruz in 1914 but who over the years had become a warm friend of the Mexican people.

Expropriation of foreign petroleum companies

Mexicans consider March 18, 1938, as the anniversary of Mexican economic independence. Cárdenas had not only restored an important resource to national patrimony but also showed that national honour and dignity could not be flouted by foreign entrepreneurs, however powerful. After engaging in propaganda campaigns, boycotts, blacklists, and other forms of economic warfare, the oil companies eventually were forced to settle their claims on essentially Mexican terms.

Once the initial bungling was over, Pemex developed the capacity to fuel the industrial revolution that marked Mexico's next epoch. No one realized at the time how important petroleum would become on the world political and economic scene in the decades ahead.

General Manuel Ávila Camacho, whom Cárdenas supported, and General Juan Andreu Almazán fought a close and bitter contest for the presidency in 1940. When Almazán lost, he sought U.S. support for a revolution. But to emphasize the U.S. position toward Ávila Camacho and Mexico, Roosevelt sent Vice President Henry A. Wallace to attend the inauguration. When Cárdenas left the presi-

dency in November 1940, a major chapter of the Mexican Revolution had closed.

Ávila Camacho's domestic policy was conciliatory. While retaining earlier forms, he placated Roman Catholics by announcing, "I am a believer." These words had political importance that transcended their immediate religious significance. They meant that the social programs of the Mexican Revolution would slow down after 1940. The overriding issues of the day, however, were diplomatic and economic; the Cárdenas resurgence had increased Mexico's self-respect but had left its economy in a depressed state. The economy would be tested during World War II.

WORLD WAR II, 1941–45

Industrialization

World War II brought profound changes to Mexico. Its basic economic structure was transformed, as to a lesser degree were its political, social, and cultural institutions. To offset wartime shortages, industrialization and urbanization were accelerated to meet local needs.

Even before Mexico entered the war, it supplied raw materials to the United States. Mexico and the United States in November 1941 signed a general agreement that resolved most of their outstanding quarrels. The old problem of U.S. agrarian claims was settled, a reciprocal-trade treaty was outlined, and the Mexican peso was stabilized and supported. The United States agreed to continue silver purchases at world prices and to provide long-term loans to Mexico. Separate agreements were reached on military aid, primarily to professionalize the Mexican Army and its small air force. To that end, the military ceased to act as a separate bloc in politics.

Mexico became an active belligerent in World War II in 1942 after Germany had sunk two of its tankers. The Mexican foreign secretary, Ezequiel Padilla, took the lead in urging other Latin-American countries to support the Allies as well. A Mexican–North American joint defense committee planned cooperative operations to be carried out in case the Japanese attacked Mexico's west coast. Former president Lázaro Cárdenas served on the committee and became minister of defense when that post was created in 1944. A small Mexican air unit operated with the United States in the Philippines. But Mexico's major contribution to the war effort was the steady supply of raw materials for U.S. industry.

If Mexico had only a minor impact on the outcome of the war, the war exerted a major impact on Mexico. With most of the free world producing war matériel, traditional Mexican imports became scarce or were unavailable. To fill this vacuum, Mexican light industry developed, almost exclusively with Mexican capital.

MEXICO SINCE 1945

Mexico's population exploded at the end of World War II. The industrialism spawned by the war became a major element in the economy. The military increasingly faded into the background as arbiters of national policy, and Mexico had an unbroken line of civilian presidents, beginning with the election of Miguel Alemán in 1946. With him the emphasis shifted from the Cárdenas approach—dividing Mexico's small agricultural land area among many persons—to the development of new resources. Massive hydraulic projects were undertaken to furnish electric power, open new lands, provide flood control, and become the nuclei of regional agricultural-industrial complexes. The nationalized oil industry became a major producer of natural gas and petrochemicals in an effort to meet burgeoning domestic needs. Economic integration was accomplished by the extension of railroad, highway, and airline networks to nearly all regions.

Postwar Mexico was marked by a continuity of basic policies unprecedented in Mexican history and by the peaceful constitutional transfer of presidential power from one civilian regime to the next. President Alemán was the chief architect of new departures in the official party. The name was changed from the Party of the Mexican Revolution to the Institutional Revolutionary Party (Partido Revolucionario Institucional; PRI). Suffrage in Mexico doubled when President Adolfo Ruiz Cortines enfranchised women, who first voted in 1958. Electoral reform laws broadened the political base, but opposition parties grew slowly as the PRI dominated the political power mechanisms of the state. By the 1990s the conservative National Action Party (Partido de Acción Popular; PAN) and the leftist Revolutionary Democratic Party (Partido de la Revolución Demócrata; PRD) had become significant.

In the latter part of the 20th century, despite some notable periods of economic strain, Mexico experienced unprecedented prosperity. Mexico's economic growth in the 1970s was financed with international loans totaling almost $80 billion. Government planners calculated easy repayment from projected oil revenues, including income from the huge reserves discovered in 1976 in Tabasco and Chiapas states. They were unable, however, to predict the world oil glut of the early 1980s and the sharp fall in oil prices. Mexico found it increasingly difficult to pay even the interest on its huge foreign debt.

Economic crisis

Other problems included high unemployment and underemployment, an unfavourable balance of trade, and an alarming inflation rate. A lack of confidence in the economy prompted wealthy Mexicans to reinvest their assets abroad. The Mexican peso declined rapidly in foreign-exchange markets. President José López Portillo, elected in 1976, nationalized the country's banks and imposed strict foreign-currency controls to achieve some economic stability. Miguel de la Madrid Hurtado, who was elected to succeed López Portillo in 1982, established a program of economic austerity that gradually restored international confidence in the Mexican economy. (H.F.C./M.C.M.)

In September 1985 an earthquake killed some 7,000 people in Mexico City, and many blamed the federal government for the slow pace of reconstruction. Economic liberalization, narcotics traffic, and the flow of immigrants across the U.S.-Mexico border also continued to garner attention. De la Madrid was succeeded in 1988 by PRI candidate Carlos Salinas de Gortari. Salinas signed the North American Free Trade Agreement (NAFTA) with the United States and Canada in 1992, fostering increasing overland trade and the opening of new *maquiladoras* (foreign-owned assembly plants). Rebellion erupted on Jan. 1, 1994, when the Zapatista National Liberation Army seized several towns in Chiapas state and demanded social justice for Mexico's Indians. More than 145 people died in the initial fighting.

In 1994 PRI candidate Ernesto Zedillo replaced Salinas in the presidency. Zedillo faced a sudden economic crisis, public demonstrations in Mexico City, and ongoing civil unrest in Chiapas. He continued his predecessor's neoliberal social and economic policies while instituting reforms that effectively loosened the PRI's grip on power. The party subsequently lost key electoral races, including the presidential election of 2000, which was won by Vicente Fox of PAN, thus ending 71 years of uninterrupted rule by the PRI. (H.F.C./M.C.M./Ed.)

For later developments in the history of Mexico, see the BRITANNICA BOOK OF THE YEAR.

For coverage of related topics in the *Macropædia* and *Micropædia,* see the *Propædia,* sections 952, 966, and 974.

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(E.C.G./An.Pa./H.B.P./J.J.Jo./H.F.C./M.C.M.)

Mexico City

Founded in the 14th century by the Aztecs, who named it Tenochtitlán, the future Mexico City soon became the centre of the largest empire in pre-Columbian Mesoamerica. Modern Mexico City (Spanish: Ciudad de México) is the capital of the United Mexican States and the centre of the country's political, economic, and cultural life. Although it was once called the "City of Palaces" and was said to have the world's "most transparent air," rapid population growth and industrial development have led to overcrowding, pollution, and social tensions. Still, the city retains considerable charm and has notable examples of colonial and modern architecture.

Mexico City is located in the central Mexican plateau, in the Valley of Mexico—more properly a basin—just north of the Neo-Volcánica Range. Although in 1970 Mexico City was officially equated for the first time with the Federal District—the federally controlled area designated as the nation's capital—the term Mexico City continues to be used for the entire metropolitan area. Whereas the Federal District has an area of 571 square miles (1,479 square kilometres), the metropolitan area is more than twice that size. The metropolitan area has tripled in size since the 1980s and is one of the fastest growing urban centres in the world.

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Physical and human geography

CHARACTER OF THE CITY

Mexico City is a metropolis of contrasts. Although it is one of the world's largest and most populous urban areas, the former small towns engulfed in its growth have preserved much of their traditional character. Distinctively Latin-American and proud of its origins—both Indian and Spanish—it has nonetheless acquired, by virtue of its proximity to the United States, a clear North American character in some areas. The city's colonial and 19th-century buildings stand side by side with steel-and-glass constructions. The wealth of the west side and of some of the southern suburbs contrasts with the poverty of the northeast and of the illegal settlements known as *ciudades perdidas* ("lost cities") in the metropolitan area.

A centre of power

Mexico City has long been a symbol of the centralization of power: first in the Aztec empire, then in the Viceroyalty of New Spain, and finally in independent Mexico. Resentment of the capital's perceived privileges has long been a source of friction with the rest of the country, but Mexico City and some of its monuments are regarded nonetheless as symbols of the entire nation.

LANDSCAPE

The city site. Mexico lies in an endorheic (characterized by interior drainage) basin at an altitude of approximately 7,350 feet (2,240 metres). It is walled in by the sierras of Monte Alto and Monte Bajo to the west, the Sierra de las Cruces to the southwest, and the sierras of Ajusco and Chichinautzin to the south. Toward the east, the city ends in a plain that meets the Sierra Nevada, with its two volcanoes, Ixtacihuatl (17,342 feet) and Popocatépetl (17,883 feet). Both volcanoes had been considered dormant, but in 1994 Popocatépetl began to emit smoke, ash, and gases (it had last been active in the 1920s). Volcanic activity continued, and in December 2000 Popocatépetl began spewing hot rocks. Further pyroclastic flows have occurred, putting the area on alert and causing occasional evacuations of those living close to the volcano. To the north, Tepeyac Hill and the Sierra de Guadalupe were the traditional limits of the city, but new urban areas have developed around and beyond them.

The surrounding mountains

The island where Tenochtitlán was built—surrounded by lakes that would eventually be dried out—was chosen as the site of the colonial city. Construction expanded to the lake beds as these were desiccated. Their soft subsoil has proved highly unstable during earthquakes and accounts for a gradual sinking of some downtown sections, a process that has threatened many historical landmarks. Although the city's central area is flat, the land rises gently as it approaches the western and southwestern mountains.

Climate. Mexico City is located within the world's tropical zone, but high altitude accounts for its relative coolness. The annual median temperature is 64° F (18° C); seasonal changes are small. Night frosts occur in December and January, the coldest months, but even then temperatures rise to the mid-70s during the day. April and May are the warmest months. The rainy season, which usually lasts from late May until September, brings temperatures down and moderates the usual dryness of the air.

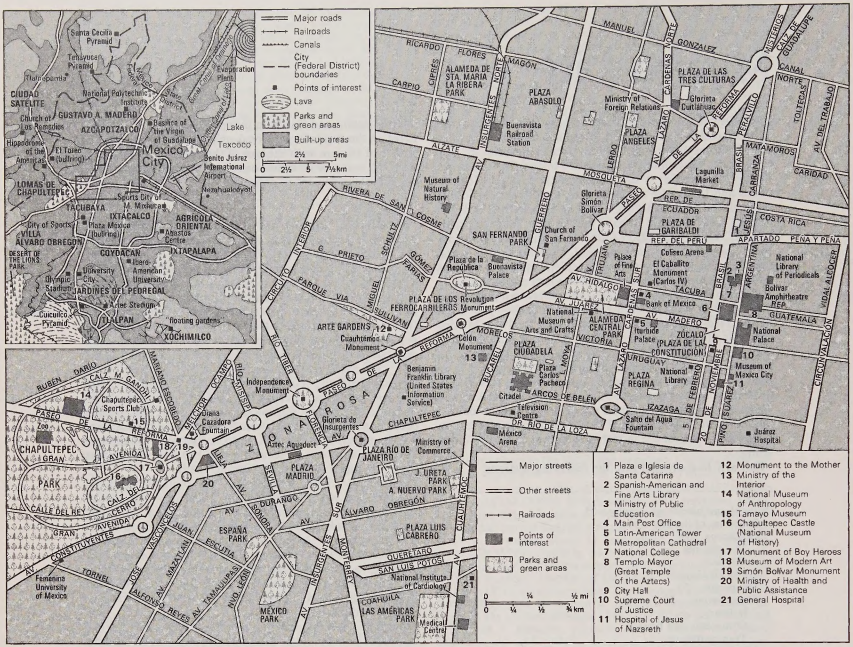
Effects of air pollution

Air pollution—made up mostly of ozone, suspended particles, and sulfur dioxide—has affected the climate by partially blocking the Sun's rays. Poor air circulation out of the mountain-walled city aggravates pollution. The prevailing winds, especially strong during February and March, blow from the northeast and sweep dust particles into the city, although the partial regeneration of Lake Texcoco has begun to alleviate this problem. Thermal inversions often trap smog in the valley during winter.

The weather is not homogeneous throughout the city. The higher and more wooded areas of the west and southwest are cooler and receive more rainfall than the rest. The north and northeast, largely depleted of vegetation, are the driest and hottest areas.

The central plaza

The city layout. The island where the Aztecs built their capital became the central area of Mexico City. The Zócalo (previously known as the Plaza Mayor and now officially called the Plaza de la Constitución) is the traditional hub of the city. On the Zócalo's northern side, close to the former site of the main Aztec temple, stands the Metropolitan Cathedral. The National Palace, formerly the viceroy's palace, which is the official seat of the republic's executive power, was built over the ruins of the Aztec emperor's palace. The colonial city extended just a few blocks around the Zócalo, and in that area, known as the historical centre, many buildings predating independence still stand.



Central Mexico City and (inset) its metropolitan area.

The Alameda Central (Central Mall) roughly marks the western edge of the old colonial city. From its vicinity the Paseo de la Reforma—a wide, tree-lined boulevard—sweeps southwest toward Chapultepec. This wooded hill has been transformed into a public park, and its 18th-century castle is now a history museum. Upon reaching Chapultepec, Reforma turns west and advances into some of the city's wealthiest *colonias* (neighbourhoods), such as Polanco and Lomas de Chapultepec.

Chapultepec and environs

Avenida Insurgentes is Mexico City's main north–south axis. It crosses Paseo de la Reforma near the historical centre and continues both north and south to the end of the urban area. The Pink Zone ("Zona Rosa") is the main tourist and entertainment area. The city becomes increasingly residential and middle-class toward the south, although Avenida Insurgentes preserves its commercial and business nature. A number of former small towns in the south, such as Tacubaya, Mixcoac, San Ángel, and Coyoacán, have been incorporated into the city. Insurgentes traverses University City, the campus of the National Autonomous University of Mexico, before ending in Tlalpan, another formerly independent town and now the southern edge of the city. West of the southern portion of Insurgentes is the Pedregal de San Ángel, a wealthy residential *colonia* with notable examples of modern architecture.

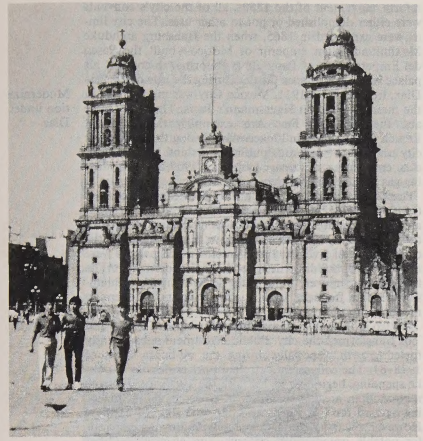
At the southeastern tip of the city, Xochimilco, another small town subsumed by the city, is a popular tourist destination because of its *chinampas,* or "floating gardens," boats made out of reeds on which the Indians have grown plants since pre-Columbian times. The artificially preserved Xochimilco Lake is one of the few remnants of the old lake system in the basin. A number of middle-class *colonias* spread to the north of Xochimilco, but in the north the city becomes increasingly poor and more densely populated. East of the historical centre the Benito Juárez International Airport, once outside the city, is now surrounded by heavily populated working-class areas. North and northeast of the airport there are miles of poverty-ridden *colonias,* many lacking essential services. Outside the Federal District, but still part of the metropolitan area, lies Ciudad Nezahualcóyotl, one of the metropolis's poorest areas; it would be one of the largest cities in the country if measured on its own.

Xochimilco Lake

North of the historical centre stands Tlatelolco, a lower-middle-class residential development on the site of a former Indian city conquered by the Aztecs. Farther north is the Villa de Guadalupe Hidalgo, famed for its shrine of the Virgin of Guadalupe, a pilgrimage destination for Mexicans from throughout the country. Although "la Villa" was traditionally considered the northern edge of the city, urbanization has continued northward into the State of Mexico. To the northwest there are industrial zones, some within the Federal District (Azcapotzalco, for example) and some beyond it (Naucalpan). Farther northwest, around Ciudad Satélite, lies another cluster of middle-class residential suburbs, also in the State of Mexico.

Owing to the metropolitan area's enormous dimensions, each of its sections has developed its own commercial and service areas. The city centre, once the preferred middle-class shopping district, is now of marginal importance. Huge suburban shopping malls, such as Plaza Satélite in the northwest and Perisur in the south, have usurped the downtown area's commercial importance. The central Merced market, the city's main food-distribution centre

Decentralization of commerce



The Metropolitan Cathedral on the Zócalo in Mexico City.
Chip and Rosa María de la Cueva Peterson

since colonial times, was replaced in the 1980s by a modern supply centre (Abastos Centre) on the city's east end.

THE PEOPLE

Mexico City is one of the fastest-growing urban areas in the world. With a population of some 3,000,000 in 1950, it grew at rates of more than 3 percent annually in the following decades. By the 1980s it was the home of more than one-fifth of the country's population.

Racial composition

The city was traditionally inhabited by mestizos (people of mixed European and Indian descent) and criollos (Mexicans of European descent), but steady immigration from the countryside has given it a more Indian character. Although there is no formal racial discrimination, criollos constitute a disproportionate number of the upper and upper-middle classes.

Most Mexico City dwellers are Roman Catholic, although a number of Protestant churches have gained converts. There is also a small but influential Jewish community.

THE ECONOMY

Industry. Mexico City's metropolitan area accounts for more than 30 percent of the nation's industrial production. A trend to move heavy industry out of the city began in the 1950s, but a number of major plants remain within the urban area, especially in the northwest. The main industries are construction and the production of chemicals, plastics, cement, and yarns and textiles. Light industry is becoming predominant in the city's economy.

Commerce and finance. Because of the relative affluence of its residents and the fact that the city serves as the main supply centre for the country's central area, more than 40 percent of the nation's domestic sales occur in Mexico City. With the emigration of heavy industry, services constitute an increasingly important part of the local economy. Tourism is a major source of income.

Even more than other economic activities, Mexico's financial services are concentrated in the capital. The number of banking institutions, more than 50 in the late 1970s, dropped to less than 20 as a result of mergers following the government takeover of private banks in 1982. The country's only stock exchange operates in the city, where the Bank of Mexico, the central bank, is also located.

Transportation. Mexico City is the hub of the national transportation system. Five main highways link the capital with all regions of the country as well as with the United States and Guatemala. Railway lines run south, east, and north from the city. The Benito Juárez International Airport handles both national and international flights. In the late 1980s some flights began to land and depart from the Toluca airport in order to alleviate the former's perennial congestion.

The city's internal transportation system is chaotic and overextended. By the late 1980s close to 4,000,000 motor vehicles circulated in the urban area, and their number is growing rapidly. They creep at an average speed of about 12 miles an hour, and "rush hour" in many areas lasts virtually all day. In 1982 the Federal District's private bus system was expropriated by the government, while massive investments have been made to expand the efficient but overcrowded Metro (subway) system.

ADMINISTRATION AND SOCIAL CONDITIONS

Government. Most residents of Mexico City do not elect their own local government. The country's president appoints a regent, or mayor, who heads the administration of the Federal District. The regent appoints delegates who assume executive responsibility over the Federal District's 16 *delegaciones* (city districts), each of which functions with considerable autonomy. Many of these *delegaciones* have populations larger than those of most cities and some states within the country. The areas outside of the Federal District choose their own mayors (*presidentes municipales*) and participate in the election of the governor of the State of Mexico. Federal District residents vote for deputies (representatives) and senators to the federal Congress, as well as for the nation's president. In the late 1980s an elective advisory committee was established. Mexico City is the seat of the executive, legislative, and judicial powers of the country.

Administrative units

Services. Water supply has long been a problem for Mexico City. After its own reserves were virtually exhausted, expensive conveyance systems were built to bring drinking water from increasingly remote areas. The drainage system was partially renovated in the 1970s and '80s. Some electricity is produced within the city, but most is purchased from outside plants. The telephone system, always inadequate, suffered a major blow when the 1985 earthquake destroyed the city's main exchange; in the late 1980s a new decentralized system was installed. Propane gas, commonly used for cooking and for heating water, is distributed in portable tanks or by tanker trucks that fill home containers; home heating is virtually nonexistent.

Health. The oldest hospital in the Western Hemisphere—the Hospital of Jesus of Nazareth—was founded in Mexico City by Hernán Cortés in the early 16th century. The government operates numerous health facilities, including the gigantic General Hospital and the Medical Centre, a conglomerate of specialized units. There are also many private hospitals. Patients from throughout the country often travel to the capital for treatment.

Although sanitary standards are higher than in the rest of Mexico, gastrointestinal diseases remain common, particularly among lower-class children. Also prevalent are respiratory illnesses, a consequence of pollution, and psychological disorders stemming from overcrowding. With the improvement in general sanitary conditions, illnesses more characteristic of developed countries, such as cardiovascular problems and cancer, have become more common.

Education. Mexico City boasts a literacy rate of more than 90 percent, significantly higher than that of the rest of the country, and its educational facilities are unsurpassed in Mexico. The public school system is complemented by a large number of private schools. Dropout rates at the elementary and secondary school levels remain high.

The National Autonomous University of Mexico

The capital has the largest concentration of higher-education facilities in the nation. The National Autonomous University of Mexico, founded in 1551, is one of the largest in the world, with more than 350,000 students. Its buildings are beautifully decorated with murals by painter Diego Rivera and others. The National Polytechnic Institute and the Metropolitan Autonomous University are among the other important public institutions of higher education. Private universities include the Ibero-American

University, the Anáhuac University, and the United States International University. There are a number of specialized postgraduate and research institutions, including the prestigious College of Mexico.

CULTURAL LIFE

Mexico City has always been one of the prominent cultural centres of Latin America. There are several symphony orchestras and dozens of art galleries and museums, theatre groups, and dance companies in the city. The downtown Palace of Fine Arts is the traditional concert and opera hall. The University Cultural Centre, at the National University campus, houses the National Library, a major symphony hall, and a number of theatres. The National Museum of Anthropology is generally considered the world's finest in its specialty. Mexico City is also home for the country's most important art, music, and dance schools.

Mexico City is one of the main book- and newspaper-publishing centres in the Spanish-speaking world. There are numerous news, literary, and other specialized magazines.

Each neighbourhood has its own parks and gardens. Chapultepec Park, the largest and most beautiful of these, encompasses about 1,600 acres (647 hectares) in the southwest. Its grounds contain museums, a zoo, botanical gardens, an amusement park, lakes, and fountains. Desert of the Lions ("El Desierto de los Leones"), another park 10 miles southwest of the city, occupies a wide expanse of mountains, pine forests, springs, and aqueducts. The Alameda Central, west of the Zócalo, was created in 1592.

The most popular spectator sports are association football (soccer) and bullfighting. Soccer is played in the Aztec Stadium and in the National University's Olympic Stadium. Plaza México is the largest bullring in the world.

History

THE EARLY PERIOD

Origins. The Aztecs arrived in the Valley of Mexico in the 13th century. According to tradition, they founded Tenochtitlán ("Place of the High Priest Tenoch") after much wandering when they saw on an island in Lake Texcoco the sign that their god Huitzilopochtli had indicated—an eagle perched on a cactus, eating a serpent. Tenochtitlán quickly spread over the island, marshes, and swamps. As it developed into a city, it was divided into *calpulli,* or districts, each with communal lands and schools.

When the Spaniards led by Hernán Cortés arrived in 1519, Tenochtitlán had about 100,000 inhabitants. The island was connected to the mainland by three causeways—Tepeyac to the north, Ixtapalapa to the south, and Tacuba to the west—which converged on the ceremonial centre near the main temple and the emperor's palace.

The colonial city. Cortés razed Tenochtitlán in 1521 and constructed a Spanish city on its ruins. The city was chartered and its *cabildo,* or town council, recognized in 1522; it was given leadership over other *cabildos* of New Spain in 1535. It soon became the most important city of the Americas, with jurisdiction extending well into the present United States and as far south as Panama.

Rise to preeminence

Mexico City continued as a lakeside centre until constant floods necessitated the filling of the lakes of the valley floor. During the 17th century the capital comprised a well-laid-out assemblage of homes, public buildings, churches, and convents. In their execution of European designs, the colonists and Indian artisans employed local *tezontle,* a light and porous volcanic rock, to create elaborate facades. This Baroque style reached its ultimate expression in the 18th century, the golden age of architecture in New Spain, after which Neoclassical ideas were introduced by the sculptor and architect Manuel Tolsá.

THE CITY AFTER INDEPENDENCE

Before the revolution. After the brief reign of Emperor Agustín de Iturbide of Mexico, the republican constitution of 1824 established the Federal District to centralize the country's government in Mexico City. The capital was captured by U.S. troops in the 1840s. During the anticlerical reform movement of the 1850s, all of the city's convents were either demolished or put to other uses. The city limits were expanded in 1865, when the Habsburg archduke Maximilian—then emperor of Mexico—built the Paseo del Emperador (now Paseo de la Reforma) to connect his palace with Chapultepec Castle. During the rule of Porfirio Díaz, from 1876 to 1911, Mexico City was modernized in the manner of Baron Haussmann's Paris. The Post Office and the Palace of Fine Arts exemplify the dominant French architectural influence. Also during this period the city undertook numerous public works and utilities projects, completing a drainage system in 1907 and introducing gas and electric lighting and streetcars.

Modernization under Díaz

The 20th century. During the Mexican Revolution (1910–17), the city became a battlefield. Disruption in rural areas resulted in an exodus from the countryside to the capital. In 1924 urban works were renewed with the construction of Avenida Insurgentes. French palaces were replaced with buildings designed in the modern style. The first skyscrapers were built in the 1930s, but the soft subsoil and the frequent seismic activity restricted them to modest proportions.

Mexico's prosperity and stability during the 1950s and '60s transformed the city. Public investment subsequently fueled growth, especially during the oil-boom years of 1978–81. The collapse of petroleum prices decreased public spending, beginning in 1982. In the 1980s and '90s the metropolitan area's population increased rapidly, spreading beyond the Federal District into the state of Mexico. However, the city failed to keep up with growing demands for potable water, sewer systems, and electricity. Other problems included worsening violent crime, air pollution, and seismic activity. In 1985 an earthquake killed some 7,000 people, and from the late 1990s the nearby volcano Popocatépetl erupted intermittently. The Mexican government relinquished control of the Federal District in 1997 in an effort to improve local planning, services, and accountability. That year Cuauhtémoc Cárdenas Solorzano was elected to a two-year term as the district's first mayor; his leftist Party of the Democratic Revolution (PRD; Partido de la Revolución Democrática) continued to play a leading role in the government at the beginning of the 21st century.

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(S.S./F.Be./Ed.)

Michelangelo

Michelangelo was considered the greatest living artist in his lifetime, and ever since then he has been held to be one of the greatest artists of all times. A number of his works in painting, sculpture, and architecture rank among the most famous in existence. Although the frescoes on the ceiling of the Sistine Chapel (Vatican) are probably the best known of his works today, the artist thought of himself primarily as a sculptor. His practice of several arts, however, was not unusual in his time, when all of them were thought of as based on design, or drawing. Michelangelo worked in marble sculpture all his life and in the other arts only at certain periods. The high regard for the Sistine ceiling is partly a reflection of the greater attention paid to painting in the 20th century and partly, too, of the fact that it, unlike many of the artist's works in the other media, was completed.

Alinari/Art Resource, NY



Joseph of Arimathea (or, possibly, Nicodemus), detail of the "Pietà" by Michelangelo, *c.* 1550–55, which is thought to be a self-portrait. In the Duomo, Florence.

A side effect of Michelangelo's fame in his lifetime was that his career was more fully documented than that of any artist of the time or earlier. He was the first artist whose biography was published while he was alive, and there were two rival biographies. The first was the final chapter in the series of artists' lives (1550) by the painter and architect Giorgio Vasari. It was the only chapter on a living artist and explicitly presented Michelangelo's works as the culminating perfection of art, surpassing the efforts of all those before him. Despite such an encomium, Michelangelo was not entirely pleased and arranged for his assistant Ascanio Condivi to write a brief separate book (1553); probably based on the artist's own spoken comments, this account shows him as he wished to appear. After Michelangelo's death Vasari in a second edition (1568) offered a rebuttal. While scholars have often preferred the authority of Condivi, Vasari's lively writing, the importance of his book as a whole, and its frequent reprinting in many languages have made it the most usual basis of popular ideas. Michelangelo's fame also led to the preservation of countless mementos, including hundreds of letters, sketches, and poems, again more than of any contemporary. Yet despite the enormous benefit that has accrued from all this, in controversial matters often only Michelangelo's side of an argument is known.

Early life and works. Michelangelo Buonarroti was born March 6, 1475, to a family that had for several generations been small-scale bankers in Florence but had in the case of the artist's father failed to maintain its status. The father had only occasional government jobs, and at the time of Michelangelo's birth he was administrator of the small dependent town of Caprese. A few months later, however, the family returned to its permanent residence in Florence. It was something of a downward social step to become an artist, and Michelangelo became an apprentice relatively late, at 13, perhaps after overcoming his father's objections. He was apprenticed to the city's most prominent painter, Domenico Ghirlandajo, for a three-year term, but he left after one year, having (Condivi recounts) nothing more to learn. Several drawings, copies of figures by Ghirlandajo and older great painters of Florence, Giotto and Masaccio, survive from this stage; such copying was standard for apprentices, but few examples are known to survive. Obviously talented, he was taken under the wing of the ruler of the city, Lorenzo de' Medici, known as the Magnificent. Lorenzo surrounded himself at table with poets and intellectuals, and Michelangelo was included. More important, he had access to the Medici art collection, which was dominated by fragments of ancient Roman statuary. (Lorenzo was not such a patron of contemporary art as legend has made him; such modern art as he owned was to ornament his house or make political statements.) The bronze sculptor Bertoldo, a Medici friend and in charge of the collection, was the nearest to a teacher of sculpture he had, but Michelangelo did not follow his medium or in any major way his approach. Still, one of the two marble works that survive from the artist's first years is a variant on the composition of an ancient Roman sarcophagus, and Bertoldo had produced a similar one in bronze. This composition is the "Battle of the Centaurs" (*c.* 1492). The action and power of the figures foretell the artist's later interests much more than does the "Madonna of the Stairs" (*c.* 1491), a delicate low relief that reflects recent fashions among such Florentine sculptors as Desiderio da Settignano.

Apprenticeship with Ghirlandajo

Florence was at this time regarded as the leading centre of art, producing the best painters and sculptors in Europe, and the competition among artists was stimulating. The city was, however, less able than earlier to offer large commissions, and leading Florentine-born artists, such as Leonardo da Vinci and Leonardo's teacher, Verrocchio, had moved away for better opportunities in other cities. The Medici were overthrown in 1494, and even before the end of the political turmoil Michelangelo had left.

In Bologna he was hired to succeed a recently deceased sculptor and carve the last small figures required to complete a grand project, the tomb and shrine of St. Dominic (1494–95). The three marble figures are original and expressive. Departing from his predecessor's fanciful agility, he imposed seriousness on his images by a compactness of form that owes much to classical antiquity and to the Florentine tradition from Giotto onward. This emphasis on seriousness is also reflected in his choice of marble as his medium, while the accompanying simplification of masses is in contrast to the then more usual tendency to let representations match as completely as possible the texture and detail of human bodies. To be sure, although these are constant qualities in Michelangelo's art, they often are temporarily abandoned or modified because of other factors, such as the specific functions of works or the stimulating creations of other artists. This is the case with Michelangelo's first surviving large statue, the "Bacchus," produced in Rome (1496–97) following a brief return to Florence. (A wooden crucifix, recently discovered, attributed by some scholars to Michelangelo and now housed in the Casa Buonarroti, Florence, has also been proposed as the antecedent of the "Bacchus" in design by those who credit it as the artist's work.)

"Bacchus"

The "Bacchus" relies on ancient Roman nude figures as a point of departure, but it is much more mobile and more complex in outline. The conscious instability evokes the god of wine and Dionysiac revels with extraordinary virtuosity. Made for a garden, it is also unique among Michelangelo's works in calling for observation from all sides rather than primarily from the front.

The "Bacchus" led at once to the commission (1498) for the "Pietà," now in St. Peter's Basilica. The name refers not (as often presumed) to this specific work but to a common traditional type of devotional image, this work being today the most famous example. Extracted from narrative scenes of the lamentation after Christ's death, the concentrated group of two is designed to evoke the observer's repentant prayers for sins that required Christ's sacrificial death. The patron was a French cardinal, and the type was earlier more common in northern Europe than Italy. The complex problem for the designer was to extract two figures from one marble block, an unusual undertaking in all periods. Michelangelo treated the group as one dense and compact mass as before so that it has an imposing impact, yet he underlined the many contrasts present, of male and female, vertical and horizontal, clothed and naked, dead and alive, to clarify the two components. The artist's prominence, established by this work, was reinforced at once by the commission (1501) of the "David" for the cathedral of Florence. For this huge statue, an exceptionally large commission in that city, Michelangelo reused a block left unfinished about 40 years before. The modeling is especially close to the formulas of classical antiquity, with a simplified geometry suitable to the huge scale yet with a mild assertion of organic life in its asymmetry. It has continued to serve as the prime statement of the Renaissance ideal of perfect humanity.

"David"

On the side Michelangelo produced in the same years (1501–04) several Madonnas for private houses, the staple of artists' work at the time. These include one small statue, two circular reliefs that are similar to paintings in suggesting varied levels of spatial depth, and the artist's only easel painting. While the statue ("Madonna and Child") is blocky and immobile, the painting ("Holy Family") and one of the reliefs ("Madonna and Child with the Infant St. John") are full of motion; they show arms and legs of figures interweaving in actions that imply movement through time. The forms carry symbolic references to Christ's future death, common in images of the Christ Child at the time; they also betray the artist's fascination with the work of Leonardo. Michelangelo regularly denied that anyone influenced him, and his statements have usually been accepted without demur. But Leonardo's return to Florence in 1500 after nearly 20 years was exciting to younger artists there, and recent scholars have generally agreed that Michelangelo was among those affected. Leonardo's works were probably the most powerful and lasting outside influence to modify his work, and he was able to blend this artist's ability to show momentary processes with his own to show weight and strength, without losing any of the latter quality. The resulting images, of massive bodies in forceful action, are those special creations that constitute the larger part of his most admired major works.

The influence of Leonardo da Vinci

The middle years. After the success of the "David" in 1504 Michelangelo's work consisted almost entirely of vast projects. He was attracted to these ambitious tasks while at the same time rejecting the use of assistants, so that most of these projects were impractical and remained unfinished. In 1504 he agreed to paint a huge mural for the Florence city hall to form a pair with another just begun by Leonardo. Both murals recorded military victories by the city, but each also gave testimony to the special skills of the city's much vaunted artists; Leonardo's design shows galloping horses, Michelangelo's active nudes—soldiers stop swimming and climb out of a river to answer an alarm. Both works survive only in copies and partial preparatory sketches. In 1505 the artist began work on a planned set of 12 marble Apostles for the Florence cathedral, of which only one, the "St. Matthew," was even begun. Its writhing ecstatic motion for the first time shows the full blend of Leonardo's fluid organic movement with his own monumental power. This is also the first of Michelangelo's unfinished works that have fascinated later observers. His figures seem to suggest that they are fighting to emerge from the stone. This would imply that their incomplete state was intentional, yet he undoubtedly did want to complete all of the statues. He did, however, write a sonnet about how hard it is for the sculptor to bring the perfect figure out of the block in which it is potentially present. Thus, even if the works remained unfinished due only to lack of time and other external reasons, their condition, nonetheless, reflects the artist's intense feeling of the stresses inherent in the creative process.

Pope Julius II's call to Michelangelo to come to Rome spelled an end to both of these Florentine projects. The Pope sought a tomb for which Michelangelo was to carve 40 large statues. Recent tombs had been increasingly grand, including those of two popes by the Florentine sculptor Antonio Pollaiuolo, those of the doges of Venice, and the one then in work for Holy Roman Emperor Maximilian I. Pope Julius had an ambitious imagination, parallel to Michelangelo's, but because of other projects, such as the new building of St. Peter's and his military campaigns, he evidently became disturbed soon by the cost. Michelangelo believed that Bramante, the equally prestigious architect at St. Peter's, had influenced the Pope to cut off his funds. He left Rome, but the Pope brought pressure on the city authorities of Florence to send him back. He was put to work on a colossal bronze statue of the Pope in his newly conquered city of Bologna (which the citizens pulled down soon after when they drove the papal army out) and then on the less expensive project of painting the ceiling of the Sistine Chapel (1508–12).

The Sistine Chapel had great symbolic meaning for the papacy as the chief consecrated space in the Vatican, used for great ceremonies such as electing and inaugurating new popes. It already contained distinguished wall paintings, and Michelangelo was asked to add works for the relatively unimportant ceiling. Twelve Apostles were planned as the theme—ceilings normally showed only individual figures, not dramatic scenes. Traces of this project are seen in the 12 large figures that Michelangelo produced: seven prophets and five sibyls, or female prophets found in classical myths. The inclusion of female figures was very unusual though not totally unprecedented. Michelangelo placed these figures around the edges of the ceiling and filled the central spine of the long curved surface with nine scenes from Genesis: three of them depicting the creation of the world, three the stories of Adam and Eve, and three the stories of Noah. These are naturally followed, below the prophets and sibyls, by small figures of the 40 generations of Christ's ancestors, starting with Abraham. The vast project was completed in less than four years; there was an interruption perhaps of a year in 1510–11 when no payment was made.

Sistine ceiling

The work began at the end, with the Noah scenes placed over the entrance door, and moved toward the altar in the direction opposite to that of the sequence of the stories. The first figures and scenes naturally show the artist reusing devices from his earlier works, such as the Pietà, since he was starting on such an ambitious work in an unfamiliar medium. These first figures are relatively stable, and the scenes are on a relatively small scale. As he proceeded, he quickly grew in confidence. Indeed, recent investigations of the technical processes used show that he worked more and more rapidly, reducing and finally eliminating such preparatory helps as complete drawings and incisions on the plaster surface. The same growing boldness appears in the free, complex movements of the figures and in their complex expressiveness. While remaining always imposing and monumental, they are more and more imbued with suggestions of stress and grief. This may be perceived in a figure such as the prophet Ezekiel halfway along. This figure combines colossal strength and weight with movement and facial expression that suggest determination to reach a goal that is uncertain of success. Such an image of the inadequacy of even great power is a presentation of heroic and tragic humanity and is central to what Michelangelo means to posterity. Nearby

the scene of the creation of Eve shows her with God and Adam, compressed within too small a space for their grandeur. This tension has been interpreted as a token of a movement away from the Renaissance concern with harmony, pointing the way for a younger generation of artists like Pontormo, often labeled Mannerists. Michelangelo's work on the ceiling was interrupted, perhaps just after these figures were completed. When he painted the second half, he seemed to repeat the same evolution from quiet stability to intricacy and stress. Thus he worked his way from the quietly monumental and harmonious scene of the creation of Adam to the acute, twisted pressures of the prophet Jonah. Yet in this second phase he shows greater inward expressiveness, giving a more meditative restraint to the earlier pure physical mass.

As soon as the ceiling was finished, Michelangelo reverted to his preferred task, the tomb of Pope Julius. In about 1513–15 he carved the "Moses," which may be regarded as the realization in sculpture of the approach to great figures used for the prophets on the Sistine ceiling. The control of cubic density in stone evokes great reserves of strength; there is richer surface detail and modeling than before, with bulging projections sharply cut. The surface textures also have more variety than the earlier sculptures, the artist by now having found how to enrich detail without sacrificing massiveness. Of about the same date are two sculptures of bound prisoners or slaves, also part of the tomb project but never used for it, since in a subsequent revised design they were of the wrong scale. Michelangelo kept them until old age, when he gave them to a family that had helped him during an illness; they are now in the Louvre. Here again he realized in stone types painted in many variants on the ceiling, such as the pairs of nudes that hold wreaths above the prophets' thrones. The complexity of their stances, expressive of strong feeling, was unprecedented in monumental marble sculpture of the Renaissance. The only earlier works of this nature were from the Hellenistic period of classical antiquity, well known to Michelangelo through the discovery of the Laocoön group in 1506. The old man and his two adolescent sons forming that group certainly stimulated the three statues by Michelangelo as well as the related figures on the ceiling. Yet the first of the ceiling figures in 1508 were not so affected; Michelangelo utilized the Hellenistic twists and complications only when he was ready for them, and he had been moving in this direction even before the Laocoön was found, as is evident in the case of the "St. Matthew" of 1505.

Julius II's death in 1513 cut off most of the funds for his tomb. Pope Leo X, his successor, a son of Lorenzo the Magnificent, had known Michelangelo since their boyhoods. He chiefly employed Michelangelo in Florence on projects linked to the glory of the Medici family rather than of the papacy. The city was under the rule of Leo's cousin Cardinal de' Medici, who was to be Pope Clement VII from 1523 to 1534, and Michelangelo worked with him closely in both reigns. The Cardinal took an active interest in Michelangelo's works. He made detailed suggestions, but he also gave the artist much room for decision. Michelangelo was moving into architectural design with a small remodeling project at the Medici mansion and a large one at their parish church, San Lorenzo. He approached such work with enthusiasm, caused no doubt by the large scale and the involvement with masses of stone to be manipulated expressively. The larger project never materialized, but Michelangelo and the Cardinal did better with a more modest related one, the new chapel attached to the same church for tombs of the Medici family.

The Medici Chapel

The immediate occasion for the chapel was the deaths of the two young family heirs, named Giuliano and Lorenzo after their forebears, in 1516 and 1519. Michelangelo gave his chief attention up to 1527 to the marble interior of this chapel, to both the very original wall design and the carved figures on the tombs; the latter are an extension in organic form of the dynamic shapes of the wall details. The result is the fullest existing presentation of Michelangelo's intentions. Windows, cornices, and the like have strange proportions and thicknesses, suggesting an irrational, willful revision of traditional classical forms in buildings. Abutting these active surfaces, the two tombs on opposite walls of the room are also very original, starting with their curved tops. A male and a female figure sit on each of these curved bases; these are allegories symbolizing on one tomb day and night, according to the artist's own statement, and dawn and dusk on the other, according to early reports. Such personifications had never appeared on tombs before, and they refer, again according to Michelangelo, to the inevitable movement of time, which is circular and leads to death. The figures are among the artist's most famous and accomplished creations. The immensely massive figures of "Day" and "Dusk" are relatively tranquil in their mountainous grandeur, though "Day" perhaps implies inner fires. Both female figures have the tall, slim proportions and small feet considered beautiful at the time, but otherwise they form a contrast: "Dawn," a virginal figure, strains upward along her curve as if trying to emerge into life; "Night" is asleep, but in a posture suggesting stressful dreams.

These four figures are naturally noticed more immediately than the effigies of the two Medici buried there, placed higher and farther back in wall niches. These effigies, more usual in execution, also form a contrast; they are traditionally described as active and thoughtful, respectively. Rendered as standard types of young soldiers, they were at once perceived not as portraits but as idealized superior beings, both because of their high rank and because they are souls beyond the grave. Both turn to the same side of the room. It has naturally been thought that they focus on the "Madonna," which Michelangelo carved and which is at the centre of this side wall, between two saints. The heads of the two effigies, however, are turned in differing degrees, and their common focus is at a corner of the chapel, at the entrance door from the church. On this third wall with the "Madonna" the architectural treatment was never executed.

The Laurentian Library

During the same years Michelangelo designed another annex to the same church, the Laurentian Library, required to receive the books bequeathed by Pope Leo; it was traditional in Florence and elsewhere that libraries were housed in convents. The design for this one was constrained by the existing buildings, and it was built on top of older structures. A small available area on the second floor was used as an entrance lobby and contains a staircase leading up to the larger library room on a new third floor. The stairhall, known as the *ricetto,* contains Michelangelo's most famous and original wall designs. The bold and free rearrangement of traditional building components goes still further, for instance, to place columns recessed behind a wall plane rather than in front of it as is usual. This has led to the work's being cited frequently as the first and a chief instance of Mannerism as an architectural style, when it is defined as a work that intentionally contradicts the classical and the harmonious, favouring expressiveness and originality, or as one that emphasizes the factors of style for their own sake. By contrast the long library room is far more restrained, with traditional rows of desks neatly related to the rhythm of the windows and small decorative detail in the floor and ceiling. It recalls that Michelangelo was not invariably heavy and bold but modified his approach in relation to the particular case, here to a gentler, quiet effect. For that very reason it has often been less noticed in the study of his work. At the opposite end of the long room, across from the stairway, another door led to a space intended to hold the library's rarest treasures. It was to be a triangular room, a climax of the long corridor-like approach, but this part was never executed on the artist's plan.

Michelangelo as a designer of fortifications

The sack of Rome in 1527 saw Pope Clement ignominiously in flight, and Florence revolted against the Medici, restoring the traditional republic. It was soon besieged and defeated, and Medici rule permanently reinstalled, in 1530. During the siege Michelangelo was the designer of fortifications. He showed understanding of modern defensive structures built quickly of simple materials in complex profiles that offered minimum vulnerability to attackers and maximum resistance to cannon and other artillery. This new weapon, which had come into use in the middle of the 14th century, had given greater power to the offense

in war. Thus, instead of the tall castles that had served well for defensive purposes in the Middle Ages, lower and thicker masses were more practical. The projecting points, which also assisted counterattack, were often of irregular sizes in adaptation to specific hilly sites. Michelangelo's drawings with rapid lively execution reflecting this flexible new pattern have been much admired, often in terms of pure form.

When the Medici returned in 1530, Michelangelo returned to work on their family tombs. His political commitment probably was more to his city as such than to any specific governmental form. Two separate projects of statues of this date are the "Apollo" or "David" (its identity is problematic), used as a gift to a newly powerful political figure, and the "Victory," a figure trampling on a defeated enemy, an old man. It was probably meant for the never forgotten tomb of Pope Julius because the motif had been present in the plans for the Julius tomb. Victor and loser both have intensely complicated poses; the loser seems packed in a block, the victor—like the "Apollo"—forms a lithe spiral. The "Victory" group became a favourite model for younger sculptors of the Mannerist group, who applied the formula to many allegorical subjects.

In 1534 Michelangelo left Florence for the last time, though he always hoped to return to finish the projects he had left incomplete. He passed the rest of his life in Rome, working on projects in some cases equally grand but in most cases of quite new kinds. From this time on a large number of his letters to his family in Florence were preserved; many of them concentrated on plans for his nephew's marriage, essential to preserve the family name. Michelangelo's father had died in 1531 and his favourite brother at about the same time; he himself showed increasing anxiety about his age and death. It was just at this time that the nearly 60-year-old artist wrote letters expressing strong feelings of attachment to young men, chiefly to the talented aristocrat Tommaso Cavalieri, later active in Roman civic affairs. These have naturally been interpreted as indications that Michelangelo was a homosexual, but such a reaction according to the artist's own statement would be that of the ignorant. The idea seems even less likely when one considers that no similar indications had emerged when the artist was younger. The correlation of these letters with other new events seems consistent instead with the view that he was seeking a surrogate son, choosing for the purpose a younger man who was admirable in every way and would welcome the role.

Michelangelo's poetry is also preserved in quantity from this time. He apparently began writing short poems in a way common among nonprofessionals in the period, as an elegant kind of letter, but developed in a more original and expressive way. Among some 300 preserved poems, not including fragments of a line or two, there are about 75 finished sonnets and about 95 finished madrigals, poems of about the same length as sonnets but of a looser formal structure. In English-speaking countries people tend to speak of "Michelangelo's sonnets," as though all of his poems were written in that form, partly because the sonnets were widely circulated in English translations from the Victorian period, partly because the madrigal is unfamiliar in English poetry. (It is not the type of song well known in Elizabethan music, but a poem with irregular rhyme scheme, line length, and number of lines.) Yet the fact that Michelangelo left a large number of sonnets but only very few madrigals unfinished suggests that he preferred the latter form. Those written up to about 1545 have themes based on the tradition of Petrarch's love poems and a philosophy based on the Neoplatonism that Michelangelo had absorbed as a boy at Lorenzo the Magnificent's court. They give expression to the theme that love helps human beings in their difficult effort to ascend to the divine.

Michelangelo's poetry

In 1534 Michelangelo returned after a quarter century to fresco painting, executing for the new pope, Paul III, the huge "Last Judgment" for the end wall of the Sistine Chapel. This theme had been a favoured one for large end walls of churches in Italy in the Middle Ages and up to about 1500, but thereafter it had gone out of fashion. It is often suggested that this renewal of a devout tradition came from the same impulses that were then leading to the Counter-Reformation under the aegis of Paul III. The work is in a painting style noticeably different from that of 25 years earlier. The pervasive colour harmony is a simple one of brown bodies against dark blue sky. The figures have less energy and their forms are less articulate, the torsos tending to be single fleshy masses without waistlines. At the top centre Christ as judge lifts an arm to save those on his right and drops the other arm to damn those on his left, suggesting in the idiom of the period a scale to weigh men in the balance. The saved souls rise slowly through the heavy air, as the damned ones sink. At the bottom of the wall skeletons rise from tombs, a motif taken directly from medieval precedents. To the right Charon ferries souls across the River Styx, a pagan motif which Dante had made acceptable to Christians in his *Divine Comedy* and which had been introduced into painting about 1500 by the Umbrian artist Signorelli. Michelangelo admired this artist for his skill in expressing dramatic feeling through anatomical exactitude.

"The Last Judgment"

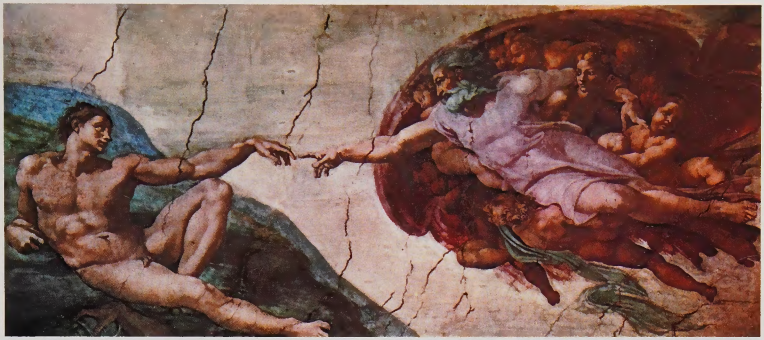
The last decades. In his late years Michelangelo was less involved with sculpture and, along with painting and poetry, more with architecture, an area in which he did not have to do physical labour. He was sought after to design imposing monuments for the new and modern Rome that were to enunciate architecturally the city's position as a world centre. Two of these monuments, the Capitoline Square and the dome of St. Peter's, are still among the city's most notable visual images. He did not finish either, but after his death both were continued in ways that probably did not depart much from his plans.

The small Capitoline Hill had been the civic centre in ancient Roman times and was in the 16th century the centre of the lay municipal government, a minor factor in a city ruled by popes, yet one to which they wished to show respect. Michelangelo remodeled the old city hall on one side of the square and designed twin buildings for the two sides adjacent to it. He gave them rich and powerful fronts, using as his main device the juxtaposition of colossal columns, which rise through two stories to the top, with much smaller one-story columns crowded next to them. This invention creates a forcefully dynamic rhythm while also articulating in a rational way the structure behind the facades. He also produced a special floor design for the square between these two new buildings—an oval pattern that frames a statue at its centre (the ancient Roman monument of the emperor Marcus Aurelius) and gives the whole area the effect of a monumental room. Because of the hilly site, the square is not rectangular but wider on the city hall side and narrower on the opposite side, which was left open. This open side is the entrance for the public, reached by climbing a long flight of stairs. The visitor finds the two facades to his left and right inclined away from each other as they recede from the entrance; this counteracts the tendency of perspective to make walls seem to move nearer each other as they are farther off and so reinforces the effect of a grand expanse.

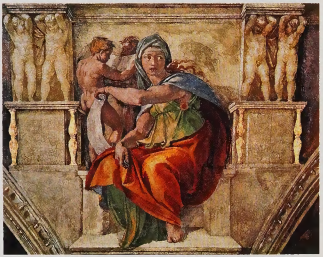
Capitoline Square

The dome of St. Peter's functions chiefly as a visual focus for the observer at a distance, representing a physical goal as well as expressing the dominant meaning of the city. It has been copied for this dual purpose many times, as, for instance, in the Capitol at Washington, D.C. It derives from the dome of the cathedral of Florence, which is 100 years older, perhaps the first great dome to be oriented chiefly outward in its effect rather than being meant chiefly to cover the interior. But it was Michelangelo's dome that gave this shift its universal acceptance. The dome, however, was not built until after Michelangelo's death, and the extent to which it follows his intentions has been much debated. As built by his successor, the dome is more pointed than the pure hemisphere seen in Michelangelo's best known project. But Michelangelo changed his ideas and may well have moved in that direction too.

During his life Michelangelo's major energy in working at St. Peter's was given to the lower part. He discarded the ideas of the architects who had been working on it just before him, approving only those of the original designer, Bramante. He reverted to the earlier plan for a church with four equal cross arms instead of the more conventional Latin cross plan of the more recent altered



"The Creation of Adam," detail of a ceiling fresco by Michelangelo, 1508–12. In the Sistine Chapel, Vatican, Rome.



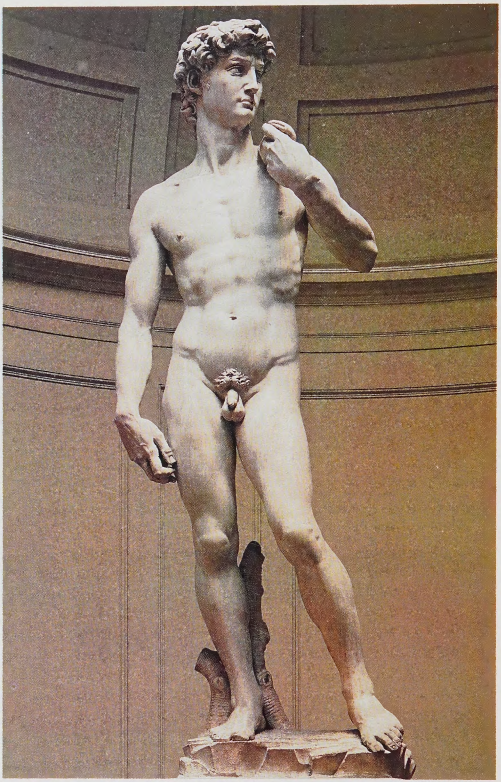
"Delphic Sibyl," detail of a ceiling fresco by Michelangelo, 1508–12. In the Sistine Chapel, Vatican, Rome.



"The Last Judgment," fresco by Michelangelo, 1534–41. In the Sistine Chapel, Vatican, Rome. 1370 x 1220 cm.

Photographs, SCALA/Art Resource, New York City

"David," marble sculpture
by Michelangelo, 1501–04.
In the Accademia, Florence.
Height 434 cm.



"Pietà," marble sculpture
by Michelangelo, 1499.
In St. Peter's Basilica, Rome.
Height 174 cm.





"Moses," marble sculpture
by Michelangelo, c. 1513–15.
In San Pietro in Vincoli,
Rome. Height 235 cm.



"Doni Tondo" ("Holy
Family"), tempera
on wood panel by
Michelangelo,
c. 1503–07. In the
Uffizi, Florence.
Diameter 120 cm.

Photographs: (top left) SCALA/Art Resource, New York City; (top right) Nimatallah/Art Resource, New York City; (bottom right) © Francis G. Mayer—Corbis; (bottom left) Erich Lessing—Art Resource, New York City

scheme. He also disliked the quantity of repeated smaller decorative elements added by the most recent architect, which diminished the effect of great size. He modified Bramante's interior in specifics, making it still more nearly a unified space. This is enclosed by huge semicircular sections of wall on the four sides, creating spaces comparable to the hemispherical space inside the dome. Most of his actual construction work was on the curving wall behind the altar, and there he carried still further the contrast between colossal and smaller supports next to each other, seen already on the Capitoline Hill. This time they are not load-carrying columns but thin pilasters that fit against the continuously curving walls on the exterior. They thus impart both a strong upward thrust and an equally strong horizontal rhythm as the direction of the wall continuously changes, producing an architecture of pulsing dynamism on a gigantic scale. One still can see the approach of the sculptor, who uses the projections and recessions of stone as his vehicle.

Around the base of the dome Michelangelo placed a columned walkway. The tops of the columns are tied to the dome by beams, but there is no roofing of the intervals between columns. Thus, the columns have the effect of flying buttresses on Gothic buildings, supporting the dome's heavy downward thrust. Yet the design is formally classical, and its horizontal aspect as a colonnade solves the problem of a visual transition between the dome and the horizontal lower structure of the building.

While remaining head architect of St. Peter's until his death, Michelangelo worked on many smaller building projects in Rome. He completed the main unit of the Palazzo Farnese, the residence of Pope Paul III's family. The top story wall of its courtyard is a rare example of an architectural unit fully finished under his eye. Some very imaginative and distinctive late designs, such as those for a city gate, the Porta Pia, and for the church of the Florentine community in Rome, were either much reworked later or never went beyond the plan stage in the form Michelangelo had proposed.

His last paintings were the frescoes of the Pauline Chapel in the Vatican, which still is little accessible to the public. Unlike his other frescoes, they are in the position normal for narrative painting, on a wall and not exceptionally high up. They consistently treat spatial depth and narrative drama in a way that brings them closer to other paintings of the age than to the artist's previous paintings. Among the artists Michelangelo came to know and admire was Titian, who visited Rome during the period of this project (1542–50), and the frescoes seem to betray his influence in colour. The poetry of his last years also took on new qualities. The poems, chiefly sonnets, are very direct religious statements suggesting prayers. They are no longer very intricate in syntax and ideas.

There are only two late sculptures, which Michelangelo did for himself, both presenting the dead Christ being mourned, neither one finished. The first and larger one was meant for his tomb, and the figure of the mourning Joseph of Arimathea (or, possibly, Nicodemus) is a self-portrait. (Michelangelo had introduced himself earlier in his works in the role of a sinner or penitent, notably in the "Last Judgment" in the face on the flayed skin of the martyred St. Bartholomew.) Becoming dissatisfied with this sculpture, Michelangelo broke one of the figures and abandoned the work. This constitutes still another variation on the theme of incompletion running through the artist's work. His last sculpture also went through several revisions on the same block of stone and in its current state is an almost dematerialized sketch of two figures leaning together. Michelangelo certainly had a powerful sense of his own imperfection, yet he was also aware of the quality of his work and angry at patrons for not meeting what he judged to be their obligations. He died on Feb. 18, 1564.

Assessment and influence. For posterity Michelangelo has always remained one of the small group of the most exalted artists, who have been felt to express, like Shakespeare or Beethoven, the tragic experience of humanity with the greatest depth and universal scope.

In contrast to the great fame of the artist's works, their visual influence on later art is relatively limited. This cannot be explained by hesitation to imitate an art simply because it appeared so great, for artists like Raphael were considered equally great but were used as sources to a much greater degree. It may be instead that the particular type of expression associated with Michelangelo, of an almost cosmic grandeur, was inhibiting. The limited influence of his work includes a few cases of almost total dependence, the most talented artist who worked in this way being Daniele da Volterra. Otherwise, Michelangelo was treated as a model for specific limited aspects of his work. In the 17th century he was regarded as supreme in anatomical drawing but less praised for broader elements of his art. While the Mannerists utilized the spatial compression seen in a few of his frescoes, and later the serpentine poses of his sculpture of "Victory," the 19th-century master Auguste Rodin exploited the effect of unfinished marble blocks. Certain 17th-century masters of the baroque perhaps show the fullest reference to him, but in ways that have been transformed to exclude any literal similarity. Besides Bernini, the painter Rubens may best show the usability of Michelangelo's creations for a later great artist.

MAJOR WORKS

SCULPTURE: "Madonna of the Stairs" (*c.* 1491; Casa Buonarroti, Florence); "Battle of the Centaurs" (*c.* 1492; Casa Buonarroti); "St. Petronius," "St. Proclus," and "An Angel" (1494–95; S. Domenico, Bologna, Italy); "Bacchus" (1496–97; Bargello, Florence); "Pietà" (1499; St. Peter's, Vatican City); "David" (1501–04; Accademia, Florence); "Madonna and Child" (1501–04; Notre-Dame, Brugge); "Madonna and Child with the Infant St. John" ("Taddei Madonna"); tondo, *c.* 1503; Royal Academy, London); "Madonna and Child" ("Pitti Madonna"; tondo, *c.* 1503; Bargello); "St. Matthew" (*c.* 1505; Accademia); "Moses" (*c.* 1513–15; for the tomb of Pope Julius II, 1505–45; S. Pietro in Vincoli, Rome); "Rebellious Slave" and "Dying Slave" (1513–16; Louvre, Paris); "Risen Christ" ("Christ Bearing the Cross"; 1519–20; Sta. Maria Sopra Minerva, Rome); four unfinished figures known as "Slaves" or "Prisoners" (*c.* 1520; Accademia); Medici tombs ("Dawn," "Dusk," "Day," "Night," "Giuliano de' Medici," "Lorenzo de' Medici," and "Madonna"; 1520–34; S. Lorenzo, Florence); "Apollo" ("David"; *c.* 1530; Bargello); "Victory" (*c.* 1532–34; Palazzo Vecchio, Florence); "Pietà" ("Deposition"; 1550–55; Duomo, Florence); "Rondanini Pietà" (1552–64; Castello Sforzesco, Milan).

DRAWINGS: Major collections: British Museum; Royal Library, Windsor; Ashmolean Museum, Oxford, Eng.; Casa Buonarroti, Florence; Teylers Museum, Haarlem, Neth.

ARCHITECTURE: Chapel of Leo X (dedicated to SS. Cosmas and Damian; facade, 1514; Castel Sant'Angelo, Rome); Laurentian Library (1523–59; S. Lorenzo, Florence); Palazzo Farnese (cornice of facade and top story wall of courtyard completed 1547; Rome); St. Peter's Basilica (dome designed 1557–61; Vatican City); Porta Pia (1561, Rome).

PAINTINGS: "Holy Family" ("Doni Tondo"; *c.* 1503–05; Uffizi, Florence); frescoes, Sistine Chapel ceiling (1508–12; Vatican City); "The Last Judgment" (1534–41; Sistine Chapel); "Conversion of St. Paul" (1542–45; Pauline Chapel, Vatican City); "Crucifixion of St. Peter" (1542–50; Pauline Chapel).

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(C.E.G./Ed.)

Microscopes

The microscope is an instrument that produces enlarged images of small objects, allowing them to be viewed at a scale convenient for examination and analysis. The image may be formed by optical, acoustic, or electronic means, and it is received by direct imaging, electronic processing, or a combination of these methods. The microscope may be static, in which the object is viewed directly, or dynamic, in which the image is built up by successive scans of the object.

The magnifying power of a microscope is an expression of the number of times the object being examined appears to be enlarged. Magnifying power is a dimensionless ratio. The resolution of a microscope is a measure of the size of the smallest detail on the object that can be observed. Resolution is expressed in linear units, usually millimetres.

The most familiar type of microscope is the optical, or light, microscope, in which lenses are used to form the image. Optical microscopes can be simple, consisting of a single lens, or compound, consisting of several optical components in tandem. Simple optical magnifiers may have magnifying powers of from 1 to 10 magnitudes, with resolutions to about 0.01 millimetre (mm) possible. Compound optical microscopes have magnifying powers ranging from about 2.5 to 1,000 magnitudes and provide resolutions of 0.01 to 0.0002 mm.

Other types of microscopes utilize the wave nature of various physical processes, the most important being the electron microscope, which uses a beam of electrons in its image formation. Electron microscopes have magnifying powers of 1,000 to 1,000,000 magnitudes possible, with resolutions ranging from 0.001 to 0.000 000 01 mm. Special microscopes, such as acoustic microscopes or scanning tunneling microscopes, use other physical effects, further extending the range of objects that can be viewed. Indeed, with a scanning tunneling microscope, even individual molecules and atoms can be seen. Some of these specialized microscopes, as well as the more common optical and electron microscopes, are described in this article. A brief history of microscopy is also included.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, section 723, and the *Index*.

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Optical microscopes

THE SIMPLE MICROSCOPE

General considerations. The simple microscope consists of a single or compound lens usually called a magnifier, or loupe. There are many mechanical forms in which a magnifier can be packaged to provide convenience in carrying or in use. For example, when supplied in a mount with a convenient handle, such a lens is frequently called a reading glass. A pair of lenses of low to moderate magnifying power set in a spectacle frame is often used as a magnifying aid for persons with poor vision. Higher magnification lenses are frequently packaged in a cylindrical form that can be held in place immediately in front of the eye. These are generally referred to as eye loupes or jewelers' loupes.

Basically, a simple magnifier permits the user to place his eye close to an object of interest. The closer the object is to the eye, the larger the angle that it subtends at the eye, and thus the larger the object appears. If an object is brought too close, however, the eye can no longer form a clear image. The use of the magnifying lens between the observer and the object enables the formation of a virtual image located a sufficient distance from the eye for the viewer to focus on it. To obtain the best possible image, the magnifier should be placed directly in front of the eye. The object of interest is then brought toward the eye until a clear image of the object is seen. The highest magnification will be achieved when the object is brought to the closest position at which a clear virtual image is observed. For most people, this image distance is about 25 centimetres (roughly 10 inches). As an individual ages, the nearest point of distinct vision recedes to longer distances, thus making a magnifier a useful adjunct to vision for older people.

Magnifying power and field of view

The magnifying power, or extent to which the object being viewed appears enlarged, and the field of view, or size of the object that can be viewed, are related by the geometry of the optical system. An approximate value for the magnifying power of a lens can be found by dividing the least distance of distinct vision (25 centimetres) by the focal length of the lens. Thus, for example, a lens with a focal length of 5 centimetres will have a magnifying power of about 5 magnitudes (often written as 5×).

If the diameter of the magnifying lens is sufficient to fill or exceed the size of the eye pupil, the virtual image that is viewed will appear to be of substantially the same brightness as the original object. The field of view of the magnifier will be determined by the extent to which the magnifying lens exceeds this working diameter, as well as

by the distance of the lens from the eye. The appearance of the magnified virtual image will depend upon both the aberrations present in the lens and the manner in which the lens is used.

Various aberrations influence the sharpness or quality of the image. Chromatic aberrations produce coloured fringes about the high-contrast regions of the image. Spherical aberration produces a fuzzy image. Field curvature requires users to refocus as they look over the field of view. Distortion produces curved lines from straight lines on the object. The type and degree of distortion visible is intimately related to the possible spherical aberration in the magnifier and is usually the most severe in high-power magnifiers.

The aberrations of a lens increase as the relative aperture (*i.e.*, the working diameter divided by the focal length) of the lens is increased. Therefore, the aberrations of a lens whose diameter is twice the focal length will be worse than those of a lens whose diameter is less than the focal length. There is thus a conflict between a short focal length, which permits a high magnifying power but small field of view, and a longer focal length, which provides a lower magnifying power but a larger linear field of view.

Types of magnifiers. There are several types of magnifiers available. The choice of an optical design for a magnifier depends upon the required power and the intended application of the magnifier.

For low powers, about 2–3 magnitudes, a simple double convex lens is applicable. The image can be improved if the lens has specific nonspherical or aspheric surfaces, as can be easily obtained in a plastic molded lens. Some improvement of the distortion is easily noted when an aspheric surface is used, and the manufacture of such low-power aspheric plastic magnifiers is a major industry. In order to make the magnifier lighter in weight, a Fresnel lens can be used. A Fresnel lens, usually of embossed plastic, is in the form of a thin sheet, with the lens curvature placed in a series of concentric grooves on the surface of the sheet. This has many of the same options as a normal simple lens and can have some of the advantages of the aspheric form of the lens. The necessary presence of many symmetrical grooves on the Fresnel lens does reduce the quality of the image through light scattering, however.

Compound lenses

For higher powers of 3–10 magnitudes, there are a number of forms for magnifiers in which the simple lens is replaced by a compound element made up of several lenses mounted and sometimes cemented together. Aspheric surfaces would be useful but are generally quite expensive to use in such compound magnifiers.

A direct improvement in the distortion that may be expected from a magnifier can be obtained by the use of two simple lenses, usually plano-convex (flat on one side, outward-curved on the other). This type of magnifier is based upon the eyepiece of the Huygenian telescope, in which the lateral chromatic aberration is corrected by spacing the elements a focal length apart. Since the imaging properties are provided and shared by two components, the spherical aberration and the distortion of the magnifier are greatly reduced over those of a simple lens of the same power.

A Coddington lens combines two lens elements into a single thick element, with a groove cut in the centre of the element to select the portion of the imaging light with the lowest aberrations. This is a simple and inexpensive design but suffers from the requirement that the working distance of the magnifier be very short.

More complex magnifiers, such as the Steinheil or Hastings forms, use three or more elements to achieve better correction for chromatic aberrations and distortion. In general, a better approach is the use of aspheric surfaces and fewer elements.

THE COMPOUND MICROSCOPE

General considerations. The limitation upon magnifying power imposed by the realities of the geometry of a simple magnifier can be overcome by the use of a compound microscope, in which the image is relayed by two lenses or lens systems (Figures 1 and 2). One lens, called the objective, has a short focal length and is placed close to the object being examined. It is used to form a real image in the front focal plane of the second lens, called an eyepiece, or ocular. The eyepiece then operates in a manner similar to that of the simple magnifier to form an enlarged virtual image that can be viewed by the observer. The magnifying power of the compound microscope is the product of the magnification of the objective lens and that of the eyepiece.

In addition to the two lenses, a basic compound microscope consists of a body tube, in which the lenses can be housed and kept an appropriate distance apart, and an illumination system, which either transmits light through or reflects light from the object being examined. Generally, some method for focusing the microscope must also be provided, as well as a means of supporting and positioning the object to be viewed.

The basic form of a compound microscope is monocular—that is, a single tube is used, with the objective at one end and a single eyepiece at the other. In order to permit viewing with two eyes and thereby increase comfort, a single objective can be employed in a tube with a binocular eyepiece on the other end. The binocular eyepiece has a matched pair of individual eyepiece lenses; beam-splitting prisms are used to send half of the light from the image formed by the objective to each eye. These prisms are mounted in a rotating mechanical assembly so that the separation between the eyepieces can be made to match the required interpupillary distance for the observer. (A stereoscopic microscope is configured by using two objectives and two eyepieces, enabling each eye to view the object separately, making it appear three-dimensional.)

Monocular and binocular microscopes

Optics. There are some obvious geometric limitations that apply to the design of microscope optics. The attainable resolution, or the smallest distance at which two points can be seen as separate, or resolved, when viewed through the microscope, is the first important property. This is generally set by the ability of the eye to discern detail, as well as by the basic physics of image formation.

The eye's ability to ascertain detail is in turn determined by several parameters, including the level of illumination and the degree of contrast between light and dark regions on the object. Under reasonable light conditions, a normal eye with good visual acuity is capable of seeing two high-contrast points if they subtend a visual angle of at least one arc minute in size. Thus, at a nominal viewing distance of

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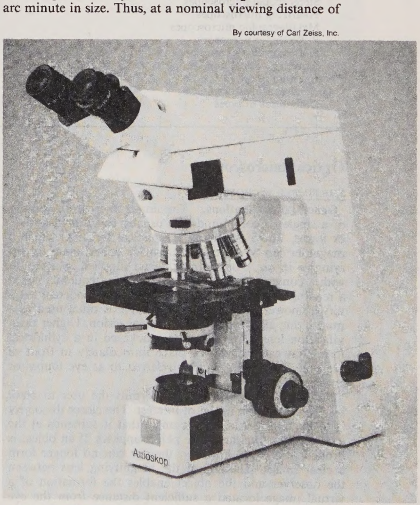


Figure 1: Binocular microscope with a rotating nosepiece.

25 centimetres, the points must be at least 0.1 millimetre apart or the eye will not be able to see them as separate. With a simple magnifier of 10 power, an observer can see two points separated by perhaps 0.01 millimetre. With a compound microscope of 100 power, one might expect the observer to be able to distinguish two points only 0.001 millimetre apart, but an additional complication arises for the high magnifications encountered in a compound microscope. When the dimensions to be resolved approach the wavelength of light, consideration must be given to the effect of diffraction upon the eye's ability to resolve details upon objects (see below *The theory of image formation*).

Numerical aperture

The resolution and the light-collecting capability of the microscope are determined by the numerical aperture of the objective. The numerical aperture is defined as the sine of half the angle of the cone of light from each point of the object that can be accepted by the objective multiplied by the index of refraction of the medium in which the object is immersed. Thus, the numerical aperture increases as the lens becomes larger or the refractive index increases. Typical values for microscope objective numerical apertures range from 0.1 for low-magnification objectives to 0.95 for dry objectives and 1.4 for immersed objectives. A dry objective is one that works with the object in air. An immersion objective requires using a liquid, usually a transparent oil, to fill the space between the object and the first element of the objective.

The limit of resolution is set by the wavelength of light and the numerical aperture. The resolution can be improved either by increasing the numerical aperture of a lens or by using light with a shorter wavelength. In an immersion objective, the effective wavelength of the light is reduced by the index of refraction of the media within which the object being examined resides. The use of immersion imaging techniques in microscopy improves the resolution capabilities of the microscope.

Mechanical components. The microscope tube separates the objective and the eyepiece and assures continuous alignment of the optics. It is a standardized length, which permits objectives and eyepieces of different powers to be interchanged with the assurance that the image quality will be maintained. Traditionally this length has been defined from the end of the screw thread that attaches the objective to the tube to a specific location at the eyepiece end of the tube. A standard length of 160 millimetres was accepted for most uses, and of 250 millimetres for metallographic microscopes. Most microscope objectives are designed to minimize aberrations at one of these distances. Use of other distances will affect the aberration balance for high-magnification objectives. Therefore, focusing of the traditional microscope requires moving the objective, the tube, and the eyepiece as a rigid unit. To achieve this, the entire tube is fitted with a rack-and-pinion mechanism that allows it, together with the objective and the eyepiece, to be moved toward or away from the specimen as needed.

The specimen in question is usually mounted on a glass slide and placed on the microscope stage (located directly below the objective). The stage is generally supplied with a pair of knobs featuring a rack-and-pinion arrangement. This permits the glass slide to be moved across the stage in two directions so that different areas of the specimen can be examined.

The accuracy with which the focusing and the movement of the slide have to be maintained increases as the depth of focus of the objective decreases. For high-numerical-aperture objectives, this depth of focus can be as small as one or two micrometres, which means that the mechanical components must provide stable motion at even smaller increments.

Several approaches have been introduced to achieve such precise stable motion at reasonable cost. Some designers have eliminated the sliding mechanism of the body tube, incorporating adjustments for the vertical movement needed for focusing, as well as the lateral motion of the object, in a single mechanical system. A more common approach has been to mount a relay objective doublet of 160-millimetre focal length into the lower end of the tube. This tube lens is attached to the tube in a fixed position and is designed to accept light from an image relayed by the objective to an infinite distance. The microscope objective itself is then designed to have aberrations corrected for an infinite object distance. An advantage of this approach is that, since the relayed image is at infinity, the microscope objective itself, a very lightweight component, can be moved to effect focusing without upsetting the aberration balance.

Because users of a microscope often desire the ability to choose between objectives of several different magnifications in order to suit the magnification to the requirements of the object, some microscopes are equipped with readily interchangeable nosepieces carrying different objectives. Others feature a rotating nosepiece that carries several objectives in a turret. In many cases, the eyepiece is designed as a portion of a zoom lens, which permits continuous variation of the magnification over a limited range.

The illumination system. The illumination system of the standard optical microscope is designed to transmit light through a translucent object for viewing. In a modern microscope, it consists of a light source, usually an electric lamp of some form, and a lens or lens system known as a condenser. The condenser concentrates the light, providing bright, uniform illumination in the region of the object under observation. Typically, the condenser focuses the image of the light source directly onto the plane of the specimen, a technique called critical illumination, or the image of the source is focused onto the condenser, which is then focused onto the entrance pupil of the microscope objective, a process called Köhler illumination. The advantage of the latter approach is that nonuniformities in the source are averaged in the imaging process. To obtain optimum use of the microscope, it is important that the light from the source both cover the object and fill the entrance aperture of the objective of the microscope. Usually, the quality of the image formation from the condenser is not critical, as it is primarily intended to provide uniform illumination. There are applications, such as phase-contrast imaging, where the quality of the source image is important, however.

The condenser

The objective. The optics of the microscope objective are defined by the focal length, numerical aperture, and field of view. Objectives that have been corrected for aberrations are further defined by the wavelength requirements and the tube length of the microscope.

Manufacturers provide objective lenses with standard

By courtesy of Carl Zeiss, Inc.

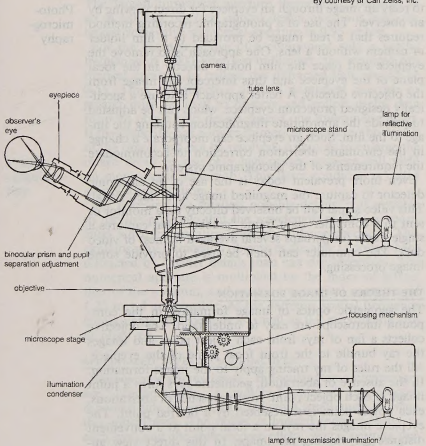


Figure 2: Components of a binocular microscope with a camera attachment.

magnifications ranging from 2× to 100×. The focal length of the objective is inversely proportional to the magnification and, in the majority of modern microscopes, equals the tube length (usually 160 millimetres) divided by the magnification. The field of view of the eyepiece is usually set to be a standard size of about 20-millimetre diameter. The field of view of the objective is then set to range from 10 millimetres for an objective with a magnifying power of 2× to 0.2 millimetres for an objective with a magnification of 100×. As a result, the angular field of view is about a total of 7° for all objectives.

Aberration correction. The numerical aperture and the complexity of the objective increase as the magnification increases. Low-power objectives, of the order of two to five magnitudes, are generally simple two-element, or doublet, lenses. Ordinary crown glass and flint glass (optical glasses with, respectively, low and high refractive indexes) can be used to obtain correction for the spherical aberration and chromatic aberration.

For objectives with magnifying powers of 10×, the required numerical aperture increases to 0.25, and a more complex type of lens is required. Most microscope objectives of this magnification use a separated pair of doublets, sharing the refractive power. The correction of spherical aberration is readily achieved, but residual chromatic aberration is obtained when normal optical glasses are used for the lens elements. For most optical applications, this is not important. For the critical high-magnification microscope objectives (magnifications greater than 25×), this aberration is visible as chromatic blur. The only method of correcting this residual aberration is through the use of special optical glasses whose dispersion properties vary from the normal glasses. There are only a few such glasses or crystalline materials that are useful for this purpose. Objectives designed using these special glasses are called apochromats.

Apochromatic lenses

Most traditional microscope objectives do not produce a flat image surface. The intrinsic field curvature is generally of little importance in the visual use of the microscope because the eye has a reasonable accommodative capability when examining the image. Field curvature is, however, a problem for video or photographic systems. Special objectives with flat-field lenses have been designed for these purposes.

High-power objectives. High-power objectives pose several design problems. Because the focal length of an objective decreases as the numerical aperture and magnifying power increase, the working distance, or distance from the objective to the object, is shortened for higher-power objectives. The need to use additional elements in the lens system for high magnifications further shortens the working distance to only 10 to 20 percent of the focal length. Thus, an objective with a magnification of 40× and a focal length of 4 millimetres may have a working distance of less than 0.4 millimetre, which clearly becomes a problem. A number of objectives with increased working distance have been designed. These use a negative lens element between the object and the eyepiece, which has the added attraction of providing some field flattening as well. These objectives are especially of value in use with video detectors.

In objectives with magnifying powers of 25× or greater, meniscus-shaped aplanatic elements are designed into the microscope objective in the space between the object and the pairs of doublets that carry out the relayed imaging. These aplanatic components have the optical property of converging the light without adding spherical aberration to the image and are important in that they provide some increase in the numerical aperture without introducing considerable additional aberration.

The highest-power microscope objective available is the immersion objective. When this type of objective is used, a drop of oil must be placed between the object on the microscope slide and the bottom of the objective. The objective is then moved toward the slide until it contacts the drop of oil, capturing a region of oil between the slide and the objective. The oil used typically has an index of refraction which matches that of the glass in the first component of the objective and which is greater than that of air. Increasing the refractive index in this way increases the numerical aperture, thus permitting higher magnifications. The first component used in immersion objectives is generally a hyper-hemisphere (a small optical surface shaped like a hemisphere but with a bounding curve exceeding 180 degrees), which acts as an aplanatic coupler between the slide and the rest of the microscope objective. An immersion objective with a high numerical aperture typically consists of a hyper-hemisphere followed by one or two aplanatic collectors and then two or more sets of doublets. Such objectives are made with magnifying powers greater than 50×, the extreme being about 100×.

Depth of focus. The large numerical aperture of most microscope objectives severely restricts the focusing requirements of the objective. The depth of focus is shown in the table as the accuracy with which the focal plane must be located in a direction along the axis of the microscope optics in order that the highest possible resolution can be obtained.

Maximum Resolving Power and Depth of Focus for a Visual Microscope

objective focal length (mm)	numerical aperture (N.A.)	maximum useful magnification in compound microscope	maximum resolution on object (mm)	objective depth of focus (mm)
32	0.10	100×	0.002 5	0.025
16	0.25	250×	0.001	0.003 8
8	0.50	500×	0.000 5	0.000 86
4	0.95	1,000×	0.000 26	0.000 24
3	1.38	1,500× (oil immersion)	0.000 18	0.000 10

The eyepiece. The eyepiece is selected to examine the relayed image under conditions that are comfortable for the viewer. The magnifying power of the eyepiece generally does not exceed 10×. The field of view is then about 40° total, a convenient value for a relatively simple optical design. The observer must place his eye in the exit pupil of the eyepiece, the point at which the light rays leaving the eyepiece come together. In most cases an eye relief (or distance from the exit pupil to the last element of the eyepiece) of about one centimetre is desirable. Too short an eye relief makes viewing difficult for observers who wear corrective eyeglasses.

All the objectives described above are nominally intended to relay an image through an eyepiece for direct viewing by an observer. The use of a photographic recording method requires that a real image be provided to a film holder or camera without a lens. One approach is to remove the eyepiece and place the film holder directly in the focal plane of the eyepiece and thus intercept the image from the objective directly. A better approach is to use a specifically designed projection eyepiece, which can be adjusted to provide the appropriate magnification coupling the image to the film. Such an eyepiece can incorporate a change in the chromatic aberration correction to accommodate the requirements of the photographic system.

Photomicrography

Even more prevalent today is the use of an electronic detector to capture the magnified image as a video signal. This video signal can be observed directly on a monitor or sent to a computer via a frame "grabber" that captures a single frame (or perhaps several averaged frames) of video data. The computer can then be used to provide some image processing.

THE THEORY OF IMAGE FORMATION

The geometric optics of image formation in the compound microscope are easy to understand. The objective collects a fan of rays from each object point and images the ray bundle to the front focal plane of the eyepiece. All the rules of ray tracing apply to the image formation. In the absence of aberration, geometric rays form a point image of each object point. In the presence of aberrations, each object point is represented by a blurred point. The eyepiece images the rays to a focal point at a convenient distance for viewing the image. In this direct view approach, the brightness of the image is determined by the sizes of the apertures of the lenses and by the size of the

pupil of the eye. The focal length and resulting magnification of the objective should be chosen to attain the desired resolution of the object at a size convenient for viewing with the eyepiece.

The actual image formation in the microscope is complicated by the diffraction and interference that take place in the imaging system and by the requirement to use a light source that is imaged into the focal plane.

The modern theory of image formation in the microscope was initiated by the German physicist Ernst Abbe in 1873. The starting point for the Abbe theory is that objects in the focal plane of the microscope are illuminated by convergent light from a condenser. The convergent light from the source can be considered as a collection of many plane waves propagating in a specified set of directions and superimposed to form the incident illumination. Each of these effective plane waves is diffracted by the details in the object plane: the smaller the detail structure of the object, the wider the angle of diffraction.

The structure of the object can be represented as a sum of sinusoidal components. The rapidity of variation in space of the components is defined by the period of each component, or the distance between adjacent peaks in the sinusoidal function. The spatial frequency is the reciprocal of the period. The finer the details, the higher the required spatial frequency of the components representing the object detail. Each spatial frequency component produces diffraction at a specific angle dependent upon the wavelength of light. For example, spatial frequency components having a period of one micrometre would have a spatial frequency of 1,000 lines per millimetre. The angle of diffraction for such a component for visible light with a wavelength of 550 nanometres will be 33.6°.

The microscope objective collects these diffracted waves and directs them to an image plane, where interference between the diffracted waves produces an image of the object. Because the aperture, of the objective is limited in size, not all the diffracted waves from the object can be transmitted by the objective. Abbe showed that the greater the number of diffracted waves reaching the objective, the finer the detail that can be reconstructed in the image. He designated the term numerical aperture as the measure of the objective's ability to collect diffracted light and thus also of its resolving power. On this basis, it is obvious that the greater the magnification of the objective, the greater the required numerical aperture of the objective. The largest numerical aperture theoretically possible in air is 1.0, but practical optical design questions limit the largest achievable numerical aperture to 0.95 or less.

For the example above of a component with a spatial frequency of 1,000 lines per millimetre, the required numerical aperture to collect the diffracted light would be 0.55. Thus, an objective of 0.55 numerical aperture or greater must be used to observe and collect useful data from an object with details spaced one micrometre apart. If the objective has a lower numerical aperture, the details of the object will not be resolved. Attempts to enlarge the image detail by use of a high-power eyepiece will yield no more useful resolution. This latter condition is called empty magnification.

Empty magnification

For resolving the smallest possible details, it is possible to use the principle that the wavelength of light is shortened when propagating through a dense medium. This explains why immersion objectives are able to collect light diffracted by smaller details than can dry objectives. The numerical aperture is multiplied by the index of refraction of the medium, and working numerical apertures of 1.25 to 1.4 are possible. At the extreme, spatial frequency components with periods as small as 0.4 micrometre can be observed.

SPECIALIZED TYPES OF MICROSCOPES

Stereoscopic microscopes. Binocular stereomicroscopes are, fundamentally, a matched pair of microscopes mounted side by side, usually with a small angle between the optical axes. The object is imaged independently to each eye, and the stereoscopic effect, which permits discrimination of height on the object, is retained. The effect can be exaggerated by proper choice of the design parameters for the microscopes. For practical reasons, the magnifying power of such instruments is usually in the range of 5 to 50 magnitudes. These microscopes are important in any work in which fine adjustment of tools or devices is to be made. For example, much use of the stereomicroscope is made in biological laboratories for dissection of subjects and in the operating room for microsurgical procedures. Moderate-power stereomicroscopes are even more widely used in the electronics manufacturing industry, where they enable human workers, as well as computer-controlled machines, to bond leads to tiny integrated-circuit chips.

Polarizing microscopes. Polarizing microscopes are conventional microscopes with additional features that permit measurement of the details of polarization effects. The light source of such an instrument is equipped with a polarizing filter, or polarizer, so that the light it supplies is linearly polarized (*i.e.*, the light waves vibrate in a specific direction rather than randomly in all directions as in ordinary light). When this linearly polarized light passes through the object under examination, it may be unaffected or, if the object is birefringent, it may be split into two beams with different polarizations. A second filter, a polarization analyzer, is fitted to the eyepiece, where it blocks out all but one polarization of the light. The analyzer can be rotated to obtain maximum contrast in the image, and so the direction of polarization of the light transmitted through the object can be determined. The eyepiece can also be equipped with a polarization retarder, which shifts the phase of the light between selected polarization directions and which can be rotated to measure the amount of elliptic polarization produced by the object.

Many precautions must be taken in the design and construction of a polarizing microscope to avoid using optical components that introduce undesirable polarization retardation in the beam of light after it has left the object. There is a basic limitation placed upon the use of objectives with high numerical apertures wherein the necessary high angles of incidence on the surface produce some depolarization. Specialized microscope objectives that minimize this effect have been designed and produced. Polarizing microscopes are primarily used to examine the nature of crystals in geologic samples and to analyze the details of birefringence and stress in biological structures.

Metallographic microscopes. Metallographic microscopes are used to identify defects in metal surfaces and to determine the crystal grain boundaries in metal alloys. This type of microscope employs a type of illumination, called vertical illumination, in which the light source is inserted into the microscope tube below the eyepiece by means of a beam splitter. Light progresses through the objective and is imaged through the objective onto the object. The light reflected or scattered back to the objective is then imaged back at the eyepiece. In this manner, opaque objects such as metals can be examined under the microscope.

Vertical illumination

Reflecting microscopes. Microscopes of this type feature reflecting rather than refracting objectives. They are used to carry out microscopy over a wide range of visible light and especially in the nonvisible ultraviolet or infrared regions, where conventional optical glasses do not transmit. The reflecting microscope objective usually consists of two components, a relatively large, concave primary mirror and a smaller, convex secondary mirror, which is located between the primary mirror and the object and serves to relay the image from the primary mirror to the focal plane of the eyepiece. Although reflecting objectives do not have chromatic aberrations, they usually need to be corrected for spherical aberrations, either by using aspheric reflecting components or by adding appropriate refracting lenses. One disadvantage of the reflecting microscope is that the secondary mirror causes a small obstruction in the centre of the exit pupil of the eyepiece. The shape of the pupil is annular, with out-of-focus blurs having unusual shapes because of the obstruction.

Phase-contrast microscopes. Many biological objects of interest consist of cell walls, cell nuclei, and other structures that are transparent; they transmit as much light as the mounting medium that surrounds them does. Because there is no colour or transmission contrast in such an

object, it is not possible to observe the structure using a conventional microscope. The index of refraction of the structure varies slightly from the surrounding material, however. Thus, the propagation of light through such an object provides a change in the optical path across the object, as well as a resulting shift in the phase of the light that has passed through the structure of interest relative to light passing around the structure. This phase-shift information can be used to form a visible image if it is converted into intensity variations that are detectable by the observer, and in 1934 the Dutch physicist Frits Zernike developed a method for doing just that. In a phase microscope, the phase difference between light that is diffracted by a specimen and light that is direct and undeflected is one-quarter of a wavelength or less. By placing an appropriate mask in the back focal plane of the objective to provide selective filtering of the diffracted light, Zernike increased this phase difference by another quarter wavelength. Waves that differ in phase by half a wavelength cancel one another. In places in the phase image where this occurs, no light is transmitted. As a result, phase differences caused by variations in the specimen appear as intensity variations in the image.

Zernike's contribution

There are several approaches to achieving a good-quality image by this technique. One of the most common is the use of an annular light source imaged onto an annular mask in the back focal plane. Other techniques use edges, small dots, or other combinations of source shape and mask shape.

Scanning optical microscopes. The size of the field of view of a microscope is limited by the geometric optics and by the ability to design optics that provide a constant aberration correction over a large field of view. If a scanning arrangement is used, the objective can be used over a series of small fields, and the results from each field can be used to build up an image of a large region. In addition, scanning permits the acquisition of an image while only a small portion of the field is illuminated at a time. This eliminates extraneous light scattered by objects other than the one of interest in the centre of the field.

The simplest design for a scanning microscope is using a microscope in a reverse direction. The light source is focused by a condenser upon a small aperture. The light passing through this aperture is in turn focused on the object by the objective to form a small spot with very little diffraction. The light transmitted by the object being examined is then collected by a condenser working in reverse, with a photodetector located at the point where a light source would normally be located. The object is scanned in a raster pattern, and the varying electrical signal from the photodetector is collected and displayed on a monitor. Since the only light passing through the object at each point is the light used in forming each picture element, extraneous light scattered by the object is eliminated, and considerably higher contrast in the image is obtained.

Variants in scanning patterns include employing a rapid scan over a short distance along a slowly moving object. Usually a high-speed rotating mirror is used to move the illuminated spot repeatedly over a line crossing the object. A slower, but synchronized, motion moves the object past the high-speed scanned line. This scanning method requires the use of an objective with sufficient field coverage to accommodate only the high-speed scan line length.

Scanning microscopes can be used for detailed investigation of the properties of objects, including the evaluation of spectral absorption by collecting light of different colours at each point in the scanning. An additional possibility is the measurement of fluorescence effects, in which the incoming light is blocked by a filter that permits only the fluorescent colours to reach the photodetector.

Confocal scanning microscopy

The most interesting new development in scanning optical microscopy is confocal scanning microscopy. In this technique, two microscopes are used, examining the same region of an object from opposite sides of the object. A small illuminated aperture is focused onto the object by the illuminating microscope. The receiving microscope is configured identically, with a photodetector following a small aperture in the magnified focal plane of the receiving microscope. The two microscopes are adjusted to focus on the same region in space. This effectively prevents any extraneous light or any light scattered at the confocal image region from reaching the detector. The object is then scanned to build up an image from the detected signal.

The confocal scanning microscope has the unique ability to produce images of a single plane, or optical section, of an object. Because the rejection of scattered and extraneous light is excellent in the confocal arrangement, the image is formed only by light from a specific region. If several scans are made with the pair of microscopes successively focused upon different depth planes in the object, a three-dimensional structure can be inferred from this complete set of imagery. (R.R.Sh.)

Electron microscopes

GENERAL CONSIDERATIONS

Fundamental research by many physicists in the first quarter of the 20th century suggested that cathode rays (*i.e.,* electrons) might be used in some way to increase microscope resolution. Louis de Broglie, a French physicist, in 1924 opened the way with the suggestion that electron beams might be regarded as a form of wave motion. De Broglie derived the formula for their wavelength, which showed, for example, that, for electrons accelerated by 60,000 volts, the effective wavelength would be 0.05 angstrom—*i.e.,* 1/100,000 that of green light. If such waves could be used in a microscope, then a valuable increase in resolution would result. In 1926 it was demonstrated that magnetic or electrostatic fields could serve as lenses for electrons or other charged particles, and this discovery initiated the study of electron optics. In 1931 a two-lens electron microscope was devised. It produced enlarged images of the electron source. Later, in 1933, a true electron microscope was built. A year or so later, the resolution of the optical microscope was surpassed, but the specimen was severely damaged by the heating effects of the electron beam, a problem that was not solved for some years. In 1935 the construction of the first commercially built electron microscope was begun in England, and it was soon followed by the production of microscopes in Germany and the United States. Progress in the construction of electron microscopes was rapid, with a great impetus to the achievement of high resolution being the introduction, in 1946, of a device called a stigmator, which compensates for astigmatism of the objective lens.

Electron microscopes are now available that are easy to operate and reliable and that give point-to-point resolutions of less than 0.2 nanometre (Figure 3). Such high resolutions, coupled with suitable advances in the methods of specimen preparation, permit the direct visualization of many molecules and some atoms. There are two basic types of electron microscope: the transmission electron microscope (TEM), which can only image specimens a fraction of a micrometre or less in thickness, and the scanning electron microscope (SEM), in which a beam of electrons is scanned over the surface of a solid object and used to build up an image of the details of the surface structure. There are also several special types of electron microscope. Among the most valuable is the electron-probe microanalyzer, which allows a chemical analysis of the composition of materials to be made by using the incident electron beam to excite the emission of characteristic X radiation by the various elements composing the specimen. These X rays are detected and analyzed by spectrometers built into the instrument. Such probe microanalyzers are able to produce an electron scanning image so that structure and composition may be easily correlated.

Types of electron microscopes

Differences of types. There are many differences between optical and electron microscopes. The electron microscope requires that the electron beam be in a vacuum, because electrons cannot travel any appreciable distance in air at atmospheric pressure. The column of the electron microscope is evacuated by pumps, and the specimen, photographic plates, and any other necessary apparatus are introduced into the vacuum by means of air locks. Unlike the optical microscope, in which the lenses are of fixed focus and the distance between specimen and objective lens is varied, the electron microscope has variable-

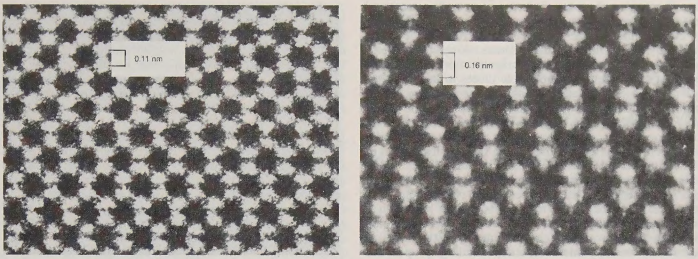


Figure 3: Micrographs, taken with a transmission electron microscope, showing the atomic structure of (left) the diamond surface designated (110) and (right) the silicon surface designated (110). Both images show a spacing of about 0.1 nanometre clearly resolved.
By courtesy of Prof. Hiroshi Fujita, Osaka University

focus lenses, and the distance between specimen and objective lens and separation of the lenses remain constant. The magnification is determined mainly by the value of the current (for magnetic lenses) through the intermediate and projector lens coils. The image is focused by changing the current through the objective lens coil. Another difference is that the optical microscope is usually operated so that the image is a virtual one, while in the electron microscope the final image is invariably real and is visualized on a fluorescent screen or recorded for study on a photographic plate.

In the optical microscope the image is formed by absorption of light in the specimen; in the electron microscope the image results from a scattering of electrons by atoms in the specimen. A heavy atom is more effective in scattering than one of low atomic number, and the presence of heavy atoms will increase the image contrast. The electron microscopist may incorporate more heavy atoms into the specimen for this purpose.

Lenses. Although early microscopes relied on electrostatic lenses, modern instruments use electromagnetic lenses. These consist of a solenoid of wire together with a magnetic pole piece that concentrates and shapes the magnetic field. The lenses used for the condenser and for the projector system of the microscope differ from the objective lens only in details. For example, the manufacturing and performance tolerances for a condenser or projector lens are less demanding than for an objective lens.

Efforts to improve the resolution of the electron microscope have tended toward production of a single-field condenser-objective lens of low aberrations. In such a lens, the upper part acts as a condenser and the lower as the objective; the specimen is inserted into the centre of the lens, where the axial magnetic field (the field along the axis of the instrument) is at a maximum.

Electron lens aberrations

All electron-optical lenses show spherical aberration, distortion, coma, astigmatism, curvature of field, and chromatic aberration due to variations in the wavelengths of the electrons. Such changes of electron velocity may be due either to variations in the high-voltage supply to the electron gun or to energy losses from collisions of electrons with atoms in the specimen. The first effect may be minimized by careful stabilization of the high-voltage supply, and, for the very thin specimens and the high electron energies commonly used, the second effect may usually be neglected. The resolving power of the microscope is ultimately limited by the spherical aberration of the objective lens. It is not possible to correct this aberration by adding a second lens of opposite characteristics, as can be done for the optical microscope, because magnetic electron lenses are always convergent. Computer-aided lens design has led to great improvements in performance, but electron lenses still require much smaller numerical apertures than do optical lenses in order to function optimally.

Astigmatism in the electron microscope is largely due to deviations from cylindrical symmetry in the radial components of the magnetic field of the lens and is the result of imperfect construction of the lens. The interaction of the electron beam with residual gas molecules in the column may also lead to deposits along the beam path that charge up under the influence of the beam and introduce asymmetries. Astigmatism may usually be completely corrected by use of the stigmators fitted to the objective lens.

THE TRANSMISSION ELECTRON MICROSCOPE

Principal components

The transmission electron microscope has three essential systems: (1) an electron gun, which produces the electron beam, and the condenser system, which focuses the beam onto the object, (2) the image-producing system, consisting of the objective lens, movable specimen stage, and intermediate and projector lenses, which focus the electrons passing through the specimen to form a real, highly magnified image, and (3) the image-recording system, which converts the electron image into some form perceptible to the human eye. It usually consists of a fluorescent screen for viewing and focusing the image and a camera for permanent records. In addition, a vacuum system, consisting of pumps and their associated gauges and valves, and power supplies are required.

The electron gun and condenser system. The source of electrons, the cathode, is a heated, V-shaped tungsten filament or, in high-performance instruments, a sharply pointed rod of lanthanum hexaboride. The filament is surrounded by a control grid, sometimes called a Wehnelt cylinder, with a central aperture arranged on the axis of the column; the apex of the cathode is arranged to lie at or just above or below this aperture. The cathode and control grid are at a negative potential equal to the desired accelerating voltage and are insulated from the rest of the instrument. The final electrode of the electron gun is the anode, which takes the form of a disk with an axial hole. Electrons leave the cathode and shield, accelerate toward the anode, and, if the stabilization of the high voltage is adequate, pass through the central aperture at a constant energy. The control and alignment of the electron gun are critical in ensuring satisfactory operation.

The intensity and angular aperture of the beam are controlled by the condenser lens system between the gun and the specimen. A single lens may be used to converge the beam onto the object, but, more commonly, a double condenser is employed. In this the first lens is strong and produces a reduced image of the source, which is then imaged by the second lens onto the object. Such an arrangement is economical of space between the electron gun and the object stage and is more flexible, because the reduction in size of the image of the source (and hence the final size of illuminated area on the specimen) may be varied widely by controlling the first lens. The use of a small spot size minimizes disturbances in the specimen due to heating and irradiation.

The image-producing system. The specimen, mounted on a copper grid, is carried in a small holder in a movable specimen stage that allows an area of up to three millimetres in diameter to be examined. The objective lens is

usually of short focal length (one to five millimetres) and produces a real intermediate image with a magnification of 20–200 magnitudes. This image is in turn further magnified by the projector lens or lenses. A single projector lens may provide a range of magnification of 5:1, and by the use of interchangeable pole pieces in the projector a wider range of magnifications may be obtained. Modern instruments employ two projector lenses (one called the intermediate lens) to permit a greater range of magnification and to provide a greater overall magnification without a commensurate increase in the physical length of the column of the microscope.

For practical reasons of image stability and brightness, the microscope is often operated to give a final magnification of 1,000–250,000 magnitudes on the screen. If a higher final magnification is required, it may be obtained by photographic enlargement. The quality of the final image in the electron microscope depends largely upon the accuracy of the various mechanical and electrical adjustments with which the various lenses are aligned to one another and to the illuminating system. The lenses require power supplies of a high degree of stability; for the highest standard of resolution, electronic stabilization to better than one part in a million is necessary.

Image quality

Image recording. The electron image must be made visible to the eye by allowing the electrons to fall on a fluorescent screen fitted at the base of the microscope column. Such a screen is satisfactory for quick observations and for focusing and aligning the instrument. A low-power binocular optical microscope fitted outside the column allows the image on the screen to be inspected at a magnification of about 10 magnitudes, but the image suffers from poor contrast, lack of brightness, and the inherent grain of the screen. By allowing the electrons to fall on the emulsion of a photographic plate, the latent image can then be developed and fixed exactly as in ordinary photography, and prints at any degree of further enlargement may be obtained from the negative. Such further enlargement allows all the detail present in the image to be resolved by the eye and also allows some control over the contrast.

Image-intensification systems have been developed using some form of television tube, with the final image presented on a cathode-ray-tube monitor. Because image intensifiers permit electronic amplification, beam currents that are too low to register an image for direct viewing on a fluorescent screen may be used to permit examination of materials susceptible to radiation damage, such as polymers and biological tissue.

THE SCANNING ELECTRON MICROSCOPE

The scanning electron microscope, designed for directly studying the surfaces of solid objects, utilizes a beam of focused electrons (of 5–25 kilovolts energy) as an electron probe that is scanned in a regular manner over the specimen. The electron source and electromagnetic lenses that generate and focus the beam are similar to those described for the transmission electron microscope (Figure 4). The action of the electron beam stimulates emission of high-energy backscattered electrons and low-energy secondary electrons from the surface of the specimen. These are collected and passed to a scintillator, which produces light when bombarded with electrons. The light is passed to a photomultiplier tube, where it is converted back to an electric signal with an effective gain of 10,000 times or more. The resultant amplified current is used, in turn, to modulate the brightness of a display cathode-ray (television) tube that is scanned in synchronism with the probe beam in the microscope column. There is thus a one-to-one relation between the brightness of each point on the display tube and the number of electrons emitted from the corresponding point on the surface of the specimen. In this way, a map of the specimen is built up, with a magnification equal to the ratio between the sizes of the picture on the display tube and the area scanned by the probe. In modern instruments, a point-to-point resolution of one nanometre is attainable (Figure 5).

No elaborate specimen-preparation techniques are required for examination in the scanning electron microscope, and large and bulky specimens may be accommodated. It is desirable that the specimen be rendered

Preparation of specimens

By courtesy of JEOL U.S.A., Inc.

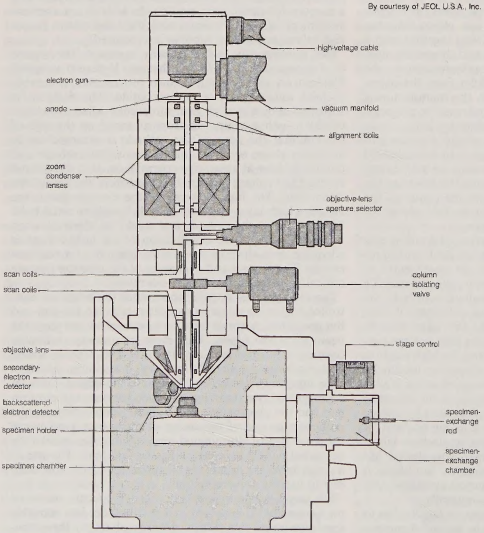


Figure 4: Components of a scanning electron microscope.

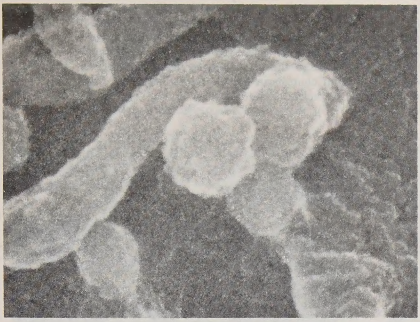


Figure 5: Micrograph of AIDS viruses on a human T-9 cell, taken with a scanning electron microscope.
Custom Medical Stock Photo/Dr. R. Becker

electrically conducting, otherwise a sharp picture will not be obtained. Conductivity is usually achieved by evaporating a film of metal 50 to 100 angstroms thick onto the specimen in a vacuum (such a thickness does not materially affect the resolution of the surface details). If, however, the scanning electron microscope can be operated at between one and three kilovolts of energy, then even nonconducting specimens may be examined without the need for a metallic coating.

Scanning instruments have been combined with transmission electron microscopes to form scanning transmission electron microscopes. These have the advantages that very thick sections may be studied without chromatic aberration limitation and that electronic methods may be used to enhance the contrast and brightness of the image.

HIGH-VOLTAGE INSTRUMENTS

Several different types of instrument have been constructed to operate at accelerating voltages in excess of the 200–300 kilovolts normally used in the conventional transmission instrument. High-voltage microscopes now in commercial production are designed for accelerating voltages of up to 1,500 kilovolts.

These instruments have several advantages over the conventional TEM: (1) the theoretical resolving power of the instrument increases as the accelerating voltage increases; (2) thick specimens are easily penetrated by the beam; (3) chromatic aberration caused by energy losses and scattering in the specimen is decreased; and (4) specimen heating and irradiation damage of organic samples are decreased. Many metals and semiconductors suffer increased damage at these high energies, however, because the incident electrons may knock an atom from its correct position in the crystal lattice.

Although the gain in resolution at 1,000 kilovolts is theoretically about two and a half times that of a 100-kilovolt instrument, such increases have not been fully achieved in practice. It is primarily for the increased penetrating power and consequent reduction in chromatic aberration that the high-voltage instruments are used, as, for example, in the study of metals and alloys. Some biological systems, such as bacteria and whole cells, may also be examined with advantage at high voltage.

THE ELECTRON-PROBE MICROANALYZER

A limitation of the conventional electron microscope is that it provides no chemical information. Electron-probe microanalyzers have been developed (since 1947) to carry out nondestructive elemental analysis at resolutions approaching those of the transmission electron microscope. This is done by measuring the energy and intensity of the characteristic X rays emitted by a specimen when a focused electron beam impinges on it. As in the scanning electron microscope, the probe is scanned so that an image of the distribution of a chosen element may be built up on a cathode-ray tube.

X-ray microprobe analysis has proven to be so valuable that a majority of scanning electron microscopes, as well as many transmission electron microscopes, are now equipped with X-ray spectrometers as accessories. The technique has found wide applications in mineralogy, metallurgy, and solid-state science, as well as in the clinical and life sciences.

X-ray microprobe analysis

THE FIELD-EMISSION MICROSCOPE

In this instrument a wire with a sharpened tip is mounted in a cathode-ray tube. Electrons are drawn from the tip by a high electrical field and travel toward the screen on which the image is formed. Only strong metals, such as tungsten, platinum, and molybdenum, can be examined in this way because the high field at the tip exerts a large mechanical stress. The magnification is proportional to the ratio of the radius of curvature of the screen on which the image forms to the radius of the metal tip; it may reach up to one million magnitudes.

A development of the field-emission microscope is the field-ion microscope, in which the tip is surrounded by a low pressure of helium gas. The gas is ionized at the atom planes on the tip and produces an image that can have a magnification of up to 10 million magnitudes. The field-ion microscope has been applied mainly to the study of metals and semiconductors, but a few biological images have been obtained. A further development of the field-ion microscope is the atom probe. In this instrument, individual atoms are removed from the tip by pulsing the electric field. The atoms pass through a time-of-flight spectrometer, which measures their energy and charge-to-mass ratio. In this way, the chemical nature of each atom in the field-ion image may be determined.

OTHER PARTICLE MICROSCOPES

In principle, microscopes can be made that utilize any beam of energetic particles, and instruments employing ions, protons, and positrons have been demonstrated. The efficiency of the practical sources of such beams is very low by comparison with those of electrons, however, and consequently the application of such microscopes has been restricted to specialized studies. (S.Br./Da.C.J.)

Acoustic microscopes

GENERAL CONSIDERATIONS

The optical microscope reveals much of the microscopic world, but its domain is restricted; it does not include opaque materials, opalescent liquids, nor media that absorb light completely. Sergei Y. Sokolov at the V.I. Ulyanov (Lenin) Electrotechnical Institute, Leningrad, suggested that these restrictions could be lifted if sound waves were used in a new form of microscope. Sokolov recognized that a microscope using sound waves with a frequency of 3,000 megahertz (MHz) would have a resolution equal to that of the optical microscope. He advanced his idea in the early 1940s, at a time when the required technology did not exist. Since then, however, the technology has been developed, and the high frequencies required for Sokolov's microscope are found in the microwave systems used for radar and for satellite communications. During the 1970s, several groups of researchers in the United States employed these frequencies to build sound systems. The microscope that evolved from this effort is known as the scanning acoustic microscope.

Sound is a term commonly associated with the waves in air that can be detected by the human ear. The phenomenon is more general, however; sound waves travel through liquids and solids as well. The descriptive term "acoustics" is used for these waves. Acoustic waves easily propagate through materials impervious to optical waves. The energy is carried by the periodic motion of particles, where alternate regions of compression and rarefaction move through the media at the velocity of sound.

The differences between the optical and acoustic instruments can be clarified with a short description of three

Characteristics of waves

parameters used to characterize waves—wavelength, wave velocity, and frequency. These parameters are easily visualized by observing ocean waves. The wavelength is the distance between the crests, the wave velocity is the speed of the moving crests, and the frequency is the frequency of impact of the crests on the shoreline. If the spacing between crests is 10 metres and if they move with a velocity of 10 metres per second, the crests will hit the shoreline with a frequency of 1 per second. If the velocity is reduced to 0.1 metre per second and a distance of 10 metres is maintained between crests, the frequency of impact will be reduced to 0.1 per second. Similarly, in sound systems, where the velocity is reduced by a factor of 100,000 below the velocity of optical waves, the acoustic wavelength is comparable to the optical wavelength if the sound frequency is reduced by the same factor of 100,000 below the frequency of optical waves. The resolution of an acoustic microscope operating at 3,000 MHz is equal to the resolution of the optical microscope.

INSTRUMENTATION

The instrumentation of an acoustic microscope is completely different from that of a traditional optical microscope. The central component of the acoustic system is a small sapphire rod. A thin film of piezoelectric material is deposited on the flat end of the sapphire crystal, and a spherical depression on the opposite end of the crystal rod acts as the lens. The endface with the cavity is immersed in water, along with the specimen. The thin film of piezoelectric material, usually zinc oxide (ZnO), expands and contracts when a periodic electric field is applied across it. The film acts as a transducer to convert electromagnetic energy into acoustic energy. The periodic expansions then travel through the crystal as acoustic waves.

The acoustic velocity in water is less than it is in sapphire, and the waves that cross the crystal-water interface are refracted through a large angle. The refraction is so large that the plane waves in the sapphire rod are converted in the liquid into spherical waves that converge to a narrow "waist," or focus, near the centre of curvature of the spherical lens. In a scanning system, the minimum resolvable feature is determined by the waist diameter. The diameter of the acoustic beam at the waist is less than one wavelength.

The elastic properties of the sample are examined with the acoustic beam that emerges from the lens. The examination is carried out point by point by mechanically scanning the lens over the area under investigation. The waves reflected from the sample travel back through the liquid, through the lens, and through the crystal to the ZnO transducer. There they are reconverted into electrical signals. In this way, the energy is quickly transferred into and out of the acoustic system. The images are displayed on the screen of a monitor and recorded by photographing the display on the screen. Mechanical scanning, together with the reconversion to electronic signals, forms the analog to the photographic film of an optical microscope.

In another configuration, a cylindrical lens is used to focus the acoustic energy into a narrow line. It is used to measure features on the surface along a given direction and characterize the anisotropic properties of surfaces.

Types of acoustic waves used

The acoustic microscope utilizes three types of acoustic waves in its various operating modes; these are (1) longitudinal waves, in which the particle motion is in the direction of wave motion, (2) shear waves, in which the particle motion is transverse to the direction of wave motion, and (3) surface waves, in which the energy clings to the interface between the sample and the liquid. (The surface wave, first described by the 19th-century scientist Lord Rayleigh, now bears his name.)

Longitudinal waves are employed in the most common mode, where the acoustic pulse reflected from the sample surface is recorded for each position of the probing beam. Changes in the elastic properties of the sample show up as differences in both amplitude and phase of the reflected signal.

Rayleigh waves are extraordinarily effective in enhancing the contrast for obscure surface structure. When the incident beam is defocused by moving the lens toward the sample, the longitudinal waves in the liquid are coupled to the surface waves on the sample interface. In this circumstance, the interchange of energy between the longitudinal and surface modes combine in such a way as to create an interference pattern at the transducer. These patterns are sensitive to small changes in the elastic properties of the surface. Minute cracks or scratches show up with excellent contrast (Figure 6).

By courtesy of Olympus Optical Co., Ltd.

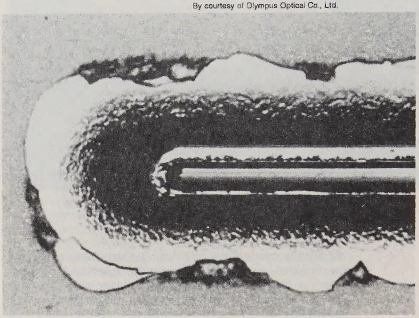


Figure 6: Micrograph, taken with an acoustic microscope operating at 200 MHz, of aluminum coating on a metal plate. The coating is only a few micrometres thick. The centre sharp line in the image is the trace of a scratch with a steel ball; the white area surrounding the line is the coating that is peeling.

The range of acoustic microscopy

The electronic components in the acoustic microscope are adapted from the technology used to generate the short pulses of radio-frequency energy in radar systems. The system operates with coherent signals over a wide range of frequencies. In water, the frequency range extends from 5 to 5,000 MHz; the wavelength ranges from 300 to 0.3 micrometres. Cryogenic instruments with liquid helium as the working fluid are used to extend the system to even shorter wavelengths. The velocity of sound in helium is about one-sixth that of water, which means that the wavelength is reduced by the same factor. Furthermore, at very low temperatures (near 0.1 K, or −459° F), the sound absorption in helium is less than it is in water. These two factors have been exploited to build an instrument operating at 16,000 MHz with a resolution of 15 nanometres.

APPLICATIONS

The acoustic microscope is employed for different purposes at the different frequency ranges. At higher frequencies, it is used primarily to study the elastic properties of surfaces and the internal constituents of biological cells. At lower frequencies, below 500 MHz, where the acoustic energy penetrates deeply into the sample, the instrument is used to reveal the structures that lie beneath the surface.

The acoustic microscope is especially effective for identifying defects in various materials. For example, a metal heat sink of some kind is used to dissipate the heat in silicon devices that generate power. These devices are attached to the heat sink with a thin layer of solder. Inhomogeneities and imperfections in the solder layer will decrease the amount of heat transferred to the heat sink, increase the temperature, and degrade the operation. When the layer of solder is examined with an acoustic microscope, the inhomogeneities show up with strong contrast.

Another example occurs in the fabrication of silicon devices, in which thin films of metals and oxides are frequently deposited on the silicon surface. The adhesion between the film and the substrate is a parameter that must be controlled. If this adhesion is faulty, the reflection coefficient for the acoustic waves is increased, and the defective sections are thus sharply defined in the images.

Some of the other unique and valuable applications of the acoustic microscope include examining the integrity

of the bonds between layers in laminated and composite materials, studying the density and distribution of glass and carbon fibres used to strengthen composite materials, detecting the presence of microcracks and voids near the surface, and monitoring the strain associated with the fabrication of microstructures.

Scanning tunneling microscopes

Basic operation

The scanning tunneling microscope (STM) appeared in 1981 when Gerd Binnig and Heinrich Rohrer of the IBM Zürich Research Laboratory in Rüschlikon, Switz., set out to build a tool for studying the local conductivity of surfaces. Its principle of operation is based on the quantum mechanical phenomenon known as tunneling, in which the wavelike properties of electrons permit them to "tunnel" beyond the surface of a solid into regions of space that are forbidden to them under the rules of classical physics. The probability of finding such tunneling electrons decreases exponentially as the distance from the surface increases. The scanning tunneling microscope makes use of this extreme sensitivity to distance. The sharp tip of a tungsten needle is positioned a few angstroms from the sample surface. A small voltage is applied between the probe tip and the surface, causing electrons to tunnel across the gap. As the probe is scanned over the surface, it registers variations in the tunneling current, and this information can be processed to provide a topographical image of the surface.

Binnig and Rohrer chose the surface of gold for their first image. When the image was displayed on the screen of a television monitor, they saw rows of precisely spaced atoms and observed broad terraces separated by steps one atom in height. Binnig and Rohrer had discovered in the scanning tunneling microscope a simple method for creating a direct image of the atomic structure of surfaces. Their discovery opened a new era for surface science, and their impressive achievement was recognized with the award of the Nobel Prize for Physics in 1986.

INSTRUMENTATION

The advance of this new form for surface microscopy was impeded by four instrumental problems: (1) the isolation of the experiment from the natural vibrations that are present in every laboratory, (2) the approach of the probe tip to the sample surface, (3) the scanning of the probe across the sample surface, and (4) the sharpening of the tip. The techniques that Binnig and Rohrer employed to solve these problems are elegant and straightforward and are briefly described here. Their solutions are used almost unaltered to the present time.

The sample and the scanning probe are protected from vibrations by being placed on a stage that is suspended from springs within another section or stage. This outer stage is in turn suspended from springs within a stainless steel frame. The structure is equipped with magnets and copper plates that will, if necessary, induce eddy currents that damp any motion of the stages. The placement and scanning movement of the probe are controlled by a tripod made of piezoelectric materials (which expand or contract when voltage is applied) and by a piezoelectric plate with three metal feet that can be fastened to a metal plate carrying the sample. Applying voltage to one leg of the tripod (or to the piezoelectric plate) causes the other tripod legs (or one or more of the metal feet) to move slightly. Both the direction and the magnitude of this movement can be precisely controlled. The probe is sharpened by applying a strong electric field; this dislodges the surface atoms of the tip until only a few (ideally, one) remain.

Differences between the STM and the SEM

The scanning tunneling microscope is an electron microscope with a resolution sufficient to resolve single atoms. The sharp tip in the STM is similar to that in the scanning electron microscope, but the differences in the two instruments are profound. In the SEM, electrons are extracted from the tip with a series of positively charged plates placed a few centimetres downstream from the tip. The electrons at the apex of the tip are confined to the region within the metal by a potential barrier. The attractive force from the positive charge on the plates is sufficient to permit the electrons to overcome the barrier and enter the vacuum as free particles. The apertures in the downstream plates form an electron lens that converts the diverging beam from the tip into a beam converging to a focus on the surface of the sample.

In the STM, the setup is much simpler. The plates that form the lens in the SEM are removed, and the tip is positioned close to the sample. The electrons move through the barrier in a way that is similar to the motion of electrons in a metal. In metals, electrons appear to be freely moving particles, but this is illusory. In reality, the electrons move from atom to atom by tunneling through the potential barrier between two atomic sites. In a typical case, with the atoms spaced five angstroms apart, there is a finite probability that the electron will penetrate the barrier and move to the adjacent atom. The electrons are in motion around the nucleus, and they approach the barrier with a frequency of 10^{17} per second. For each approach to the barrier, the probability of tunneling is 10^{-4}, and the electrons cross the barrier at the rate of 10^{13} per second. This high rate of transfer means that the motion is essentially continuous and tunneling can be ignored in metals.

Tunneling cannot be ignored in the STM; it is all-important. When the tip is moved close to the sample, the spacing between the tip and the surface is reduced to a value comparable to the spacing between neighbouring atoms in the lattice. In this circumstance, the tunneling electron can move either to the adjacent atoms in the lattice or to the atom on the tip of the probe. The tunneling current to the tip measures the density of electrons at the surface of the sample, and this information is displayed in the image. In semiconductors, such as silicon, the electron density reaches a maximum near the atomic sites. The density maxima appear as bright spots in the image, and these define the spatial distribution of atoms. In metals, on the other hand, the electronic charge is uniformly distributed over the entire surface. The tunneling current image should show a uniform background, but this is not the case. The interaction between tip and sample perturbs the electron density to the extent that the tunneling current is slightly increased when the tip is positioned directly above a surface atom. The periodic array of atoms is clearly visible in the images of materials such as gold, platinum, silver, nickel, and copper.

APPLICATIONS

Several surfaces have been studied with the STM. The arrangement of individual atoms on the metal surfaces of gold, platinum, nickel, and copper have all been accurately documented (Figure 7). The absorption and diffusion of different species such as oxygen and the epitaxial growth of gold on gold, silver on gold, and nickel on gold also have been examined in detail.

The surfaces of silicon have been studied more extensively than those of any other material. The surfaces are

By courtesy of C.A. Lang, Stanford University

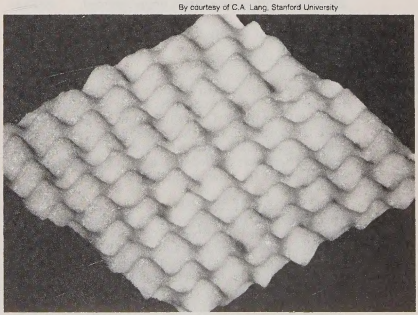


Figure 7: The atomic structure of the (111) surface of gold as revealed by a scanning tunneling microscope.

Surface reconstruction

prepared by being heated in vacuum to temperatures so high that the atoms there rearrange their positions in a process called "surface reconstruction." The reconstruction of the silicon surface designated (111) has been studied in minute detail. Such a surface reconstructs into an intricate and complex pattern known as the "Takayanagi" 7×7 structure. The position, the chemical reactivity, and the electronic configuration of each atomic site on the 7×7 surface has been measured with the STM. The reconstruction of the silicon surface designated (100) is more simple. The surface atoms form pairs, or dimers, that fit into rows that extend across the entire silicon surface.

The initial stages in the formation of interfaces between silicon and metal layers have been the subject of numerous STM studies. The atomic structure of these modified surfaces has been catalogued for such metals as gallium, indium, aluminum, gold, and silver.

The internal structure and organized behaviour of molecules deposited on graphite and gold substrates are easily imaged in the STM. The study of alkane molecules and the molecules of liquid crystals constitutes much of the definitive work with the STM. Biological molecules are attracting attention, and definitive studies of these molecules should be forthcoming.

"Vacuum tunneling" of electrons from tip to sample can take place even though the environment in the region surrounding the tip is not a vacuum but is filled with molecules of gas or liquids. With a tip-sample spacing as small as five angstroms, there is little room for molecules—even though they may exist in the surrounding atmosphere. The STM can operate in ambient atmosphere as well as in high vacuum. Indeed, it has been operated in air, in water, in insulating fluids, and in the ionic solutions used in electrochemistry. It is much more convenient than ultrahigh-vacuum instruments. When a high-vacuum environment is employed, its purpose is not to improve the performance of the STM but rather to ensure the cleanliness of the sample surface.

The STM can be cooled to temperatures less than 4 K—the temperature of liquid helium. It can be heated above 500° C (973 K). The low temperature is used to investigate the properties of superconducting materials, while the high temperature is employed to study the rapid diffusion of atoms across the surface of metals and their corrosion.

The STM is used primarily for imaging, but there are many other modalities that have been explored. The strong electric field between tip and sample has been utilized to move atoms along the sample surface. It has been used to enhance the etching rates in various gases. In one instance, a voltage of four volts was applied; the field at the tip was strong enough to remove atoms from the tip and deposit them on the substrate. This procedure has been employed with a gold tip to fabricate small gold islands or clusters on the substrate with several hundred atoms of gold in each cluster. These so-called nanostructures are used to pattern the surface with a scale that is unprecedented. (C.F.Q.)

Development of the microscope

THE SIMPLE MICROSCOPE

Earliest microscopes

The earliest simple microscopes used drops of water captured in a small hole to function as a magnifying lens. It is not clear when crude glass lenses first began to be employed, but by the 17th century Antonie van Leeuwenhoek, a Dutch scientist, had developed techniques for making good-quality ground lenses for simple microscopes. These were limited in magnifying power and were used primarily for botanical studies.

THE COMPOUND MICROSCOPE

The compound microscope, using an objective and an eyepiece, was first described in the 16th century, but all drawings of the period indicate very impractical arrangements of lenses. The first useful compound microscope was constructed in the Netherlands sometime between 1590 and 1608. Three spectacle makers—Hans Jansen, his son Zacharias, and Hans Lippershey—have each received credit for the invention. This early microscope was limited by the use of very simple lenses, and the resolution was limited by blurring due to spherical aberration and chromatic aberration.

Further development of the compound microscope in the 17th and 18th centuries occurred primarily in England and Italy, albeit along slightly different paths. Many Italian instruments were designed for the examination of opaque objects by use of reflected light. The Italian microscope designer Eustachio Divini introduced the idea of using two plano-convex lenses to form an eyepiece that permitted some aberration correction. Many mechanical innovations, including equipping body tubes with screw-thread focusing mechanisms and using spring stages to hold specimen slides, were developed by the Italian microscopists.

In England the 17th-century scientist Robert Hooke introduced several techniques for improving the quality of microscopes. His instruments began a trend in England toward the development of elegant devices, incorporating many mechanical advances. English optics, however, continued to be constructed of simple lenses that suffered from spherical aberration and chromatic aberration. The spherical aberration could be limited somewhat by placing a stop (a disk with a small central aperture) behind the lens; but the chromatic aberration, which was believed to be intrinsic to refracting lenses, remained uncorrected until 1733, when Chester Moor Hall, an amateur optician, found by trial and error that combining a convex crown glass lens with a concave lens made of new lead-containing flint glass corrected the problem. While the original invention was intended for making achromatic telescope lenses, several workers recognized the application to microscopes, and in 1774 Benjamin Martin used a set of achromats for a microscope objective. This led to major improvements in the quality of microscope images and to many new designs for microscope objectives. As a result, by 1820 there were many types of new achromatic microscopes on the market.

Introduction of achromatic lenses

The appearance of new varieties of optical glasses encouraged continued development of the microscope in the 19th century, and considerable improvements were made in understanding the geometric optics of image formation. The English scientist Joseph Jackson Lister in 1830 published a work describing a theoretical approach to the complete design of microscope objectives. In 1834 George Biddell Airy, an English astronomer, determined that the resolving power in telescopes was limited by the finite wavelength of light due to diffraction. In 1873 Ernst Abbe related this concept to the ability of the microscope to resolve fine periodic structure in microscopic objects. Thus was born the modern theory of the microscope, which included the effects of light interference in determining the limit of resolution of the microscope. Abbe correctly related the limit of optical resolution to the wavelength of light and the numerical aperture of the objective, and he explained the relation between the type of light illuminating the object in the microscope and the appearance of the image. Abbe also invented the oil-immersion objective, in which the resolution was improved by immersion of the object in a medium with a high refractive index.

OTHER TYPES OF MICROSCOPES

Constant improvements in the optics and mechanical features of microscopes continued through the early 20th century. In 1938 Frits Zernike constructed the first phase-contrast microscope. In phase-contrast microscopy, the principles of diffraction image formation are used to convert minute changes in the optical path through an object into visible contrast in the image. Previously, the structure of many biological specimens could be revealed only if they were stained with a coloured dye to enhance the contrast in the image. With the phase-contrast microscope, the staining step could be eliminated. This concept was extended in many ways for use in industrial and scientific measurements.

In the search for higher resolution, light of ever shorter wavelength was used to illuminate the object. Ultraviolet microscopy was developed in the early 20th century by the German scientists August Köhler and Moritz von Rohr. The discovery of the wavelength of the electron and its dependence upon the energy of the electron beam

Electron microscopy

by Louis de Broglie in 1924 launched an interest in the use of electron beams in microscopes. Rapid development of such devices through the 1930s by the Russian-born American electronic engineer Vladimir Zworykin led to a good understanding of electron optics and the extension of resolution to the angstrom level.

Other types of microscopy were developed in the period from 1960 to 1970. The scanning electron microscope opened new areas of investigation in medical and physical sciences by permitting the examination of a wide variety of objects. The concept of scanning was also applied to optical microscopes, making resolution in depth as well as lateral dimensions possible.

By 1980, microscopy had been extended to employ almost any physical process that had a wavelength and could form an image, including high-energy particle beams with very short wavelengths. Acoustic microscopes using ultrasound as the imaging process were first suggested in 1936 and were finally developed into practical devices in 1970. These microscopes permit the examination of objects in a manner complementary to optical microscopy and provide additional information about the fundamental structure of the objects.

The ultimate microscopy, that of individual atoms, became possible in 1981 with the invention of the scanning tunneling microscope by Binnig and Rohrer (see above *Scanning tunneling microscopes*). In this type of microscope, the image is obtained by recording the electron current induced in an extremely fine tip as it is passed over a surface. The image is built up on a video display and enhanced by image processing to show details smaller than an atomic dimension. The instrument is mechanically simple but electronically sophisticated.

Electronics dominates new developments in all areas of microscopy. Image processing and enhancement of the visibility of low-contrast specimens by computers and digital displays is now commonplace. The extension of these techniques to the automatic recognition of certain structures in biological and physical objects is a matter of significant current development. (R.R.Sh.)

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Ancient Middle Eastern Arts and Architecture

The ancient history and art of the Middle East were subjects on which Western scholars remained in almost total ignorance until the end of the 18th century. Certainly, the standing monuments of Egypt had been observed and described by travelers of earlier generations, but their history and significance were not understood until the discovery of the Rosetta Stone in 1799 and the subsequent decipherment of Egyptian hieroglyphs. Where other countries were concerned, some sort of historical outline could be reconstructed from the writings of the Greek historian Herodotus and the Old Testament, but spectacular architectural remains at sites such as a Persepolis, in Iran, or Boğazköy, in Turkey, had rarely been visited, much less recorded. As for portable antiquities, it was said that the total of those representing the ancient civilization of Mesopotamia could be contained in a box three feet square.

Archaeological excavation began in the 1840s and systematic recording of monuments at about the same time. It is well to remember that the extensive knowledge of ancient Middle Eastern art and architecture now accumulated depends almost exclusively on these two forms of activity. It is also necessary to bear in mind that the chronological sequence of archaeological discoveries made in past years has tended to be in inverse relationship to their actual antiquity. This may help to explain the frequent changes of criteria by which Middle Eastern works of art have been judged and the consequently unreliable character of early commentaries on them. By the mid-20th century, scholars were in a better position to assess the overall contribution of these countries to the evolution of world civilization and the formative beginnings of creative art. They were able not only to evaluate the importance of regional developments but also to comprehend the pattern of their diffusion and interrelation. The evidence on which such judgments must be based is, in fact, still no more than a chance residue—microscopically small—of the vast body of artifacts, works of art, and literature accumulated by the ancient peoples to be considered.

The countries of the Middle East occupy a unique position in the early history of art and architecture in that so many basic conceptions and formulas that in later ages were taken for granted had their genesis in this region. When, for instance, the early inhabitants of Mesopotamia erected monumental buildings, carved statues, or engraved stelae (stone slabs or pillars used for commemorative purposes), they were creating precedents of complete originality no less remarkable than their invention of writing or their mastery of primary elements in philosophy and science. It was the prodigy of their initiative in devising such forms of expression that, in the space of a few centuries, assured the transition from the pedestrian cultures of prehistory to what is now called civilization.

All this took place about the beginning of the 3rd millennium BC, but the artistic brilliance of that era should not obscure the more modest accomplishments by which it had been foreshadowed during the preceding millennia. For at least 40 centuries, families all over the Middle East had inhabited small farming settlements, combining agriculture with stockbreeding and occasional hunting. The forms of their buildings were utilitarian, and (with the exception of one precocious group, at Çatalhüyük, in Anatolia) their approaches to art were restricted to personal ornament and the decoration of pottery or domestic implements. Even in this limited sphere, their aptitude, in those days, for artistic expression, like their economy and social organization, varied little from one country to another. Each occasionally manifested a spasmodic impulse toward innovation, but ensuing developments usually proved ephemeral; in no single country can one detect any continuous thread of progressive invention before the late 4th millennium BC.

When the great awakening did take place, its effects were at first restricted to the river valleys of Egypt and Mesopotamia, where people would soon live in cities ruled by dynasties of kings. Each of these two great centres of civilization developed its own traditional forms of artistic expression, the evolution of which persisted almost without interruption until superseded by the classical culture of Greece. Elsewhere in the Middle East—in Persia, Anatolia, the Levant—the transformation took place more slowly. The divisive effects of regional geography inhibited cultural cohesion, and historical circumstances impeded its continuity. Some scholars have considered the ancient art of these secondary countries as largely derivative and "peripheral" to the mainstream of Middle Eastern accomplishment. More recent discoveries, however, have begun to show that, in each case, factors such as environment and national temperament combined to produce aspects of stylistic originality.

For historical discussions of the regions covered in this article, see MESOPOTAMIA, THE HISTORY OF ANCIENT; SYRIA; PALESTINE; ISRAEL; JORDAN; ARABIA; TURKEY AND ANCIENT ANATOLIA; and IRAN; see also MIDDLE EASTERN RELIGIONS, ANCIENT. For information on Middle Eastern arts and architecture from the 7th century onward, see ISLĀMIC ARTS. For a discussion of the visual arts of ancient Egypt, see EGYPTIAN ARTS AND ARCHITECTURE, ANCIENT.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, sections 613, 626, and 627, and the *Index*.

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Mesopotamian arts and architecture

Location of Mesopotamia

The name Mesopotamia has been used with varying connotations by ancient writers. If, for convenience, it is to be considered synonymous with the modern state of Iraq, it can be seen in terms of two fairly well-defined provinces: a flat alluvial plain in the south and, in the north, the uplands through which the country's twin rivers flow in their middle courses. This geographic division of the area is reflected in the history of its cultural development from the earliest times.

The first traces of settled communities are found in the northern region and date from the mid-6th millennium BC, a period that archaeologists associate with the transition from a Neolithic to a Chalcolithic age. It is of some importance that this period also corresponds to the earliest use of painted ornament on pottery vessels, since the designs used for this purpose are the most reliable criteria by which ethnological groupings and migratory movements can be distinguished. Archaeologically, such groupings are, for the most part, arbitrarily named after the site at which traces of them were first found, and the same names are sometimes attributed to the prehistoric periods during which they were predominant. Hence, Hassuna, Hassuna-Sāmarrā', and Halaf in northern Iraq are the names given to the first three periods during which known early settlements were successively occupied by peoples whose relations were apparently with Syria and Anatolia. The designs on their pottery, sometimes in more than one colour, usually consist of zones filled with "geometric" ornament in patterns reminiscent of woven fabrics. These designs are often adapted to the shape of the vessels with creditable artifice. Only in Hassuna-Sāmarrā' pottery do devices occasionally appear that consist of animal, bird, or even human figures, ingeniously stylized and aesthetically attractive. Such motifs, however, appear to be adopted from contemporary Iranian ceramics. The only other notable art form popular at this time is that of hominoid figurines of stone or clay, associated with primitive religious cults; however, their formal idiosyncrasies vary greatly from group to group, and the meaning of their symbolism is unknown. Nor can they—or the pottery designs—be considered as ancestral to Mesopotamian art of historical times, the antecedents of which must be sought in southern Iraq.

Here, in the delta, the earliest phase of prehistory is associated with the name Ubaid I; and, since this phase has a parallel in Susiana, north of the Iranian frontier, the first settlers in both areas may have a common origin. Among these settlers, according to some scholars, was the germ of Sumerian genius, but this is not indisputably authenticated until the end of the 4th millennium. By 3100 BC, however, the presence of the Sumerians is finally proved by the invention of writing as a vehicle for their own language. From then onward, successive phases in the evolution of Sumerian art can satisfactorily be studied.

Three factors may be recognized as contributing to the character of Mesopotamian art and architecture. One is the sociopolitical organization of the Sumerian city-states and of the kingdoms and empires that succeeded them. From the earliest times, cities were fortified by and adorned with public buildings; irrigation systems were organized and jealously protected; armies were efficiently equipped and troops trained in concerted action; victories were celebrated and treaties ratified. Because interstate warfare or foreign conquests were primary preoccupations of Mesopotamian rulers, it is understandable that in most periods a certain class of artworks was dedicated simply to the glorification of their military prowess.

The role of religion

A second and even more important factor, however, is the major role played by organized religion in Mesopotamian affairs of state. Particularly in Sumerian times, the municipal and economic organization of a city was the responsibility of the temple, with its hierarchical priesthood in which was vested an authority almost equal to that of the ruler and his advisory council of elders. Accordingly, in the early days of Sumer and Babylonia, architectural attention was paid primarily to religious buildings, and all sculpture served religious purposes. The elaboration and adornment of palaces was an innovation of Assyrian times (see below *Assyrian period*).

The third factor that contributed to the character of Mesopotamian art is the influence of the natural environment. The practical limitations imposed upon both artist and architect by the geology and climate of southern Iraq are immediately apparent. Since no stone or wood was available in the alluvial plain, sculptors were dependent on scarce imported material or compelled to use such substitutes as terra-cotta (baked clay). Architecture also was profoundly affected, first, by the restriction of building material to brickwork and, second, by problems of roof construction, only partially solved by the contrivance of brick vaulting, in the 2nd millennium BC. For the Assyrians, in the north, good-quality stone was plentiful, but the cost of quarrying and transport, combined with an obstinate conservatism, caused it to be regarded as a luxury material and its use to be confined to sculptured ornament and conspicuous architectural features.

An equally apparent, if more abstract, association between Mesopotamian art and environment can be detected when the intellectual climate engendered by the latter is understood. In a country where summer and winter temperatures reach thermometric extremes, where agriculture depends exclusively on the artificial distribution of river water and contends precariously with the timing of seasonal floods, where the herdsman is afflicted by the depredations of wild beasts and the cultivator by the menace of poisonous insects—in such a country, the inhabitants must have felt themselves in perpetual conflict with hostile and potentially destructive elements in nature. All this confrontation and frustration is reflected in the melancholy undertones of their religious beliefs, particularly those of the Sumerians, for whom success and prosperity came to be identified with the principle of fertility and thus could only be attained by the appeasement of capricious deities. Such convictions are inherent in the fabric of their complicated mythology, which lends itself easily to expression in pictorial form and provides the predominant subject of almost all Sumerian art. Furthermore, since their mythical traditions and religious beliefs persisted for many centuries after the demise of the Sumerians themselves, they provided the basic imagery of almost all Mesopotamian art.

SUMERIAN PERIOD

Architecture. The beginnings of monumental architecture in Mesopotamia are usually considered to have been contemporary with the founding of the Sumerian cities and the invention of writing, in about 3100 BC. Conscious attempts at architectural design during this so-called Protoliterate period (*c.* 3400–*c.* 2900 BC) are recognizable in the construction of religious buildings. There is, however, one temple, at Abū Shahrayn (ancient Eridu), that is no more than a final rebuilding of a shrine the original foundation of which dates back to the beginning of the 4th millennium; the continuity of design has been thought by some to confirm the presence of the Sumerians throughout the temple's history. Already, in the Ubaid period (*c.* 5200–*c.* 3500 BC), this temple anticipated most of the architectural characteristics of the typical Protoliterate Sumerian platform temple. It is built of mud brick on a raised plinth (platform base) of the same material, and its walls are ornamented on their outside surfaces with alternating buttresses (supports) and recesses. Tripartite in form, its long central sanctuary is flanked on two sides by subsidiary chambers, provided with an altar at one end and a freestanding offering table at the other. Typical temples of the Protoliterate period—both the platform type and the type built at ground level—are, however, much more elaborate both in planning and ornament. Interior wall ornament often consists of a patterned mosaic of terra-cotta cones sunk into the wall, their exposed ends dipped in bright colours or sheathed in bronze. An open hall at the Sumerian city of Uruk (biblical Erech; modern Tall al-Warkā', Iraq) contains freestanding and attached brick columns that have been brilliantly decorated in this way. Alternatively, the internal-wall faces of a platform temple could be ornamented with mural paintings depicting mythical scenes, such as at 'Uqair.

The Sumerian platform temple



Figure 1: Representation of lion-headed bird Imdugud and two stags, copper relief from Tall al-'Ubayd, Iraq, that combines bas-relief with sculpture in the round, Early Dynastic period (*c.* 2900–*c.* 2400 BC). In the British Museum. Height 1.07 m.

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The two forms of temple—the platform variety and that built at ground level—persisted throughout the early dynasties of Sumerian history (*c.* 2900–*c.* 2400 BC). It is known that two of the platform temples originally stood within walled enclosures, oval in shape and containing, in addition to the temple, accommodation for priests. But the raised shrines themselves are lost, and their appearance can be judged only from facade ornaments discovered at Tall al-'Ubayd (Figure 1). These devices, which were intended to relieve the monotony of sun-dried brick or mud plaster, include a huge copper-sheathed lintel, with animal figures modeled partly in the round; wooden columns sheathed in a patterned mosaic of coloured stone or shell; and bands of copper-sheathed bulls and lions, modeled in relief but with projecting heads. The planning of ground-level temples continued to elaborate on a single theme: a rectangular sanctuary, entered on the cross axis, with altar, offering table, and pedestals for votive statuary (statues used for vicarious worship or intercession).

Considerably less is known about palaces or other secular buildings at this time. Circular brick columns and austerely simplified facades have been found at Kish (modern Tall al-Uhaimer, Iraq). Flat roofs, supported on palm trunks, must be assumed, although some knowledge of corbeled vaulting (a technique of spanning an opening like an arch by having successive cones of masonry project farther inward as they rise on each side off the gap)—and even of dome construction—is suggested by tombs at Ur, where a little stone was available.

The corbel vault

Sculpture. Practically all Sumerian sculpture served as adornment or ritual equipment for the temples. No clearly identifiable cult statues of gods or goddesses have yet been found. Many of the extant figures in stone are votive statues, as indicated by the phrases used in the inscriptions that they often bear: "It offers prayers," or "Statue, say to my king (god). . . ." Male statues stand or sit with hands clasped in an attitude of prayer. They are often naked above the waist and wear a woolen skirt curiously woven in a pattern that suggests overlapping petals (commonly described by the Greek word *kaunakes,* meaning "thick cloak"). A togalike garment sometimes covers one shoulder. Men generally wear long hair and a heavy beard, both often trimmed in corrugations and painted black. The eyes and eyebrows are emphasized with coloured inlay. The female coiffure varies considerably but predominantly consists of a heavy coil arranged vertically from ear to ear and a chignon behind. The hair is sometimes concealed by a headdress of folded linen. Ritual nakedness is confined to priests.

It has been thought that the rarity of stone in Mesopotamia contributed to the primary stylistic distinction between Sumerian and Egyptian sculpture. The Egyptians quarried their own stone in prismatic blocks, and one can see that, even in their freestanding statues, strength of design is attained by the retention of geometric unity. By contrast, in Sumer, stone must have been imported from remote sources, often in the form of miscellaneous boulders, the amorphous character of which seems to have been retained by the statues into which they were transformed.

Beyond this general characteristic of Sumerian sculpture, two successive styles have been distinguished in the middle and late subdivisions of the Early Dynastic period. One very notable group of figures, from Tall al-Asmar, Iraq (ancient Eshnunna), dating from the first of these phases, shows a geometric simplification of forms that, to modern taste, is ingenious and aesthetically acceptable (Figure 2). Statues characteristic of the second phase, on the other hand, though technically more competently carved, show aspirations to naturalism that are sometimes overly ambitious. In this second style, some scholars see evidence of occasional attempts at portraiture. Yet, in spite of minor variations, all these figures adhere to the single formula of presenting the conventional characteristics of Sumerian physiognomy. Their provenance is not confined to the Sumerian cities in the south. An important group of statues is derived from the ancient capital of Mari, on the middle Euphrates, where the population is known to have been racially different from the Sumerians. In the Mari statues there also appears to have been no deviation from the sculptural formula; they are distinguished only by technical peculiarities in the carving.

Deprived of stone, Sumerian sculptors exploited alternative materials. Fine examples of metal casting have been found, some of them suggesting knowledge of the cire perdue (lost-wax) process, and copper statues more than half life-size are known to have existed. In metalwork, however, the ingenuity of Sumerian artists is perhaps best judged from their contrivance of composite figures. The earliest and one of the finest examples of such figures—and of Sumerian sculpture as a whole—comes from a Protoliterate level of excavation at Tall al-Warkā'. It is the limestone face of a life-size statue (Iraqi Museum, Bagh-

Metal sculpture

By courtesy of the Oriental Institute, the University of Chicago



Figure 2: Stone statuettes of worshipers and perhaps deities, from the Temple of Abu, Tall al-Asmar, Iraq, Early Dynastic period (*c.* 2900–*c.* 2400 BC). In the Iraqi Museum, Baghdad. Height of tallest statuette 72.1 cm.



Figure 3: "Ram in the Thicket," offering stand from Ur (now Tall al-Muqayyar, Iraq) made of wood, gold, and lapis lazuli, Early Dynastic period, 2650–2550 BC. In the University Museum, University of Pennsylvania, Philadelphia. Height 50.8 cm.

The University Museum, University of Pennsylvania, Philadelphia (neg. #T4-33c5)

dad), the remainder of which must have been composed of other materials; the method of attachment is visible on the surviving face. Devices of this sort were brought to perfection by craftsmen of the Early Dynastic period, the finest examples of whose work are to be seen among the treasures from the royal tombs at Ur: a bull's head decorating a harp, composed of wood or bitumen covered with gold and wearing a lapis lazuli beard (British Museum); a rampant he-goat in gold and lapis, supported by a golden tree (Figure 3; University Museum, Philadelphia); the composite headdresses of court ladies (British Museum, Iraqi Museum, and University Museum); or, more simply, the miniature figure of a wild ass, cast in electrum (a natural yellow alloy of gold and silver) and mounted on a bronze rein ring (British Museum). The inlay and enrichment of wooden objects reaches its peak in this period, as may be seen in the so-called standard or double-sided panel from Ur (British Museum), on which elaborate scenes of peace and war are depicted in a delicate inlay of shell and semiprecious stones (Figure 4). The refinement of craftsmanship in metal is also apparent in the famous wig-helmet of gold (Iraqi Museum), belonging to a Sumerian prince, and in weapons, implements, and utensils.

Relief carving in stone was a medium of expression popular with the Sumerians and first appears in a rather crude form in Protoliterate times. In the final phase of the Early Dynastic period, its style became conventional. The most common form of relief sculpture was that of stone plaques, 1 foot (30 centimetres) or more square, pierced in the centre for attachment to the walls of a temple, with scenes depicted in several registers (horizontal rows). The subjects usually seem to be commemorative of specific events, such as feasts or building activities, but representation is highly standardized, so that almost identical plaques have been found at sites as much as 500 miles (800 kilometres) apart. Fragments of more ambitious commemorative stelae have also been recovered; the Stele of Vultures (Louvre Museum) from Telloh, Iraq (ancient Lagash), is one example. Although it commemorates a military victory, it has a religious content. The most important figure is that of a patron deity, emphasized by its size, rather than that of the king. The formal massing of figures suggests the beginnings of mastery in design, and a formula has been devised for mutiplying identical figures, such as chariot horses.

Cylinder seals

In a somewhat different category are the cylinder seals so widely utilized at this time. Used for the same purposes as the more familiar stamp seal and likewise engraved in negative (intaglio), the cylinder-shaped seal was rolled over wet clay on which it left an impression in relief. Delicately carved with miniature designs on a variety of stones or shell, cylinder seals rank as one of the higher forms of Sumerian art.

Prominent among their subjects is the complicated imagery of Sumerian mythology and religious ritual. Still only partially understood, their skillful adaptation to linear designs can at least be easily appreciated. Some of the finest cylinder seals date from the Protoliterate period (Figure 5, top). After a slight deterioration in the first Early Dynastic period, when brocade patterns or files of running animals were preferred (Figure 5, bottom), mythical scenes returned. Conflicts are depicted between wild beasts and protecting demigods or hybrid figures, associated by some scholars with the Sumerian epic of Gilgamesh. The

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Figure 4: Peace side of the "Standard of Ur," mosaic of lapis lazuli, shell, coloured stone, and mother-of-pearl, from the Royal Cemetery, Ur, Early Dynastic period, *c.* 2500 BC. In the British Museum. Length 47 cm.



Figure 5: *Sumerian cylinder-seal impressions.*
(Top) Feeding the sacred herd, seal impression from Tall al-Warkā', Iraq, Protoliterate period (before *c.* 2900 BC). In the State Museum of Berlin. (Bottom) Horned animals engraved in the brocade style, seal impression from Tall al-Asmar, Iraq, first Early Dynastic period (*c.* 2900–*c.* 2750 BC). In the Oriental Institute, the University of Chicago.
By courtesy of (top) the Vorderasiatisches Museum, Staatliche Museen zu Berlin, (bottom) the Oriental Institute, the University of Chicago

monotony of animated motifs is occasionally relieved by the introduction of an inscription.

AKKADIAN PERIOD

Sargon of Akkad's (reigned *c.* 2334–*c.* 2279 BC) unification of the Sumerian city-states and creation of a first Mesopotamian empire profoundly affected the art of his people, as well as their language and political thought. The increasingly large proportion of Semitic elements in the population were in the ascendancy, and their personal loyalty to Sargon and his successors replaced the regional patriotism of the old cities. The new conception of kingship thus engendered is reflected in artworks of secular grandeur, unprecedented in the god-fearing world of the Sumerians.

Architecture. One would indeed expect a similar change to be apparent in the character of contemporary architecture, and the fact that this is not so may be due to the paucity of excavated examples. It is known that the Sargonid dynasty had a hand in the reconstruction and extension of many Sumerian temples (for example, at Nippur) and that they built palaces with practical amenities (Tall al-Asmar) and powerful fortresses on their lines of imperial communication (Tell Brak, or Tall Bīrāk at-Taḥtānī, Syria). The ruins of their buildings, however, are insufficient to suggest either changes in architectural style or structural innovations.

Sculpture. Two notable heads of Akkadian statues have survived: one in bronze and the other of stone. The bronze head of a king (Figure 6), wearing the wig-helmet of the old Sumerian rulers, is probably Sargon himself (Iraqi Museum). Though lacking its inlaid eyes and slightly damaged elsewhere, this head is rightly considered one of the great masterpieces of ancient art. The Akkadian head (Iraqi Museum) in stone, from Bismāyah, Iraq (ancient Adab), suggests that portraiture in materials other than bronze had also progressed.

Relief sculpture

Where relief sculpture is concerned, an even greater accomplishment is evident in the famous Naram-Sin (Sargon's grandson) stela (Louvre), on which a pattern of figures is ingeniously designed to express the abstract idea of conquest (Figure 7). Other stelae and the rock reliefs (which by their geographic situation bear witness to the extent of Akkadian conquest) show the carving of the period to be in the hands of less competent artists. Yet two striking fragments in the Iraqi Museum, which were found in the region of An-Nāṣiriyah, Iraq, once more provide evidence of the improvement in design and craftsmanship that had taken place since the days of the Sumerian dynasties. One of the fragments shows a procession of naked war prisoners, in which the anatomic details are well observed but skillfully subordinated to the rhythmical pattern required by the subject.

Some compensation for the paucity of surviving Akkadian sculptures is to be found in the varied and plentiful repertoire of contemporary cylinder seals. The Akkadian seal cutter's craft reached a standard of perfection virtually unrivaled in later times. Where the aim of his Sumerian predecessor had been to produce an uninterrupted, closely woven design, the Akkadian seal cutter's own preference was for clarity in the arrangement of a number of carefully spaced figures.

The Akkadian dynasty ended in disaster when the river valley was overrun by the mountain tribes of northern Iran. Of all the Mesopotamian cities, only Lagash appears somehow to have remained aloof from the conflict and, under its famous governor Gudea, to have successfully maintained the continuity of the Mesopotamian cultural tradition. In particular, the sculpture dating from this short interregnum (*c.* 2100 BC) seems to represent some sort of posthumous flowering of Sumerian genius (Figure 8, left). The well-known group of statues of the governor and other notables, discovered at the end of the 19th century, long remained the only criterion by which Sumerian art could be judged, and examples in the Louvre and British Museum are still greatly admired. The hard stone, usually diorite, is carved with obvious mastery and brought to a fine finish. Details are cleverly stylized, but the musculature is carefully studied, and the high quality of the carving makes the use of inlay unnecessary. The powerful impression of serene authority that these statues convey justifies their inclusion among the finest products of ancient Middle Eastern art.

SUMERIAN REVIVAL

The short historical interlude represented by the Gudea sculptures was followed by a full-scale Sumerian revival, one that lasted for four centuries and culminated in the unification of the whole country under the rule of Ḥammurabi in the early 18th century BC. Dominated first by the powerful 3rd dynasty of Ur and later by the rival states of Isin and Larsa, the peoples of ancient Sumer reverted to their pre-Akkadian cultural traditions. On their northern frontiers the Sumerian culture was extended to increasingly prosperous younger city-states, such as Mari, Ashur, and Eshnunna, located on the middle courses of the Tigris and Euphrates rivers.

In all these cities, both old and new, the period is



Figure 6: Bronze head of a king, perhaps Sargon of Akkad, from Nineveh (now in Iraq), Akkadian period, *c.* 2300 BC. In the Iraqi Museum, Baghdad. Height 30.5 cm.
By courtesy of the Directorate General of Antiquities, Baghdad, Iraq



Figure 7: "Victory Stele of Naram-Sin" (reigned 2254–2218 BC), stone, Akkadian period. In the Louvre, Paris. Height 1.98 m.
By courtesy of the Musee du Louvre, Paris

Advances in architecture

notable for the advances made in architectural planning and the large-scale reconstruction of ancient buildings. In the south the early promise of Sumerian architecture had reached fulfillment, first in the great ziggurats, or stepped towers, rising above their walled temple enclosures at such cities as Ur, Eridu, Kish, Uruk, and Nippur. These huge structures, with their summit sanctuaries, the appearance of which can only be guessed at, were faced with kiln-baked brick, paneled and recessed to break the monotony of their colossal facades, and were strengthened with bitumen and reinforced with twisted reeds. Tradition associates the ziggurat at Borsippa (modern Birs Nimrūd, Iraq), near Babylon, with the biblical Tower of Babel. Surrounding temples at ground level were also much elaborated. The basic plan consisted of a tower-flanked entry, central court, antecella (or inner vestibule), and sanctuary, all arranged on a single axis; however, in the larger examples this plan could be expanded by means of communicating courtyards. Facades were often elaborately decorated with panels of pilasters (recessed columns) or engaged half columns, skillfully modeled in mud-brick. At Ur, kiln-baked brick was again used to construct corbeled vaulting over huge subterranean tomb chambers, entered through funerary chapels at ground level. Here, too, there are temple-palaces, the complicated planning of which is seldom self-explanatory.

Better examples of residential palaces are found in the newer cities of the north, especially Mari, where a vast building with more than 200 rooms was constructed by a ruler named Zimrilim (*c.* 1779–*c.* 1761). In this palace is found the standard reception unit common to all Babylonian palaces: a rectangular throne room that is entered by a central doorway from a square court of honour; and behind it a great hall, in this case apparently serving some religious purpose. There also is an immense outer courtyard, overlooked by a raised audience chamber, and, in the remotest corner of the building, a heavily protected residential suite. In some of the main chambers, mural paintings depicting ritual scenes and processions have been preserved.

The sculpture of this period is perhaps best represented by some well-preserved statues, also from the Mari palace (Figure 8, right). Their style owes much to the preceding Gudea period in the south, but they lack the authentic stamp of Sumerian design and workmanship. The same may be said of the few surviving pieces from the reign of Hammurabi (*c.* 1792–*c.* 1750), whose conquests ended the epoch—for example, the relief at the head of the stela in the Louvre on which his law code is inscribed.

ASSYRIAN PERIOD

Architecture. Ashur, a small Sumerian city-state on the middle Euphrates, began to gain political prominence during the pre-Hammurabi period discussed above. During the latter half of the 2nd millennium BC, the frontiers of Assyria were extended to include the greater part of northern Mesopotamia, and, in the city of Ashur itself, excavations have revealed the fortifications and public buildings constructed or rebuilt by a long line of Assyrian kings. The character of these buildings suggests a logical development of Old Babylonian architecture. There are certain innovations, such as the incorporation of small twin ziggurats in the design of a single temple, while in the temples themselves the sanctuary was lengthened on its main axis, and the altar itself was withdrawn into a deep recess. For the rest, the absence of ornament and the multiplication of buttressed facades with crenellated battlements tend to monotony.

Other forms of art are inconspicuous, except perhaps the contemporary cylinder seals, which show an interest in animal forms that anticipates the relief carving of a later phase of Mesopotamian civilization. Sometimes known as Middle Assyrian, this later period corresponds to the occupation of southern Mesopotamia by the Kassites and to the Mitanni kingdom on the north Syrian frontier, neither of which contributed greatly to the total development of ancient Middle Eastern art.

The fuller manifestation of Assyrian art and architecture is not seen until the 9th century BC, when Ashurnasirpal II transferred his capital from Ashur to Nimrūd (ancient

By courtesy of (left) the Musee du Louvre, Paris, (right) Istanbul Arkeoloji Muzeleri; (left) Cliche des Musees Nationaux, Paris. © Photo R.M.N.



Figure 8: *Ancient Mesopotamian official sculpture.*
(Left) Diorite statue of Gudea, ruler of Lagash (now Telloh, Iraq), Ur III period (*c.* 2112–2004 BC). In the Louvre, Paris. Height 1.05 m. (Right) Inscribed diorite statue of Puzur-Ishtar, governor of Mari, Syria, Ur III period. Reconstructed head (original in the State Museum of Berlin) with original body, which is in the Archaeological Museum of Istanbul. Height 1.73 m.

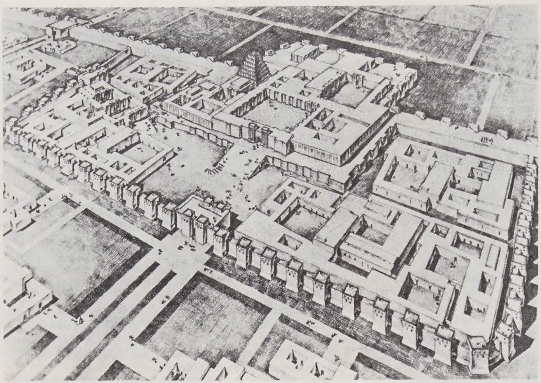


Figure 9: A reconstruction drawing of the citadel of Khorsabad, now in Iraq, as it may have appeared in the time of Sargon II (721–705 BC). Drawing by Charles Altman.
By courtesy of the Oriental Institute, the University of Chicago

Assyrian palaces

Kalakh; biblical Calah). The rise of Assyria to imperial power during this century and those that followed gave increased vitality to Mesopotamian architecture. The vast palaces brought to light in the 19th century emphasize the new interest in secular building and reflect the ostentatious grandeur of the Assyrian kings. Like the temples of earlier days, they are usually artificially raised up on a platform level with the tops of the city walls, astride which they often stand. Their gates are flanked by colossal portal sculptures in stone, and their internal chambers are decorated with pictorial reliefs carved on upright stone slabs, or orthostats. In addition to the 9th-century structure at Nimrūd, palace platforms have been exposed at Khorsabad (ancient Dur Sharrukin), where Sargon II established a short-lived capital of his own in the late 8th century BC, and at Nineveh, which was rebuilt in the 7th century, first by Sargon's son Sennacherib and then by his grandson Esarhaddon. On the platforms at both Nineveh and Nimrūd, palaces and temples were multiplied by successive kings.

The platform at Khorsabad is occupied by a single royal residence, associated with a group of three modest temples and a small ziggurat. Similar buildings occupy a walled citadel at the foot of the platform, thus completing a complex that has been thoroughly excavated and provides the most informative example of typical contemporary architecture (Figure 9). Sargon's palace itself, like that of Zimrilim 1,000 years earlier (see above *Sumerian revival*), is planned, first, around a gigantic open courtyard accessible to the public and, second, around an inner court of honour. From the latter the great throne room is entered through triple doorways, around which, in common with the main outer entrance to the palace, are concentrated a fine array of portal sculptures. The throne room has an adjoining stairway leading to a flat roof and a suite of living apartments behind. Other state rooms, conventionally planned, open onto an open terrace facing the mountains beyond. All the principal internal chambers are decorated with reliefs, except for the throne room itself, where mural painting seems to have been preferred. The individual purpose and function of the innumerable administrative and domestic offices must remain largely conjectural.

Sculpture. Any history of late Assyrian art must be concerned primarily with relief carving. Some statues in the round have been found, but the comparative ineptitude of the majority of them suggests that this form of expression did not come naturally to Assyrian sculptors. Portal sculptures, which many would consider the most characteristic Assyrian art form, are not statues in the round but "double-aspect" reliefs (that is, they are meant to be seen from either the front or the side), apparently derived from a Hittite invention of the 14th century BC. These impressive guardian figures—usually human-headed bulls or lions—decorate the arched gateways and are sometimes supplemented by others set at right angles on the adjoining facades, their heads facing sideways. Each is composed from a single block of stone weighing up to 30 tons, roughly shaped in the quarry and then carved in situ.

Orthostat reliefs

Less spectacular orthostat reliefs form a continuous frieze of ornament around the bases of interior wall faces. There is evidence that they were placed in position before the walls that they decorate had been completed. Their carving in situ could thus be executed in full daylight. This form of architectural ornament dates from the first quarter of the 9th century BC and seems to have been a genuine Assyrian innovation. The earliest slabs, from the 9th-century palaces of Ashurnasirpal II and his son Shalmaneser III at Nimrūd, are about seven feet (two metres) high, with the design arranged in two superimposed registers separated by a band of cuneiform inscription. In those from later buildings, such as Sargon II's palace at Khorsabad, the individual sculptured figures reach a height of nine feet.

The subjects of the designs on these reliefs are rarely related in any way to religion. Superstitious symbols do occasionally appear in the form of benevolent winged beings, or genies, but the primary purpose of the picture is the glorification of the king himself, either by scenes of ceremonial homage or by extended pictorial narratives of his achievements. The most popular theme, giving rise to numerous variations, involves detailed scenes of military conquest and the ruthless suppression of revolt. These are often arranged episodically to represent successive events in the progress of a single campaign: the Assyrian army prepares for war; led by the king, it crosses difficult country on the way to attack a walled city; the city is taken, burnt, and demolished; the enemy leaders are punished with conspicuous brutality; and, finally, the victory is celebrated. Scenes such as these are distinguished above all by their stylistic vitality and fanciful detail. Animals as well as men are carefully observed and beautifully drawn. The principles of perspective as later defined by the Greeks are unknown, but attention is given to the relationship of figures in space and to devices for suggesting comparative distance.

At Khorsabad, late in the 8th century BC, some notable stylistic changes are perceptible. The lively carving of narrative and historical subjects has been replaced by more tedious symbols of pomp and ceremony. In keeping with

the winged bulls and genies of the portal sculptures, stiffly arranged files of courtiers, officials, and servants stand immobilized in the routine of ceremonial homage. The monotony of the figures is occasionally relieved by the sparing use of coloured pigment on the stone.

In the 7th-century palaces of Sennacherib and Ashurbanipal at Nineveh, the reliefs suggest a reaction in favour of narrative and violent activity. The slabs are covered to their full height by complicated battle scenes in which the progress of the fighting is suggested by episodic repetition. Types of landscape are depicted schematically, and significant episodes or individuals are identified by a short inscription, without impairing the overall rhythm of the design.

Hunting scenes

In the intervals between their military campaigns, Assyrian kings appear to have been much preoccupied with hunting, and scenes from the chase provided an alternative subject for the reliefs. Lions hunted with spears from a light chariot and herds of wild asses (onagers) or gazelles are subjects that stimulated the imagination and sensibility of the Assyrian artist (Figure 10).

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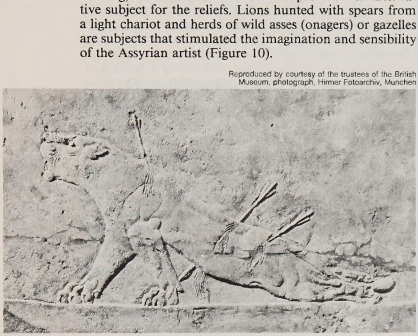


Figure 10: "Dying Lioness," detail of an alabaster mural relief from the North Palace of Ashurbanipal, Nineveh, Assyrian period, *c.* 650 BC. In the British Museum.

A contrast to these descriptive carvings is provided by the formal monumentality of the Assyrian rock reliefs, secular or religious devices carved on vertical rock faces in localities such as Bavian and Maltai to commemorate historical events that took place there.

The Assyrian talent for relief ornament was not confined to sculpture in stone. First seen during the reign of Shalmaneser III (858–824 BC) are striking examples of relief modeling in bronze. The huge wooden gates of a minor palace at Imgur-Enlil (Balawat), near Nimrūd, were decorated with horizontal bands of metal, 11 inches (28 centimetres) high, each modeled by a repoussé process (relief hammered out from behind), with a double register of narrative scenes. Their subjects are much the same as the stone reliefs, but even greater ingenuity has been used in adapting the designs to so confined a space.

Relief modeling in bronze

Painting and decorative arts. When greater economy of labour and material was necessary, mural paintings were substituted for slab reliefs. At the time of Tiglath-pileser III (744–727 BC), a country palace at Til Barsip (modern Tall al-Ahmar) was decorated in this way, with the conventional motifs of relief designs rather clumsily adapted to this very different medium. A few years later, such paintings were extensively used to decorate both wall faces and ceilings in Sargon II's palace buildings at Khorsabad. One magnificent panel of formalized ornament has been reconstructed. It is painted in primary colours on a white ground.

There is evidence that the Assyrian palaces were well equipped with furniture. The wooden components have perished, but the ivory ornaments with which the furniture was enriched have survived in great quantities. Of these "Assyrian ivories"—relief panels, inlays, and other forms of ornament—only a small proportion can be attributed to indigenous workmanship. The remainder represent either loot from the cities of Syria and Phoenicia or the work of craftsmen imported from those regions. The carving is often technically superb, and the enrichment of the ivory with gold, semiprecious stones, or coloured paste by cloisonné or champlevé processes (whereby the applied decoration is outlined by raised metal strips or fills depressed areas of the surface that have been cut out to receive it) gives increased elegance. The designs, however, are for the most part a pastiche of misunderstood Egyptian symbolism and are often less attractive than the purely Assyrian devices.

Assyrian ivories

NEO-BABYLONIAN PERIOD

During the half century following the fall of Nineveh, in 612 BC, there was a final flowering of Mesopotamian culture in southern Iraq under the last dynasty of Babylonian kings. During the reigns of Nabopolassar (625–605 BC) and his son Nebuchadrezzar II (604–562 BC), there was widespread building activity. Temples and ziggurats were repaired or rebuilt in almost all the old dynastic cities, while Babylon itself was enormously enlarged and surrounded by a double enceinte, or line of fortification, consisting of towered and moated fortress walls. Inside the city the most grandiose effect was obtained by the disposal of public buildings along a wide processional way, leading through the centre of the town to the temple and ziggurat of its patron god, Marduk. Where the street passed through the inner-city wall, the facades of the famous Ishtar Gate (Pergamon Museum, Berlin) and those facing the adjoining street were ornamented in brightly glazed brickwork, with huge figures of bulls, lions, and dragons modeled in relief. This form of decoration—a costly process, since each of the bricks composing the figures had to be separately cast—provided a solution for the problem of embellishing mud-brick facades. It appears again in the court of honour of Nebuchadrezzar's palace, using a more sophisticated design that suggests familiarity with Greek ornament. For the rest, there are few innovations in the planning of either palaces or temples during the Neo-Babylonian period. Also (strangely enough, in view of the prolonged excavations that took place at this site), examples of contemporary art are limited almost exclusively to cylinder seals and terra-cotta figurines of unpretentious design.

Syro-Palestinian arts and architecture

The countries bordering the Mediterranean between the Sinai Peninsula and the Nur Dağları (Amanus Mountains), to which the names Palestine and Syria are often loosely applied, had in fact no geographic integrity or clear historical definition. The interior of Syria and its extension beyond the Euphrates have in the past always been separated ethnographically, and sometimes politically, from the coastal cities of the Levant, the associations of which were with Cilicia and the trade routes of Palestine. In early historical times both Syria and Palestine, however, were continuously dominated by one or other of the great imperial powers—Egyptian, Mesopotamian, or Hittite. This situation was in no way conducive to the coherent development of indigenous culture; consequently, the individual contribution of these countries to the total accomplishment of ancient Middle Eastern art is of secondary importance.

An exception to this generalization must be made where prehistory is concerned, however. An archaeological sounding at Jericho, which carried back the history of settled communities far beyond the earliest finds made in the Tigris valley, uncovered a small, symmetrically planned religious building (dating from approximately 7000 BC); this should perhaps be regarded as the earliest attempt at formal architecture. In a setting only a century or so later, a strange collection of human heads was found, their features competently modeled in plaster, sometimes over the bone of actual skulls.

Jericho

Early in the 2nd millennium BC, the Levant and its coastal cities became a dependency of Egypt. Local rulers imported Egyptian works of art, which afforded some stimulation to regional craftsmanship. The tombs of the

rulers—at Byblos, for instance—were furnished with objects of fine craftsmanship in gold, ivory, ebony, and obsidian. The objects that were made locally can easily be distinguished from those imported from Egypt by the comparative ineptitude of their ornament. Egyptian motifs were generally adopted as elements in decorative design, but they were copied without precision and without regard for their meaning; the results, therefore, were of very uneven quality. The aesthetic failings of partly or wholly derivative ornamental styles characterized Levantine art for many centuries to come.

More obvious signs of regional individuality are apparent in the development of Syrian architecture at this period. It is perhaps best seen in the smaller cities of the interior, which were less subject to Egyptian influence. Two palaces at Alalakh (modern Tell Açana, Tur.), in the plain of Antioch, built, respectively, in the 15th and 13th centuries BC, show some characteristically Syrian features. Wooden-pillared porticoes at the entry to reception suites mark the development of a standard palace unit, known as a *bit hilani*, generally adopted some centuries later by the Syro-Hittites (see below *Anatolian arts and architecture: Hittite period*). Basalt orthostats, as yet unsculptured, anticipated those of the Neo-Assyrian palaces; and mural paintings, like those at Mari, decorated the chambers of an upper story in the Cretan manner. The earlier palace produced a single stone head that illustrates the contemporary Syrian sculpture style at its best. The remaining examples are crude.

During the early centuries of the 1st millennium BC, a strip of the Levant coast, from Ṭarṭūs (Syria) to somewhere south of Mount Carmel, became the homeland of a Canaanite people known as Phoenicians. As a result of archaeological excavations, something is known of their architecture as well as that of the contemporary Israelites in Palestine. Much information has been obtained about their walled cities and the development of their fortifications from the 18th century BC onward. It appears that by the time of King Solomon, in the 10th century BC, such military architecture had been standardized, for at three cities—Hazor, Megiddo, and Gezer—walls and gates alike are almost identical. Walls are of the casemate type (parallel walls with a space between) with internal chambers, and gateways are elaborate, with flanking towers and an approach through several transverse chambers. In the 9th century BC the invention of a more effective battering ram necessitated replacement of casemate walls by more solid structures.

Canaanite temples

The rather scanty remains of Canaanite temples have also been found at Hazor and elsewhere. They consisted of a courtyard, main hall, and sanctuary, all on a single axis, with occasional side chambers. The Hazor building showed a feature corresponding to the biblical description of the "brazen pillars" on either side of the central doorway of Solomon's Temple, which had been built by Phoenician craftsmen in the 10th century BC.

Two forms of Phoenician and Syrian craftsmanship take a high place in the repertoire of ancient Middle Eastern art: the carving and decoration of ivory, and the repoussé ornament of ceremonial bowls and other bronze objects. Some of the finest examples in both categories are to be found among the vast assemblage of material imported or appropriated by the Late Assyrian kings and found in their palaces, particularly at Nimrūd (Figure 11). Ivory carving has a long history in Syria and Palestine, as is shown by the well-known ivories from Megiddo, some of which are dated as early as the 14th century BC. So much study has been devoted to their design, especially to its non-Egyptian content and the original contribution of regional craftsmanship, that some scholars think it possible to distinguish purely Syrian designs from those of the Phoenician workshops.

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Figure 11: A Nubian slain by a lioness, ivory plaque enriched with gold and coloured inlay, from Nimrūd, Iraq. In the British Museum. Height 10.3 cm.

Pre-Islāmic Arabian arts and architecture

The pre-Islāmic history of the great Arabian subcontinent is primarily that of a nomadic people. By the second half of the 20th century, traces of their art and architecture had been found only in the long-settled agrarian provinces of the south and the maritime trading centres facing the Arabian Sea. For the most part, these sites fall within the frontiers of the state known until 1990 as Yemen (Aden). In ancient times the prosperity of these provinces, with their harbour towns and caravan routes, depended entirely upon trade. Merchandise from Africa, India, and the Persian Gulf, together with frankincense and myrrh (for which Arabia was famous), were carried northward to Egypt and the Mediterranean, greatly enriching the cities and tribes through whose territory they passed. The history of the several kingdoms into which Arabia was divided—Saba' (Sheba), Qatabān, Ḥimyar, and others—is now known, and their cities, long inaccessible to archaeologists, are being systematically explored.

Influences on early Arabian art

It is not surprising that the style and character of both architecture and sculpture suggest a complicated synthesis of influences, first from Egypt or Mesopotamia and later from the classical culture of the Mediterranean. In public buildings—predominantly temples dedicated to deities of an Arabian pantheon—there is a long-standing tradition of fine ashlar masonry (of hewn or squared stone) and sculptured ornament. Sculpture is also represented by a striking variety of carved memorial stelae and freestanding votive statues, often carved in alabaster. These are notable for their crude but distinctive style of portraiture or symbolism. In sculptured friezes, some Arabian motifs are recognizable—for instance, the alternation between bucrania (ox heads adorned with ribbons or garlands) and ibex (wild goat) heads.

Anatolian arts and architecture

Anatolia is the name that is currently applied to the whole Asian territory of modern Turkey. Its western half is a broad peninsula connecting the continent of Asia with Europe. Because the country lacks geographic unity, its component regions being widely differentiated in climate and economy, early students of antiquity doubted the probability of its ever having acquired an overall cultural identity and considered its contributions to ancient art to have been provincial and intermittent. Archaeological research in more recent years, however, revealed in Anatolia a deep-seated aboriginal culture productive of ideas that are reflected in the art of the peninsula throughout its history.

Written history in Anatolia commences with the introduction of cuneiform writing (composed of wedge-shaped characters) by Assyrian merchants resident at Kanesh (Kültepe) and elsewhere in the 19th and 18th centuries BC. A conventional terminology is used in reference to the previous ages, knowledge of which is entirely dependent

on the results of archaeological excavations. The earliest of these periods, the chronology of which is still imprecisely defined, are the Neolithic and the Chalcolithic. An Early Bronze Age takes up the greater part of the 3rd millennium BC. During the Middle Bronze Age the central Anatolian principalities with whom the Assyrian merchants were in contact were amalgamated in the Hittite old kingdom (*c.* 1700–*c.* 1500 BC), and in the Late Bronze Age they made up the homeland of the Hittite empire (*c.* 1400–*c.* 1190 BC). The seven centuries that followed are loosely referred to as the Iron Age.

PRE-HITTITE PERIOD

Neolithic and Chalcolithic periods. Anatolian excavations have done much to illuminate the genesis of visual arts in the earliest settled communities. In a Neolithic setting, at Çatalhüyük in the Konya plain, a township covering more than 15 acres (6 hectares) and dating from the 7th millennium BC was found. The houses, already built of sun-dried brick, were contiguous, each having several rectangular rooms similarly planned and accessible only by a wooden ladder from a flat roof. These interconnected roofs provided space for the communal life of the inhabitants. Religious shrines were elaborately ornamented with animal heads or horns, either real or imitated in plaster. Walls were decorated with coloured murals, repeatedly repainted after replastering. The subjects of the paintings were ritual hunting scenes or obscure occult imagery, both themes recalling those of Paleolithic cave paintings. Sculpture in bone or stone was fashioned with remarkable skill, either as ornament or as cult effigy.

Hacılar

At Hacılar, a Chalcolithic site near Burdur, Tur., village houses were entered at ground level; their standard plan shows the first evidence of conscious architectural symmetry. Much in evidence among the contents of these houses is pottery painted with extremely decorative designs. The same ornament was applied to anthropomorphic jars and stylized human idols found in graves. A higher standard of modeling, however, was attained in unpainted clay figurines—steatopygous females, some seated or reclining, others holding a child or tame animal.

At Hacılar some provision was made for communal defense by the strengthening of contiguous buildings on the periphery of the settlement. In a 5th-millennium level at Mersin, in Cilicia, there is a purposefully planned military fortress, with slit windows in its protective wall, a towered gateway, and standardized accommodation for the garrison.

Early Bronze Age. In the Early Bronze Age the further development of military architecture is best illustrated at Troy, where parts of a fortress were uncovered. The most convincingly reconstructed plan dates from the second phase of the Early Bronze Age (*c.* 2700–*c.* 2500 BC). It shows a polygonal enclosure, hardly 300 feet in diameter, surrounded by heavy mud-brick walls on a stone substructure. There is a single gateway, with strongly built flanking towers and gate chambers, guarding the approach through a narrow sloping corridor. Most prominent within the enclosure is a large public building thought to be an assembly hall, built to the so-called megaron plan, which two millennia later was to dictate the form of a Greek temple. Approached through an open portico, the building consists of a megaron—a wide rectangular hall with an enormous central hearth. Near it is a second, less substantially constructed building that is thought to have been the residential palace, since hoards of gold ornaments and other precious objects were discovered buried beneath it; the archaeologist Heinrich Schliemann named these objects Priam's Treasure.

At Beycesultan, buildings that were almost certainly religious shrines were uncovered—a find of some interest, since temples are virtually unknown in Anatolia at this period. Rectangular shrine chambers seemed to be arranged in pairs, with ritual installations recalling the Horns of Consecration and Tree, or Pillar, cults of Minoan Crete. A palace building at the same site, dating from the Middle Bronze Age (*c.* 1750 BC), had reception rooms at first-floor level, also in the Minoan manner. In common with most other Bronze Age buildings in Anatolia, its walls were composed of a brick-filled timber framework on stone foundations. The private houses of this period at Beycesultan were all built on the megaron plan.

The art of the Anatolian Early Bronze Age is best represented by metalwork from royal tombs at Alaca Hüyük, in the bend of the Halys River (modern Kızıl River), and from two minor sites in Pontus—Horoztepe and Mahmatlar. At Alaca Hüyük, in particular, members of a ruling family were buried among the paraphernalia of funerary ritual, accompanied by their personal possessions: weapons, ornaments, toilet articles, domestic vessels, and utensils (made of gold, silver, and bronze). One dagger has a crescent-shaped handle and a blade of iron—a metal known to have had many times the value of gold at this time—and among the ornaments there is a fine gold-filigree (openwork made with metal wire) diadem. Equally striking was the variety of objects associated with the funerary ritual: figures of animals (such as stags), finely wrought in bronze and inlaid with silver, and strange openwork grills of bronze, sometimes adorned with animals. These objects were probably mounted at the heads of poles supporting a catafalque or canopy. There are also freestanding metal figurines, one of bronze with boots and breasts enriched with silver.

Metalwork from Alaca Hüyük

From these luxury objects found at Alaca Hüyük, together with those found at Troy and elsewhere, scholars have concluded that processes known to the Anatolian metalsmiths of the Early Bronze Age included casting by cire perdue, hammering or repoussé work, sweating or soldering, granulation (decoration consisting of tiny spheres of gold soldered onto a background), filigree, and cloisonné inlay. Carnelian, jasper, nephrite, obsidian, and meerschaum were all used for ornament.

Middle Bronze Age. Objects from the houses of the Kültepe merchants, representing the art of the Middle Bronze Age, are somewhat less impressive. Rhytons (a type of drinking vessel) and theriomorphic (having an animal form) vessels in painted terra-cotta show imaginative modeling, and local deities appear in the form of small statuettes and molded reliefs. It is, however, in the designs of contemporary cylinder seals that the art and religious concepts of the indigenous peoples are fully illustrated for the first time. Here is the iconography of the Anatolian gods, complete with their sacred furniture, ritual attributes, and appropriate animals.

HITTITE PERIOD

The Hittite old kingdom, with its capital city, Hattusa (modern Boğazköy), in the Halys bend, was one of several states into which Anatolia was divided during the second quarter of the 2nd millennium BC. Its finest monuments date from the imperial period that followed. The capital city, strategically placed astride a rocky gorge, has an inner enclosure, rising up to a high citadel rock (Büyükkale). Greatly extended in imperial times, the outer city has a four-mile circuit of powerful fortifications. The double walls, with their defensive towers and substructure of cyclopean masonry (large irregular blocks without mortar), stand upon a stone-faced rampart of earth, itself protected by a stone apron wall. The corbeled arches of its gates are flanked by portal sculptures—lions or sphinxes—anticipating those of the Late Assyrian palaces. Carved on the stone doorjamb of one arch is a famous relief of a warrior wearing the characteristically Hittite short kilt and conical helmet.

Elsewhere in the city there are four buildings recognizable as temples, the largest of which has been fully excavated. It is a huge building, surrounded by ranges of store chambers, planned around a wide courtyard with pillared colonnades and a small freestanding shrine in one corner. These features and the isolated position of the main sanctuary have no parallel in the temples of Mesopotamia or Syria.

Hittite sculpture

Modern knowledge of Hittite sculpture is derived, first, from the portal sculptures of Hattusa itself and, second, from rock sculptures, including those decorating the remarkable shrine called Yazılıkaya, some distance outside the town. Here, deep clefts in the limestone, open to the sky, form a setting for the cult; the reliefs are carved

on the vertical faces of the rock. One of the recesses, or chambers, is decorated with a pageant of deities, some standing on their appropriate cult animal or identified by a hieroglyphic inscription. These figures are carved with only average proficiency, and some of the iconography is borrowed from the Hurrians, with whom the Hittite royal family had intermarried. The figures in the second, or inner, sanctuary, however, are carved with an artistry inspired by religious fervour. The figure of a young king (Tudhaliyas IV) in the protective embrace of a god is hardly less impressive than the symbolism of a huge dagger thrust into the rock before him. The rock reliefs of this period elsewhere in Anatolia—Sirkeli, Gâvur Kalesi, and Fraktin, for example—are mainly of archaeological interest. They are inferior in carving to contemporary reliefs and to those of the Iron Age, of which there is a fine example at İvriz Harabesi in the Taurus Mountains, showing a local ruler of the 8th century BC paying homage to a fertility god.

Monuments such as that at İvriz Harabesi represent a curious aftermath of Hittite history. In about 1190 BC the empire was destroyed and the Hittites driven from their homeland on the Anatolian plateau by the Phrygians, but in the 10th–8th centuries they reappeared as part occupants of small city-states such as Milid (modern Arslantepe-Malatya), Sam'al (modern Zincirli), and Carchemish, in the Taurus or north Syria, where they shared political authority with indigenous Aramaeans and other peoples. During this Syro-Hittite period, their art and architecture was of a hybrid and rather inferior character much influenced by Assyria, to which the Hittites frequently became subject, and also by Phoenicia and Egypt. Conspicuous in their buildings are the sculptured orthostats that line the bases of the walls, often of coarse, black basalt awkwardly alternating with white limestone. Columns are of wood, with bases and capitals of stone, and monolithic statues, more than life-size, are a common feature. Fortifications are still an important aspect of their cities. Those at Zincirli enclose a circular town, a half mile in diameter, with a high-walled citadel in the centre, containing a complex of palaces. Like all Syrian palaces, these incorporate one or more *bit hilani* units, consisting of a columned portico, a long reception room, with an adjoining staircase to the roof, and a varying number of retiring rooms (see above *Syro-Palestinian arts and architecture*). A striking example of these *bit hilani* is the Kaparu Palace at Tall Ḥalaf, near the source of the Khābūr River. The almost barbaric array of sculpture shows the city to have been predominantly Aramaean.

URARTU

Eastern Anatolia during the 9th–8th centuries BC was occupied by the state of Urartu, at first a minor kingdom centred on Lake Van but later extended to include parts of what are now Armenia, Iranian Azerbaijan, and Kurdistan in northern Iraq. Entrenched in a mountainous country, well organized with provincial capitals and a network of small fortress cities, it resisted aggression from the Assyrians in the south. Urartian culture was based upon that of Mesopotamia, but some scholars consider its architecture

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Figure 12: *Metalwork of Urartu.*
(Top left) Fragment of a bronze model of a city, from Toprakkale, near Van, Tur., late 8th century BC. Height 30.5 cm. (Top centre) Cast of a gold medallion representing a goddess and a worshiper, original found at Toprakkale. (Right) Bronze figurine of a god, from Van, early 7th century BC. Height 19.7 cm. (Bottom) Bronze relief showing scenes from the first campaign of Shalmaneser III against Urartu about 859 BC, from gates found at Balawat in Assyria (now Iraq). Height 24 cm. All in the British Museum.



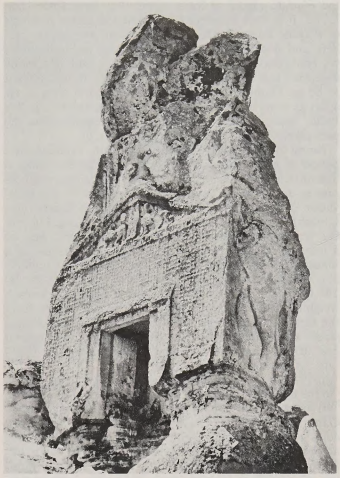


Figure 13: *Phrygian ornament and architecture.*
(Left) Terra-cotta architectural plaque from Pazarli, Anatolia, 8th century BC; in the Museum of Anatolian Civilizations, Ankara. (Right) Rock-cut temple facade at Aslankaya, near Afyonkarahisar, Anatolia.

By courtesy of (left) the Anadolu Medeniyetleri Muzesi, Ankara; photographs, (left) Arts Council of Great Britain; (right) E. Akurgal, *Die Kunst Anatoliens*

Urartian architecture

to be superior to that of the Assyrians, for the monotonous mud-brick facades of the southern plains and valleys are here replaced by a pattern of crenellated stone towers and buttresses adapted to the natural beauty of a rocky landscape. The excavation of two fortress cities, Karmirblur and Arin Berd, in Armenia, together with many others in Anatolia itself, has also revealed some unique features of Urartian architecture, including a standard form of temple: a square, towerlike building anticipating the temple-towers of Achaemenian times in Persia (Figure 12).

Urartu was renowned for its craftsmanship in bronze casting, examples of which reached Europe by way of Phrygia (Figure 12). Mural painting was practiced with some proficiency, but the drawing is weak, and the designs add little to the repertoire of Assyrian motifs, from which they are largely copied.

PHRYGIA

Plans dating from the Phrygian occupation of the Anatolian plateau (*c.* 1200 BC) have been recovered of small, fortified towns overlying the ruins of older Hittite cities. The Phrygian capital was at Gordium on the Sakarya (Sangarius) River, where excavations have revealed public buildings of the megaron type and the bastions of an impressive city gate. The rock-cut monuments of this period (Figure 13, right), concentrated around a Phrygian cult centre to the southeast of Eskişehir, include the Midas Monument: a tomb chamber framed in a relief depicting the gabled facade of a building. Ornament suggested by the sculptor has been explained by the discovery at other Phrygian sites of architectural terra-cottas: glazed tiles or panels, with human and animal figures (Figure 13, left). The contents of a royal tumulus (an artificial hillock or mound over a grave) burial at Gordium testify to the competence of Phrygian craftsmanship in other materials, including glass.

Iranian arts and architecture

Any reservation about attributing to Iran primary status among the countries contributing to the art of the ancient Middle East must be associated with the discontinuity of its early history and the comparatively incomplete state of its archaeological exploration. Nevertheless, it is clear that Iranian art maintained a distinctive identity from prehistoric times onward; thus, characteristics seen in designs on painted pottery of the 4th millennium BC can also be recognized, for instance, in the sculpture of the Achaemenian Persians. One of these characteristics—manifest in bronze casting and stone carving as well as in painted ornament—is the predominance of decoration over representation. Such purely Iranian predilections seem, surprisingly, to have survived the historical hiatus in the 2nd and 3rd millennia BC, during which the more culturally advanced regions of the country were so profoundly influenced by the ideas and artistic formulas of neighbouring Mesopotamia. During the better-documented years of the 1st millennium, they again survived, side-by-side with the innovations imposed by Greek and other foreign craftsmen, and were later in fact reciprocally transmitted to Europe.

EARLY IRANIAN PERIOD

The most artistically important, though not the most ancient, prehistoric painted pottery of Iran is derived from Susiana. The stylized shapes of animals and birds are used, their curves and contrasting angularities skillfully adapted to the sensitive shapes of the clay vessels in a manner that implies a long history of evolutionary experiment. The simplified silhouettes, which once must have appeared as individual figures, are linked together in a repetitive frieze to form a band of enrichment or to articulate some plastic feature. Nothing of this sort is to be seen in the contemporary Ubaid pottery of southern Mesopotamia, although the two cultures show a parallel progression.

In the succeeding Protoliterate period, each culture produced an independent form of pictographic writing. In Iran, this development took place in Elam, a region bordering on southern and central Mesopotamia. The Elamite use of pictographs was short-lived, however, and for a long time no further attempt was made to develop a written language. Modern knowledge of Elamite history during the centuries that followed thus depends exclusively on references in Mesopotamian literature, occasioned by the perpetual contacts between the two countries. Trade was on a large scale, and even the wars that so frequently interrupted it supplied the Elamites with Mesopotamian goods, including works of art that could serve as a pattern for Iranian artists. The stelae of Naram-Sin and Hammurabi were among major works brought as loot to

Influence of Mesopotamian art

the Elamite capital at Susa, where they have since been found. It is thus understandable that the native products of Elamite artists in the 3rd millennium BC—statues, reliefs, and smaller objects, such as cylinder seals—followed the conventions current in Mesopotamia. One interesting exception is a type of carved steatite bowl, at first thought to be an Elamite product but since found at sites as far apart as Mari on the Euphrates and Mohenjo-daro in the Indus valley, where it originated, thus emphasizing the part played by Susa in transcontinental trade.

During the late 2nd millennium BC, Elam experienced a period of great prosperity and political stability under a line of powerful rulers. The character of Elamite architecture at this time was revealed by the discovery and excavation of a vast temple complex at Choghā-Zanbīl (Dur Untash) in the Susa area. It was built by King Untash-Gal (*c.* 1265–*c.* 1245 BC) to fulfill the functions, first, of a holy shrine and centre of pilgrimage and, second, of a mausoleum for his family. Its central feature is a remarkably well-preserved ziggurat, 345 feet square and originally 144 feet high, built for the most part of baked bricks each weighing about 40 pounds (18 kilograms). Apart from the fact that it has been reconstructed with four receding stages and a summit temple, the structure of the ziggurat has little in common with that of Mesopotamian ziggurats. As described by one scholar,

> gates in the centre of each face led to diverging staircases up to the first stage, except on the southwest face, where a triple diverging staircase also led up to the second and higher stages.

Gates to the main stairways were flanked by glazed terracotta guardian animals—bulls or griffins. The paved area adjoining the ziggurat had a surrounding wall with imposing gateways. A similar outer wall enclosed a number of subsidiary temples, their dedication indicated by cuneiform inscriptions in the Elamite language. The ornamental sculptures from this complex were predominantly of glazed terra-cotta. A more striking example of contemporary Elamite sculpture is the life-size bronze statue of Queen Napirasu from Susa (now in the Louvre).

MEDIAN PERIOD

Much less is known about the northwestern part of modern Iran during the 2nd millennium BC, but from about 1000 BC onward it acquired a new importance. The southward migration of Indo-European peoples many centuries earlier, which had brought the Hittites to Anatolia and the Kassites to Babylon, was now followed by a new wave of peoples. Referred to as "Iranian," these peoples included both the Persians and the Medes. At first they were little more than a loose confederation of tribes, occupying a wide area of Iran south of the Caspian Sea. In settling there they had bypassed the eastern provinces of Urartu and the prosperous country called Mannai, south of Lake Urmia, also avoiding contact with mountain tribes of Luristan. In the 8th and 7th centuries BC, however, the weakening of Urartu and Mannai by Assyrian conquests, followed by a Scythian invasion and the final collapse of Elam, made all of western Iran accessible, and the foundations of Median empire were laid by Cyaxares.

With this complicated infusion of new elements and influences, it is hardly surprising that the Iranian art of this period shows a rich synthesis of novel characteristics. Its most conspicuous surviving products are derived from four principal sources: an excavation at Hasanlu, which was probably the capital of the Mannaeans; a chance-found treasure from Ziwiye (Ziwiyeh) in Iranian Kurdistan; tomb finds at Marlik, near Kazvin; and excavated graves in Luristan.

Principal sources

The Mannaean capital had a powerfully walled citadel, built between 1000 and 800 BC, and within it an enormous palace or temple, consisting of two-story buildings around a partially roofed courtyard. It had been destroyed by fire, and interest in its architecture, which should be considerable, has been eclipsed by the beauty of some objects recovered from the burnt debris. One was a silver cup decorated with electrum figures in two registers; there are chariots and soldiers above and, below, a lion and a horse opposed heraldically between archers. Even more remarkable was a bowl of solid gold (Archaeological Museum, Tehrān), elaborately figured with repoussé ornament, the religious or heroic imagery of which is largely incomprehensible (Figure 14). Though it shows no Assyrian influence, the associations of its linear style are with the West, and some links with Hurrian mythology have been detected in the design.

The hilltop fortress at Ziwiye falls within the territory of the Mannaean state, but the famous treasure found there dates from its later history (7th century BC). The marvelously designed objects making up the treasure include an elaborate pectoral (breast) ornament, a bracelet with lions' heads, a similarly adorned torque (rigid necklace), a ram's head rhyton, daggers, and enrichment for furniture—all of gold. As would be expected at this period, they show a variety of styles, sometimes combined in a single design, and carry suggestions of influence from Assyria, Syria, and even Egypt. The collection is thought by some to have been the property of a Scythian chief who temporarily ruled Mannai.

Dated to a period contemporary with the foundation of the Hasanlu citadel, though removed from it geographically, are the royal tombs found at Marlik. The tombs contained gold and silver vessels, comparable in design to those found at Hasanlu, and ingeniously grotesque animal figures in terra-cotta.

The Luristan bronzes

The Luristan bronzes include objects basically homogeneous in style but varying considerably in date and excavated from burial grounds in the eastern Zagros Mountains (Figure 15). There appear to have been more than 400 of these burial grounds, each comprising about 200 graves, so that the number of ornamental bronze objects reaching museums and private collections must have been very great. The burials appear to cover a long period of time; but two main groups have been distinguished, belonging, respectively, to the latter half of the 2nd millennium BC and to the Iron Age from 1000 BC onward. In the second period, particularly, there was a continual movement of Indo-European horsemen migrating from the north—a fact that helps to explain the character of the bronzes themselves, for they are nomads' gear. These portable goods and chattels of wandering tribes must have been produced by the settled craftsmen in the towns and villages of Iran for the nomads who passed through. Chariot or harness fittings are predominant: they include rein rings, bits, and ornaments, as well as weapons and various types of talismans. All suggest an indigenous school of craftsmanship catering to a changing clientele whose tastes and requirements varied with their origin. In the earlier group some very ancient Mesopotamian motifs are seen—rein rings, for instance, resembling those from the Ur tombs—but these have been explained as the belated use, in the 2nd millennium, of devices long superseded within Sumer itself.

Josephine Powell, Rome



Figure 14: Detail of a Mannaean gold bowl from Hasanlu, Azerbaijan, *c.* 900 BC. In the Archaeological Museum, Tehrān. Diameter of entire bowl 27.9 cm.



Figure 15: Bronze cheekpiece of a bridle bit from Luristan, Iran, with a hero, or god, mastering two beasts, date unknown. In the Museum of Fine Arts, Boston. 12.7 × 12.7 × 25.4 cm.
Maria Antoinette Evans Fund, courtesy the Museum of Fine Arts, Boston

ACHAEMENIAN PERIOD

There can be little doubt that, during the first half of the 8th century, when the Medes ruled northwestern Iran from their capital at Ecbatana (modern Hamadan), they developed some characteristic forms of architecture. This has been confirmed, for instance, by the discovery of a magnificent brick fortress at Nush-e Jan in that area. The evolution of a style capable of expressing the full genius of Iranian invention, however, fell to the lot of their Persian successors and fortunately is better documented by material remains.

Arrival of the Persians

The Persians first appear in history early in the mid-9th century BC as the occupants of a small state in Parsumash and Anshan, to the southeast of Susiana, ruled by a dynasty of kings to which its founder, Achaemenes, gave his name. Dependent first upon Elam and later subject to the Medes, the Persian state became more powerful in the 6th century, and in 550 BC, after defeating the Median armies, its fifth king, Cyrus II the Great, became ruler of all Iran. The empire that his further conquests created extended from Anatolia and Mesopotamia to the frontiers of India.

For Cyrus and his successors this access of temporal power and authority called for expression in the embellishment of their cities and the creation of an appropriately magnificent setting for their everyday lives. For an unsophisticated and hitherto nomadic people, this was an unprecedented requirement. Inspiration was at first sought in the existing formulas of Mesopotamia, Elam, Urartu, and Media, but from the beginning the matrix of the new style was the deep-seated artistic aptitude of the Iranians themselves. The marvels of Achaemenian art were conceived with native—and extraordinary—ingenuity. This continued to be the case even after the large-scale importation of Greek craftsmen in the time of Darius I the Great (reigned 522–486 BC).

Architecture. The earliest stages in the evolution of Achaemenian architecture are to be seen in the rather scanty remains of Cyrus' capital city at Pasargadae, north of Persepolis. The layout retained the character of a nomadic encampment: widely separated buildings—including gatehouse, residential palace, and audience hall—standing in a vast park, surrounded by a wall 13 feet thick. The audience hall provides the earliest example of a formula in design that was to become a criterion of the Achaemenian architecture: a columned hall with corner towers and external colonnades, called by the Persians an apadana. Other features are the Tomb of Cyrus, a gabled stone building on a stepped plinth, and a Zoroastrian fire temple (Zendan), a towerlike structure with a plan recalling that of the standard Urartian temple. Replicas of the Zendan were built later at Naqsh-e Rostam and elsewhere. Also at Pasargadae, the workmanship of Greek stonemasons was already recognizable, but their full contribution to the new Achaemenian style of architecture is better seen at Persepolis, to which Darius transferred the state capital in 518 BC.

The apadana

Achaemenian palaces are built on rock terraces leveled to receive them. The terrace at Persepolis measures approximately 1,600 by 1,000 feet and is more than 43 feet high, with traces of a high enclosure wall of mud brick around its outer edge and a magnificent stairway approach at its northeast corner. The palace buildings themselves, started by Darius in 518 BC and completed during the following half century by Xerxes I and Artaxerxes I, are rather closely grouped together, with little consideration for the overall composition (Figure 16). They are decorated, for the most part externally, with portal sculptures and long ranges of relief carving. Apart from the ornamental facades of the stairways by which the buildings are approached, sculpture is confined to the decoration of doors or windows. These stone-built features, together with a few internal columns, are all that have survived.

In the absence of the mud-brick walls themselves, it is

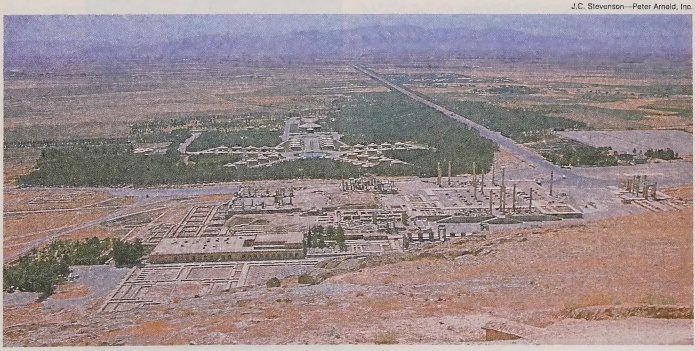

J.C. Stevenson—Peter Arnold, Inc.

Figure 16: Ruins of the royal residence (looking south) at Persepolis, Iran, begun by Darius I and completed during the reigns of Xerxes I and Artaxerxes I, Achaemenian period, late 6th–4th century BC.



Figure 17: Armenian tribute bearer carrying a jar decorated with winged griffins, detail of relief sculpture on the stairway leading to the Apadana of Darius at Persepolis, Iran, Achaemenian period, late 5th century BC.
Michael Roaf

difficult to gain a true impression of the terrace's original appearance. Most characteristic of these Persian palaces is the proliferation of columns and the tendency to plan them around a square central chamber. In the main gatehouse, with its guardian bulls and bull-men, the square appears as an independent unit. Facing it at a higher level is the largest building of all, the great Apadana (hall) of Darius. It is 272 feet square and is said to have accommodated 10,000 people. The four corner towers presumably contained guardrooms and stairs. The sculptured stairway by which it was reached bears the famous relief of the tribute bearers (Figure 17). Next comes the Throne Hall, or Hall of a Hundred Columns. It has a portico on the north side with 16 pillars and guardian bulls built into the tower walls at either end. Seven sculptured windows in the north wall are balanced by corresponding niches elsewhere, and the reveals, or jambs, of the doors also are decorated with reliefs. Again approached by an ornamental stairway, a "tripylon" unit between these main buildings leads to others only tentatively identified. The plan of the building, called the Harlem by archaeologists, is to some extent self-explanatory. The character of the Treasury is indicated by security precautions in its planning. In this building the columns were of wood, heavily plastered and painted in bright colours. Elsewhere, columns are fluted in the Greek manner, while the more elaborate capitals and bases have a floral treatment that, like much other Achaemenian ornament, is half Greek and half Egyptian. The most notable form of capital and one peculiar to Achaemenian design is the "double-figure" impost (an upper addition to the capital), taking the form of paired bulls, bull-men, or dragons. Some of these features reappear in the contemporary palace at Susa. Also from this source are figured panels of molded and glazed brick (now in the Louvre), reminiscent of Nebuchadrezzar's Babylon.

Relief Sculpture

Sculpture. Relief sculpture is by far the most striking manifestation of Achaemenian art. Adopted as the basis of the new style was the straightforward technique of the Assyrians, with its engraved detail and lack of modeling. The employment of Ionian sculptors resulted in a complete break with this tradition, and the full plastic rendering of human or animal figures became the rule. A compromise between the aesthetic sensibility of the Greek sculptors and the disciplined precision of the Iranian tradition in metalwork produced a stylistic synthesis of unrivaled elegance.

Compared with the spirit and variety of the Assyrian narrative scenes, the subjects chosen for the Persian designs may at times appear monotonous. This may be partly explained, however, by the disparity in their architectural functions: the reliefs no longer appeared as interior decoration but were effectively used to give visual emphasis to prominent features of external facades where the bright colours applied to them profited from the sunshine. Well-known Achaemenian rock reliefs, such as those of the royal tombs at Naqsh-e Rostam, near Persepolis, and the relief with a famous inscription of Darius I at Bisitūn (historically Behistun), on the road to Hamadan, are primarily of archaeological interest. Of greater artistic importance are the many surviving examples of Achaemenian metalsmiths' work, which continued to draw extensively on the native tradition of Iranian design. The Oxus Treasure (now in the British Museum) includes outstanding and characteristic examples of Achaemenian metalwork (Figure 18).

SELEUCID PERIOD

The two centuries during which the Middle East and countries beyond were ruled by Alexander the Great (336–323 BC) and his Seleucid successors (312 BC–64 BC) are poorly represented in the realm of art and architecture. Everywhere in the Middle East, local artists were subject to strong Western influence, and Western craftsmen adapted their taste to that of a Greek or Hellenistic aristocracy. If there was a Greco-Iranian style, it had little to distinguish it from Greco-Mesopotamian or, for that matter, Greco-Indian art. Architecture of about 200 BC is represented by two "Greek" temples, at Kangāvar and Khurha, in Iran, in which classical orders (Doric, Ionic, and Corinthian) are handled with so little understanding that they can hardly be called Hellenistic. There are, however, isolated examples of contemporary sculpture from eastern sites to which this term could be more justifiably applied. Bronze statuettes from Nahāvand, a fine bronze head from Shami in the Bakhtiari, the marble fragments from Susa, and a striking alabaster statue from Babylon (all now in the Louvre) acquire added interest from their provenances.

PARTHIAN PERIOD

The Parthians were a nomadic people originating in the steppe country between the Caspian and Aral seas. The dynasty of Parthian kings that was to displace the Seleucid rulers of western Asia was founded in about 250 BC. One hundred years later, their conquests extended as far as Mesopotamia, and the frontier of Europe was withdrawn to the Euphrates. For another four centuries the further

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Figure 18: Griffin rhyton (drinking vessel), silver, from the Oxus Treasure, Achaemenian period (559–330 BC). In the British Museum. Height 25 cm.

extension of the Parthian empire was resisted with varying degrees of success by the armies of Rome.

In Iran and Mesopotamia, this long era of Parthian occupation is poorly represented by newly built towns, but there are a few notable examples. One was Ctesiphon, originally a Parthian military camp facing Seleucia, the older capital city on the other side of the Tigris River. Another was Hatra, a fortress city in the Al-Jazīrah desert between the Tigris and Euphrates rivers; and a third was Gūr-Fīrūzābād, south of Shīrāz. All these show the approximately circular plan of military tradition. The palaces, sometimes built of good ashlar masonry, and even the private houses are distinguished by a feature later characteristic of Islāmic architecture: the iwan, or three-sided hall, the fourth side of which is replaced by an open archway. At Hatra and in a Parthian palace at Ashur, the iwans multiplied in number, and the adjoining facades are decorated with engaged columns, singly or in tiers, corresponding approximately to the orders of classical architecture.

Parthian palaces

Hatra is by far the best preserved and the most informative example of a Parthian city. It has an inner and an outer city wall, the former built of ashlar masonry, and a temenos (temple enclosure) enclosing the principal sacred buildings. The great central group, built during the 2nd and 1st centuries BC and still standing with many of its vaulted chambers intact, includes the Shamash temple, a characteristic Iranian sanctuary with a square central chamber, ambulatory, and outer wall incorporating a staircase to the roof. Comparable buildings have been found as far afield as Taxila in the Indus valley. Excavations by Iraqi archaeologists have revealed temples dedicated to Al-Lāt and Shahiro, who, with Shamash, make up a Hatran trinity.

In the 1st and 2nd centuries AD Hatra was ruled by a dynasty of Arab princes whose written language was Aramaic. Iraqi excavations have yielded a great wealth of sculptures dating from this period, including portrait statues of the princes and their families. This material has thrown new light on the whole subject of Parthian art, which depended formerly on such isolated survivals as the magnificent bronze statue from Shami, in the old Elamite homeland. Rock reliefs at Tang-e Sarwak, Bīsitūn, and elsewhere reveal one salient characteristic of Parthian design—that is, the preference for "frontality" or, as one scholar describes it, "the tendency for the figures to ignore one another and to face the spectator with an unblinking stare." Frontality also is characteristic of the Romano-Syrian sculptures of Palmyra and later passed into the fabric of Byzantine art.

PETRA AND PALMYRA

Two cities, strategically placed in Jordan and eastern Syria, respectively, were at times associated with Parthian history and have left monuments suggesting a compromise between Roman and Middle Eastern art. Both were caravan cities, and each in turn acquired wealth and importance from its position at the junction of arterial trade routes. Petra, in biblical Edom, was ruled by Nabataean kings from late in the 2nd century BC until 106 AD, when it became a Roman colony. Its subsequent decline was due in part to the temporary ascendancy of Palmyra, on the western fringe of the Syrian desert, whose remarkable queen Zenobia ruled a miniature empire until she was defeated by the Romans in AD 272.

The significance of Petra in the history of ancient Middle Eastern art is difficult to assess, since its art is in large part restricted to the design of rock-cut tombs or temples. Imitation building facades carved on cliff faces surround the tomb and temple entrances. Their most distinctively Oriental characteristic is the baroque effect obtained by ingenious contortions of classical Roman formulas. The dramatic beauty of their natural setting and the chromatic peculiarity of the stone from which they were hewn are assets that have enhanced their reputation. Stripped of these, their interest is primarily academic.

The architecture of Palmyra is more conventionally Roman, but it is freely associated with sculpture, and many bas-relief carvings decorate the tombs of rich merchants and other notables. Parthian influence is to be seen in their style, particularly in the frontality of the human figures.

Architecture of Palmyra

SĀSĀNIAN PERIOD

The last great Iranian dynasty to rule in the Middle East before the advent of Islām has left a heritage of ruined buildings and sculpture that are of increasing interest to those seeking the origins and antecedents of Western art. It has been said of Sāsānian art that, essentially Iranian in character, "it was receptive of foreign influences, but adapted them to the traditions of its native land, and as the art of a world empire, it spread into far distant countries."

A town called Gūr (modern Fīrūzābād) was built by the founder of the dynasty, Ardashīr I (reigned AD 224–241), with the circular plan characteristic of earlier times. A contrast is immediately seen at Bishāpūr, where Ardashīr's son Shāpūr I adopted the "grid" planning then popular in Greek cities. Building materials varied from country to country. The Sāsānian palace at Ctesiphon was built (probably in the 4th century AD) of baked brick (Figure 19). The facades on either side of its famous vaulted iwan hall (82 feet wide and 121 feet high) have blind arcading with freely simplified classical detail. A reconstruction of the palace at Gūr, built of rubble and plaster, shows a similar main facade, with cupolas (rounded vaults) over square chambers behind. Of the same material is Shāpūr I's palace at Bishāpūr, where the great hall, with its central cupola, has four iwans making a cruciform (in the form of a cross) plan. In buildings of this sort, the stucco facing of the walls was decorated with incised or painted ornament.

By courtesy of the Oriental Institute, the University of Chicago

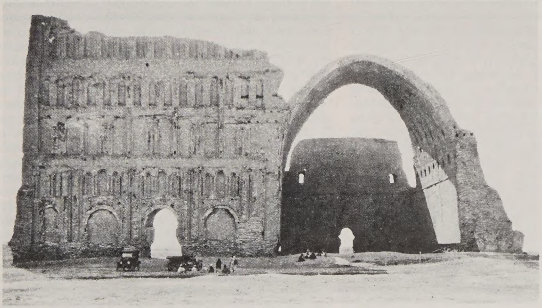


Figure 19: The facade of the Palace of Shāpūr I at Ctesiphon, Iraq, Sāsānian period, 3rd century AD.

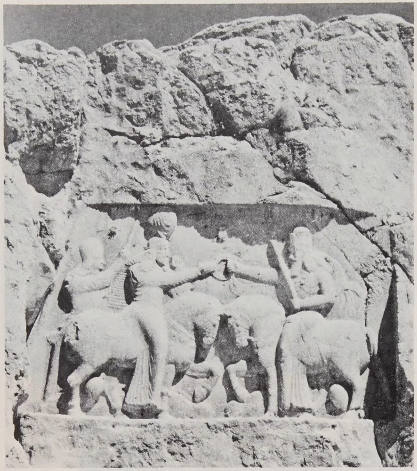


Figure 20: Sāsānian rock relief showing the investiture in AD 226 of Ardashīr I at Naqsh-e Rostam, Persia (Iran).
Paperfoto

There were also mosaic pavements, in which portraits of individuals were shown three-quarters face, the frontality of Parthian design apparently having been abandoned.

The most important and revealing examples of Sāsānian sculpture are the rock reliefs scattered over the territory of the empire; there are more than 30 in Iran alone. Their style and content reveal a facet of art history that can do much to clarify the interaction of Eastern and Western ideas at this time. The scenes generally depicted are investitures, triumphs, the defeat of enemies, and other occasions in the life of royalty. Perhaps the two most striking designs in the whole series, each of them characteristic yet differently conceived, are the Investiture of Ardashīr I at Naqsh-e Rostam (Figure 20) and the Royal Hunt relief at Tāq-e Bostān. In the first the king and his god, both mounted on horseback, are sculptured in high relief in the Roman manner but are antithetically arranged to create a typically Iranian heraldic composition. In the second the two central figures are framed in a surrounding panorama of incidental detail, perhaps inspired by similar designs in mural painting. These and other examples reveal Western influence—for instance, in the molding of drapery of the body or the Achaemenian arrangement of subordinate figures in horizontal registers. Yet, unlike Achaemenian sculpture, there is no narrative intention in these reliefs. Their static celebration of a single event, investing it with a timeless significance, is the central accomplishment of this form of Sāsānian art. (S.H.F.L.)

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Ancient Middle Eastern Religions

The religious beliefs, attitudes, and practices developed in the ancient Middle East (extending geographically from Iran to Egypt and from Anatolia and the Aegean Sea to the Arabian Peninsula and temporally from about 3000 to 330 BC, when Alexander the Great conquered much of the area) have had an enduring influence on Western civilization. While this article treats only those religions of Middle Eastern antiquity that have not survived to modern times, special attention is given in the introduction to their role as antecedents of the major Western religions (*i.e.*, Judaism, Christianity, and Islām), all of which originated in the region. For full treatment of these "inheritors" of the Middle Eastern tradition, including also the surviving Zoroastrianism and Parsiism, see under the names of the individual religions.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, section 822, and the *Index*.

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THE CULTURAL CONTEXT

General considerations

The ancient Middle East constituted an ecumene. The term ecumene comes from the Greek word *oikoumenē*, which means the inhabited world and designates a distinct cultural-historical community. The material effects of the commercial and cultural interconnections that permeated the component regions of the ancient Middle Eastern ecumene are richly supplied by archaeological excavations, which provide evidence of the spread of architectural, ceramic, metallurgical, and other products of ancient Middle Eastern man's industry. Manufacturing and services tended to be monopolized by professional guilds, including religious personnel specializing in sacrifices, oracles, divination, and other kinds of priestcraft. The mobility of such guilds throughout the entire area helps to explain the spread of specific religious ideas and techniques over great distances. Just as guild potters spread ceramic forms and methods, so also guild priests spread their religious concepts and practices from the Indian Ocean to the Aegean Sea, and from the Nile River to Central Asia. The Greek poet Homer, in the *Odyssey*, noted the mobility of guildsmen, mentioning religious personnel as well as architects, physicians, and minstrels. Guild priests called *kohanim* were found at ancient Ugarit on the Mediterranean coast of northern Syria as well as in Israel. Moreover, Mycenaean Greek (late Bronze Age) methods of sacrifice are similar to the Hebraic methods, which are preserved in many countries to this day in the traditional techniques of Jewish ritual slaughter.

Religious guilds

The "archaeological revolution." The decipherment of Mesopotamian and Egyptian literatures in the 19th century opened new vistas of ancient Middle Eastern history. Hitherto, scholarly knowledge had been limited to the contents of classical Hebrew, Greek, and Latin literatures. Explorations and excavations in the Middle East yielded not only texts but also an abundance of ancient art objects, artifacts of daily life, and architecture and thus have revolutionized scholarly knowledge of the ancient Middle East, including its religions. A ziggurat excavated at Babylon illustrates the form of the biblical Tower of Babel. The prototype of the biblical story of the Deluge has turned up in the Gilgamesh epic. A fragment (dating from about 1400 BC) of that Babylonian epic has been found at Megiddo in Israel, showing that the Mesopotamian version was current in Palestine before the Hebrews, under Joshua, conquered the land about 1200 BC. A previously little-known people, the Hittites, are, because of archaeological discoveries, now recognized as a major power of antiquity with a rich legacy of religious texts, especially rituals.

The earliest and certainly the most fundamental ancient Middle Eastern civilization—the Sumerian—had vanished without a reference in the literatures of the world. Sumerology is now an important field of investigation. Biblical studies have been revolutionized by the tablets (1400–1200 BC) found from 1929 onward at Ugarit. It has be-



Kings and winged figures bearing offerings beside a sacred tree. Assyrian marble relief, reign of Ashurnasirpal II, c. 883–852 BC. In the British Museum.
By courtesy of the trustees of the British Museum

come extremely difficult to keep abreast of the continually growing body of material, and very few scholars today feel secure enough to venture beyond limited areas.

Literary sources of knowledge of ancient Middle Eastern religion. Classical literature remains an important source for ancient Middle Eastern religion. The Roman historian Livy wrote many descriptions of religious rites of the ancient Middle East. The Roman poet Virgil's *Aeneid* and *Eclogues* reflect Egyptian, Semitic, and Anatolian, as well as Greek, antecedents. The Greek biographer Plutarch's *De Iside et Osiride* ("Concerning Isis and Osiris") is still the best description of the Egyptian myth of Isis and Osiris and of the cult of the dead. The Greek satirist Lucian's *De Dea Syra* ("Concerning the Syrian Goddess") is of enduring value for an understanding of Canaanite religion. The writings of Herodotus, the 5th-century-BC Greek historian, remain an indispensable source for the cultural history and religion of the ancient Middle East. And owing to the discovery of texts from Ugarit, the Homeric epic of the Greeks is now firmly linked to Middle Eastern literature.

The Old Testament as a source of knowledge

The Hebrew Bible is still the most important single source for knowledge of the ancient Middle East, reflecting life from Egypt to Iran, and from the Bronze Age beginnings to the Hellenistic Age. There is very little in the Old Testament that does not follow the types of religious literatures in the older Middle East: psalms, hymns, laws, rituals, prophecy, wisdom literature, and other types. Sometimes parts of the Bible are related in detail to specific outside sources. The Egyptian *Wisdom of Amenemope,* first published in modern times in 1923, for example, parallels Proverbs 22:17–24:22 so closely that it effectively opened up the field of the comparative study of ancient Middle Eastern wisdom literature.

Middle Eastern worldviews and basic religious thought

THE CONCEPT OF THE SACRED

All of the ancient Middle Eastern people saw the agency of the gods in every aspect of life and nature. Everything on earth was regarded as a reflex of its prototype in the divine or sacred sphere, such as in the biblical description of the creation of man "in the image of God"; God was viewed as the primary reality of the universe, and human beings were seen as the reflection of that reality. In Egypt, Thoth was the scribe in the pantheon. Mortal scribes were viewed as the human reflections of Thoth, and "the beak of the Ibis (*i.e.,* Thoth) is the finger of the Scribe" (*Wisdom of Amenemope,* ch. XV, 17:7).

The ancient Middle Eastern people believed that the universe resulted from the injecting of order (cosmos) into chaotic primordial beings or matter, followed by divine acts of creation. Genesis 1:1–3 says that when God began to create the heavens and the earth, the "earth was without form and void, and darkness was upon the face of the deep; and the Spirit of God was moving over the face of the waters. And God said, 'Let there be light'; and there was light." Thus darkness (*i.e.,* evil) was preexistent. Moreover, the deep (*tehom* in Hebrew) is the same as the primordial dragon called Tiamat (cognate to the Hebrew *tehom*) in the Babylonian epic of creation. The first act of creation is God's evoking light (*i.e.,* the forces of good) by fiat. Accordingly, God is not responsible for the forces of evil, which were there before he embarked on the creative process. Proceeding by fiat he separated the water-containing earth from the water-containing heaven, confined the earth's waters to the bodies of water (leaving the rest as dry land), created the various species of vegetation, the heavenly bodies, the animal kingdom, and finally man, who is to rule over the earth. All this takes six days, after which God rests on the seventh, so that the Sabbath crowns the epic of creation and imposes the obligation to observe the sabbath in keeping with the principle of *imitatio Dei* (the imitation of God).

The *Enuma elish*

The Babylonian creation epic (*Enuma elish,* "When on High") states that at first there existed only the male (Apsu) and female (Tiamat) gods of the deep. They raised a family of gods that were so unruly that Apsu resolved to destroy them. Rebellion and chaos ensued. Among the deities was Marduk, the god of Babylon. Since the main version of the epic of creation is the Babylonian, Marduk occupies the role of Creator. (In the Assyrian version, Ashur is important.) Tiamat, who had embarked on a course of destruction, was slain by Marduk, who cut her in two and used her carcass to create the universe. Out of half her body he fashioned the sky containing the heavenly bodies to mark the periods of time. The epic culminates in the glorification of Marduk and the establishment of his order. The *Enuma elish* was read on the Akitu, or New Year festival, at Babylon, to reestablish order, in accordance with sympathetic transference principles, by reciting Marduk's creation. The function of the Akitu is thus to rejuvenate society for the new year.

VIEWS OF MAN AND SOCIETY

The lack of hard-and-fast barriers between gods and men left room for hybridizing. The aristocracy, in particular, claimed some divine form of ancestry. Gilgamesh, a mortal king who ruled Uruk in Mesopotamia, was, according to the Gilgamesh epic, born of the goddess Ninsun, even as among the Greeks Achilles was accepted as the son of the goddess Thetis. Sometimes kings claimed to have two divine parents. King Keret, whose epic was found at Ugarit, claimed to be the son of El, the head of the pantheon, and of Asherah, El's wife. Every Egyptian pharaoh was hailed as "the son of Re" (the sun god). This does not, however, imply the absence of a human father. The concept was one of paternity at two levels; qualitative superiority emanated from the notion of divine paternity, but one's position in society came from the human husband of one's mother. Odysseus "the Zeus-begotten son of Laertes" (*Iliad* 10:144) was a hero because Zeus presumably impregnated his mother; but he was also king of Ithaca because his mother's husband was King Laertes of Ithaca. In this regard the birth and station of Christ differ only in that Mary was a virgin when she was divinely impregnated. Though the divine component of Christ is due to his divine paternity, his position as king of the Jews comes not from his heavenly Father but from Mary's husband, Joseph, who was descended from King David (Matthew 1).

In the ancient Middle Eastern worldview, gods could become mortal, and men could become gods. Utnapishtim, the hero of the Babylonian Flood story, was deified together with his wife by the fiat of the great god Enlil: "Hitherto Utnapishtim has been but human; henceforth Utnapishtim and his wife shall be like us gods" (Gilgamesh epic 11:193–194). In the Hebrew Bible, God so loved Enoch (Genesis 5:24) and Elijah (2 Kings 2:11) that he carried them aloft to heaven as immortals. But these were special cases, and in antiquity they set no precedent for common folk. Kings enjoyed deification regularly in Egypt, though in some other traditions only upon dying. The Hittite monarch Hattusilis III refers to his father's death as "when my father Mursilis became a god" (*Apology of Hattusilis,* line 22).

Purpose of man

From the ancient Middle Eastern point of view, man was created to serve the gods, and he does so in the hope that

the gods appreciate it and will reward him for it. The gods need food and drink and depend on men to supply them. After the Flood the biblical Noah won God's goodwill, for "the Lord smelled the pleasing odor" (Genesis 8:21) of the tasty flesh and fowl offered up to him. Noah was following a long tradition, for Utnapishtim (Gilgamesh epic 11:155–161) had, after the Flood, offered sacrifices and libations to the gods who "crowded like flies" as they "smelled the sweet savor." Though gods depend on man, man also depends on the gods, and therefore service to the deities must be maintained for the welfare of the state, even as the family and the individual must do what the gods expect of them for domestic and personal welfare.

Everything on earth reflects a divine prototype, and all human affairs are divinely ordered and scrutinized. Gods may even build the cities destined to be their cultic centres and in which they are to reside, at least part of the time. The Greek god Poseidon built the walls of Troy, according to the *Iliad* (21:446–447). At Ugarit, Baal's temple was designed and built by Kothar-wa-Hasis, the god of arts and crafts. The Israelite King David gave his son Solomon plans for the Temple drawn up by Yahweh's (the Lord's) own hand (1 Chronicles 28:19).

National policy went hand in hand with theology. Ashur was the national deity of Assyria; the kings of Assyria were in theory his chief executive officers. Thus Sennacherib, king of Assyria, in undertaking a military campaign, recorded that he did so not on his own initiative but in conformity with Ashur's will: "In my second campaign, Ashur my Lord impelled me." When the Hebrews and Ammonites had a border dispute, Jephthah told the Ammonites: "Will you not possess what Chemosh your god gives you to possess? And all that the Lord our God has dispossessed before us, we will possess" (Judges 11:24). There was no such thing as secular policy in the ancient Middle East.

Since the king was the human agent of the god, he was exalted above other men. In Israel, the king was chosen by God to rule his people. God's representative was a priest or prophet who consecrated the king by anointing his head with oil. But the king of Israel was not divine, neither while on the throne nor after death.

The divinity of kings evoked certain fictions. By sucking the breasts of goddesses, crown princes imbibed a source of divinity. The baby pharaoh sucking the breasts of Isis (who was perhaps in real life represented by her high priestess) is a common motif in Egyptian art. In Mesopotamia, it was not the usual practice for kings to claim divinity, but now and then it cropped up. Naram-Sin (23rd century BC) prefixed the sign for divinity before his name and was officially a god. The same usage is attested among kings of the 3rd dynasty of Ur (*c.* 2112 BC–2004 BC).

VIEWS OF BASIC VALUES AND ENDS OF HUMAN LIFE

Ethical emphases

The good life was one lived in accord with the regulations of one's god. In the realm of ethics and morals there was more international uniformity than there was in taboo and ritual. Honesty and kindness were universally recognized as good, theft and murder as bad. Wisdom literature tended to stress the same virtues and to condemn the same vices, regardless of the region and cult. It remained for the prophets of Israel to single out uncompromising virtue as the overriding consideration in the good life required by God. The most important factor in that system was "social justice," whereby the weak was always protected in conflicts of interest with the strong. This had an important place in what may be called "international religion"—*i.e.,* that governing relations between men from different areas belonging to different cults. That level of religion, called "fear of the gods," is tested when the strong man confronts the weak. The strong man who injures the weak lacks the fear of the gods; the strong man who helps the weak has the fear of the gods. This was religion transcending all the regional cults, and it came into play when strangers abroad were at the mercy of the local inhabitants. Odysseus in a foreign land wanted to know if the people there feared the gods or were lawless so that no stranger was safe (*Odyssey* 9:176). Abraham, too, was concerned in Philistia lest the inhabitants might kill him because there was no "fear of God(s)" (Genesis 20:11). Men of all nations and all cults knew that only among god-fearing men was there decency or safety.

There was another common trend in international religion. No matter how polytheistic a cult may have been, it left a place for the god shared by all peoples. Theos, "God" (not merely "a god"), is in Homer; *pa netjer,* "the God," occurs in Egyptian exactly like Elohim, "(the) God," in Hebrew. Nebuchadrezzar II, the 7th–6th-century-BC Babylonian king, made Zedekiah, the Judaean king, swear by Elohim (2 Chronicles 36:13), the God of the universe for Babylonians and Hebrews alike. Similarly, when the Hebrews spoke of truth uttered by Pharaoh Necho, which fell on the deaf ears of the Judaean King Josiah, the text (2 Chronicles 35:21) states that Elohim, "God," had spoken through the mouth of the pharaoh.

In Egyptian religion (followed by Judaism, Christianity, and Islām), the concept of a happy afterlife depending on one's ethical and moral record in this world was developed. Vignettes in the various Egyptian books of the dead show the deceased's heart being weighed against the feather of truth in the balances before the scribe god Thoth, who records the text. When the Bible speaks of God as "who tests the heart and the kidneys" (Psalms 7:9; Jeremiah 11:20 and 20:12) it refers to the same concept.

MYTHS AS THE BASIC MODE OF RELIGIOUS THOUGHT

Purpose of myths

Myths were developed to account for the cosmos. How did the gods bring heavens, earth, plants, beasts, and human beings into existence? What is the divine origin of human institutions and of the ecumene? What divine process is responsible for prosperity or failure? To explain such basic questions, etiological (origin or causal) myths were developed. For example, the attraction between man and woman (and the consequent institution of marriage) is explained by the myth that primeval man was one creature, subsequently divided into two parts, male and female, which are attracted to one another to regain their pristine unity. Aristophanes expresses this theory of sexual attraction in Plato's *Symposium.* Genesis relates the same theory in the familiar myth that a rib, taken out of Adam, was fashioned into Eve; and precisely because woman was taken out of man, man forsakes his father and mother to cleave unto his wife so that they become one flesh.

Myths are often invoked in magic (which, unlike religion, aims at compelling, instead of imploring, the gods). To banish evil from the life of a client, the magician may invoke the cosmic myth whereby the forces of good triumph over the forces of evil. Evil is depicted on a seal of the Akkad period (late 3rd millennium BC) in Mesopotamia as a seven-headed monster whose heads are being successively killed by good anthropomorphic (human-form) beings. At Ugarit, in mythological poems of the late Bronze Age, the good gods Baal and Anath slay the wicked Leviathan of the Seven Heads, providing the precedent for the victory of good over evil. The Hebrews also nurtured this myth whereby God slays the many-headed Leviathan (Psalms 74:14) and will do so again at the end of days, to quell evil and establish good for all eternity (Isaiah 27:1).

ASSOCIATION OF RELIGION WITH THE ARTS AND SCIENCES

Religion in the ancient Middle East was associated with both the arts and the sciences, though in the literature of the area it is difficult to disentangle the secular from the sacred. Hymns, at one level, and omen or ritual texts, at another level, are clearly religious. Yet it would be difficult to categorize the Gilgamesh epic of Mesopotamia or the Homeric epics of Greece as definitely either secular or religious. They deal with human events or worldly problems, but the gods are constantly on hand. The same may be said for two Ugaritic epics, the epic of Keret and the epic of Daniel and Aqhat, which date from the late Bronze Age. This also holds for the patriarchal narratives in the biblical book of Genesis about Abraham, Isaac, and Jacob, in which God and his messengers play the same kind of role in human affairs as do the gods in the Homeric or Ugaritic epics.

Religion had close ties with science as well as with literature and art. Astronomy, mathematics, and time

reckoning are sciences in which the ancient Middle East made great strides at an early date, long before 3000 BC. Heavenly bodies were at the same time both deities and personified numbers. The planet Venus was the "star" that the Assyrians and Babylonians called Ishtar, which was at the same time both the goddess Ishtar and the deified number 15. The Moon was not only Earth's satellite but also the lunar deity Sin and the deified number 30. The most perfect number was one, for by advancing from zero to one men believed they proceeded from nonexistence to existence. Moreover, all other whole numbers were regarded as multiples of one, representative of the Creator, the Prime Mover, of the universe. The Egyptians called Re "the one One"; the Babylonians identified the divine "One" with Anu, the god of heaven. When the Hebrew prophet Zechariah (14:9) proclaimed "on that day the Lord will be one and his name One," he indicated that the Hebrews, like their neighbours, reckoned with sacred numbers and saw in the number one a symbol of the Creator. Biblical monotheism, therefore, has more than one dimension, including not only the monotheistic principle that there is one God and none beside him but also the mathematical principle of the primacy of "one" and its deification as the Prime Mover.

Significance of the number one

THE ROLE OF MAGIC

The loftier trends of ancient Middle Eastern religion did not as a rule threaten to eliminate magic. White, or protective, magic was never seriously discouraged. Black, or destructive, magic was frowned on by organized society, regardless of whether the official religion was monotheistic or polytheistic, because black magic makes its victims unfit for functioning productively in society. Section II of the Babylonian king Hammurabi's (Hammurapi's) code punishes witchcraft (as well as false accusations of witchcraft) with the death penalty. Moreover, all organized religion tended to oppose magic that circumvented the official clergy. King Saul of Israel had characteristically banned sorcery, driving it underground. Yet when he wanted guidance from the dead prophet Samuel, Saul consulted the Witch of Endor, who was practicing her art illegally (1 Samuel 28:6–25). She was able to call up the spirit of the prophet from the underworld, which, incidentally, illustrates one of the reasons why society opposes spiritualism. The witch, by claiming to bring the greatest authorities of the past onto the current scene, threatens the authority of the establishment.

The Letters to the Dead of pharaonic Egypt were written by living persons to the dead in order to achieve practical results, in keeping with the pragmatic, down-to-earth nature of the ancient Egyptians. It was unquestioningly assumed that the dead continued to exert influence on the living. Difficulties experienced by widows, widowers, and other survivors were attributed to the malevolence or negligence of the ungrateful dead who failed to defend their dear ones in the land of the living.

The letters were most often inscribed on ceramic vessels but were sometimes written on papyrus, linen, or even on a stela. They were deposited in tombs, not necessarily those of the persons addressed. It was believed that all burials were part of one interconnected system and that the mail would be delivered to the deceased addressee as long as it was posted anywhere in this network.

The writers sometimes remind the deceased addressee of the water and offerings they have brought to the tomb. Occasionally they threaten to discontinue such services if the deceased persists in refusing to help them. A frequent grievance is that malevolent persons (often relatives) are defrauding the rightful heirs of the deceased person's estate. The writer may even vow to take legal action against the dead in the divine court of the West (*i.e.*, of the realm of the dead).

One of the letters, known as the Leiden Papyrus, is particularly interesting because of the light it sheds on Egyptian life as well as on the relations between the living and the dead. The author is a widower who has been in a bad state since his wife's death. He is convinced that his misfortunes are due to his late wife's ill will. In the letter he reminds her that he was a model husband and threatens to testify against her in the court of the West. He goes on to say that he was a young and busy officer in the pharaoh's service at the time he married her. In spite of the pressures of his important duties, he writes, he stood by his wife and did not abandon her. He even made the soldiers under his command defer to her and render service to her. Moreover, he refrained from having affairs with other women. Before his wife's death he was assigned a mission to the wild south, on which he could not take her. Nevertheless, he provided for all her needs and gave nothing to other women. When she fell ill he engaged a skillful physician who gave her the best possible care. While death was overcoming her, he virtually abstained from eating and drinking for eight months. When he finally returned home to Memphis, he gave her a first-class funeral, complete with a shroud of the finest Upper-Egyptian linen. At the time of the letter, three years have passed since the wife's death. During this time he has lived alone and remained faithful to his departed wife. Yet in spite of this flawless record, she has been afflicting him and behaving like one who does not know the difference between right and wrong. He has therefore decided to prosecute her. In closing the letter he reaffirms his fidelity, declaring that he has not touched any of the female members of the household.

Religious practices and institutions

NATURE: THE FRAMEWORK OF IDEAS AND PRACTICES

Fertility of agriculture, of edible animals, and of the human population was a paramount factor in the life and religion of the ancient Middle East. The forms that the fertility rites assumed varied from region to region, depending on climate and geography. Rain and dew were all-important in Canaan but of little significance in Egypt. In both areas water was crucial, but the source of the life-giving water was entirely different. The agricultural year varied in the two regions. In Egypt the year was divided into three seasons: inundation, sowing, and harvest. In Canaan there were two seasons: the winter, characterized by rainfall, and the summer, characterized by dew. The

The agricultural year



Egyptian sepulchral stela by Qaha, 19th dynasty.
(Top) The Syrian fertility goddess Qudsh standing on a lion in the presence of (left) the Egyptian fertility god Min and (right) a Syrian god holding a spear and the Egyptian symbol of life. (Bottom) The Syrian goddess Anath, seated, and worshipers. In the British Museum.

Reproduced by courtesy of the Trustees of the British Museum

year was punctuated by different agricultural activities, as is indicated in the Gezer Calendar, in which all 12 months are accounted for as times of profitable agricultural activity, with harvests in the rainless summer as well as in the green winter. Anxiety was caused by the uncertainty of rain in the rainy season and of dew in its season. All of the regions of the ancient Middle East schematized the blessing of good years and the threat of bad years in terms of seven-year cycles. A Mesopotamian text illustrating this is the Gilgamesh epic (8:101–113), in which the slaying of the hero Gilgamesh would initiate seven lean years. At Ugarit the slaying of the hero Aqhat evokes a curse depriving the land of rain and dew for seven (or, climactically, eight) years. The seven lean and seven fat years in the biblical story of Joseph in Egypt reflect the same system. In Egypt, of course, rain and dew are out of the picture; instead, generous Nile risings mean prosperity; inadequate risings in the season of inundation spells misery. A text of the Ptolemaic period (4th–1st century BC), purporting to record events of the Pyramid age, tells of seven lean years in the reign of Djoser (3rd dynasty; *i.e., c.* 2650–*c.* 2575 BC). The pharaoh appealed to the gods, who responded by restoring an abundant flow of the Nile.

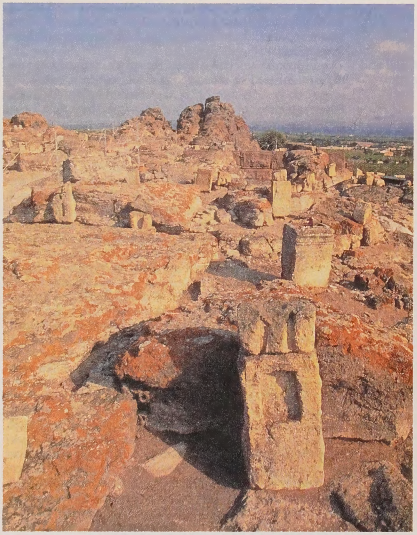
The population desired the normal pattern of times and seasons, so that "seedtime and harvest, cold and heat, summer and winter, day and night, shall not cease" (Genesis 8:22). But since the seasonal pattern is not dependable, the need for order evoked a system of cycles, notably the sabbatical, or seven-year, cycle. The sabbatical year was the seventh year, and the jubilee year followed seven sabbatical cycles. This was a pervasive system in the ancient Middle East. A Ugaritic liturgical text specially designed for this phenomenon aims at terminating a sabbatical cycle of privation and ushering in one of fertility by celebrating the birth and triumphal entrance of the deities Shahar ("Dawn") and Shalim ("Dusk"), whose advent brings an abundance of food and wine.

Fertility rites

It was only natural that fertility rites should include sexual myths that were acted out dramatically. The Ugaritic text just alluded to describes El, the head of the pantheon, copulating with two human women. This has echoes in Hosea and Ezekiel where God, as in the Canaanite literary tradition, is referred to as having a love affair with two women, symbolizing Judah and Israel. The Hebrews, however, eventually eliminated sex from their official theology as well as from their religious practices. Up to the time of King Josiah's reform (621 BC) there was a women's cult of Asherah (under *qedeshim* auspices [consecrated for fertility practices], according to 2 Kings 23:7) in the Jerusalem Temple, alongside the male cult of Yahweh. Asherah's devotees considered her the chief wife of Yahweh, even as she was the wife of El, head of the Canaanite pantheon, for in the Bible El is identified with Yahweh. But Josiah eliminated the cult of Asherah, and official Judaism has since then left no place for other gods, which meant the elimination of every goddess. Popular religion, to be sure, persisted in the female fertility principle until the destruction of the Temple in 586 BC. In Judaean excavations Astarte figurines were found in private homes down to that time. Further purification of the Hebrew religion, which was intensified by the catastrophe of 586, put an end to the practice of pagan fertility rites, including the use of goddess figurines. Without goddesses there could be no sexual activity in the pantheon, and thus Judaism has developed without a divine mother figure.

The ancient Middle East made a place for homosexuality and bestiality in its myths and rites. In the Asherah cult the *qedeshim* priests had a reputation for homosexual practices, even as the *qedeshot* priestesses for prostitution. Israel eventually banned both the *qedeshim* and *qedeshot,* while in Ugarit the *qedeshim* and *kohanim* were priestly guilds in equally good standing. Baal is portrayed in Ugaritic mythology as impregnating a heifer to sire the young bull god. The biblical book of Leviticus (18:22–27) bans homosexuality and bestiality expressly because the Canaanite population had been practicing those rites, which the Hebrews rejected as abominations.

Phoenician/Punic sites include an area called the *tophet* that contains large numbers of infant burials. One explanation of the *tophet* is that it reflects a major aspect of a fertility cult in which the first-born child belonged to the deity. The deity rewarded the parents who had sacrificed their child with future fertility. In the Hebrew Bible, just as the firstfruits of the harvest belong to God, so do the first-born of the people and their domestic animals (Exodus 13:1, 12–13, 15).



The *tophet* at Sulcis (Sardinia).
From *The Phoenicians,* © 1988 Gruppo Editoriale Fabbri, Milan; photograph: Alberto Bertoldi

The actual cases in the literature do not always specify infant sacrifice. The Bible describes how King Mesha of Moab sacrificed his crown prince to avert a military disaster (2 Kings 3:27). King Ahaz of Judah sacrificed his son in pagan fashion (2 Kings 16:3). King Manasseh of Judah sacrificed his sons by fire (2 Chronicles 33:6), filling Jerusalem with innocent blood.

The Jewish practice of redeeming a first-born son at the age of one month (Numbers 18:16–17) appears to be a milder substitute for the practice of child sacrifice. Another alternative to sacrificing a child was to dedicate it to the service of God. Hannah, by fulfilling her vow to ded-



From *The Phoenicians,* © 1988 Gruppo Editoriale Fabbri, Milan; photograph: Alberto Bertoldi

One of the Urns in the *tophet* at Sulcis, in which the skeletons of infants were found.

icate her first-born, Samuel, to God's service (1 Samuel 1:27–28) was rewarded by the birth of five other children whom she and her husband could keep for themselves (1 Samuel 2:20–21).

Ritual and myth

According to ancient views, the myth came first, and the rite imitated or reenacted it. This sequence, however, is not necessarily the order in which religion develops. Rites can be very tenacious, and when the origin of a rite has been forgotten, a myth has often been invented to explain it.

TYPES OF RELIGIOUS ORGANIZATION AND AUTHORITY

Religion occurs at different levels of society: personal, familial, local, national, and international. At the personal and international extremes there is need for but little organization. And yet in religion, as the people of the ancient Middle East saw it, there was a progression from one stage to the next. In the early myths of Genesis, God and Noah have direct personal relations. This leads to a covenant between God and all who went out of the ark: birds and beasts as well as mankind (Genesis 9:9–10). Through the sons of Noah and their descendants, who form the nations of the world (Genesis 10), there is a theoretical progress to international religion. This scheme of the relations between God and mankind, from the personal to the universal level, mirrors the historical record of religion. Judaism (followed later by Christianity and Islām) traces "the Religion" back to Abraham, who had personal and direct relations with God, as was customary in the ancient Middle Eastern milieu. Abraham's intimacy with God is similar to the intimacy between Odysseus and the Greek goddess Athena. The next step is a covenant between a particular deity and a particular person, binding the two together in a contractual relationship for all eternity from generation to generation. Such covenants were not rare; the Hittite King Hattusilis III made such a covenant with Ishtar. Abraham's covenant is unique simply because it was the only one destined to last in history.

The descendants of able men who established a dynasty or tradition would worship the God of their father, or fathers, and adhere to the original covenant. Genesis 31 portrays Jacob and Laban swearing by their respective ancestral gods: Jacob by the god(s) of Abraham and Laban by the god(s) of Nahor. Once a group expanded into a federation of clans or tribes, religious organization became necessary. A central shrine (such as the one at Shiloh in Israel) for amphictyonic (religious confederational) pilgrimage festivals required a professional priesthood and other religious personnel to take care of sacrifices, give oracular guidance, interpret dreams and omens, as well as to provide instruction. In an amphictyony of 12 tribes, each tribe could render federal service for religious and secular purposes, one month each year. A special tribe (such as the Levites in Israel, or the Magians in Iran) could be dedicated full-time to cultic duties.

Professional priesthood

A greater degree of centralization and organization of the cult would generally follow from the establishment of a powerful state. The cult of Marduk of Babylon spread in importance and influence because Babylon became the capital of a powerful kingdom in the time of Hammurabi (18th century BC) and of a mighty empire during the reign of Nebuchadrezzar (604–562 BC). The Egyptian cult of Amon-Re not only became powerful but took on the form of a universal religion as a result of the military and political triumphs of the rulers of Thebes, particularly during the reign of Thutmose III (1479–26 BC). Under Solomon, Jerusalem became the centre of a great commercial empire. The Temple of Solomon and its God, the God of Israel, were catapulted into an international prominence that was quite different from the national status that marked the extent of Hebraic religion previously. The new internationalism of Israel's involvements paved the way for the universality of the views of the prophets. The God of Israel was subsequently concerned with all mankind and not merely with one people in one small land. This ultimately meant the transformation of biblical religion from the cult of a single people to a more subtle, spiritual movement that required different organization and different personnel. The priesthood became defunct with the destruction of Herod's Temple and the cessation of sacrifices in AD 70. The new religious leaders (rabbis) were rather teachers and spiritual guides who were united by dedication to the same scripture. The spread of the devotees over the face of the earth meant that they were now divided into regional groups, serving under different sovereigns, and the individual Jewish communities were organized independently, each with its own house of worship.

Laws of purity

There were various devices for holding an ethnic-religious group together even though it might be fragmentized into scattered communities. Laws of purity, especially those pertaining to diet, kept different groups apart. Each normally respected the other's rules, but the fact that each group had different taboos kept them from breaking bread together and mingling socially. They could do business with each other in the marketplace, but they could not fraternize in each other's homes. Above all, laws of purity were deterrents to intermarriage, the major factor that breaks up religious communities and encourages homogenization.

(C.H.G.)

A SURVEY OF ANCIENT MIDDLE EASTERN RELIGIONS

Mesopotamian religions

The term Mesopotamian religions serves generally to designate the religious beliefs and practices of the Sumerians and Akkadians, who inhabited ancient Mesopotamia (modern Iraq) in the millennia before the Christian era. These beliefs and practices form a single stream of tradition. Sumerian in origin, it was added to and subtly modified by the Akkadians (Semites who emigrated into Mesopotamia from the west at the end of the 4th millennium BC), whose own beliefs were in large measure assimilated to, and integrated with, those of their new environment. For historical background, see MESOPOTAMIA, THE HISTORY OF ANCIENT.

As the only available intellectual framework that could provide a comprehensive understanding of the forces governing existence and also guidance for right conduct in life, religion ineluctably conditioned all aspects of ancient Mesopotamian civilization. It yielded the forms in which that civilization's social, economic, legal, political, and military institutions were, and are, to be understood, and it provided the significant symbols for poetry and art. In many ways it even influenced peoples and cultures outside Mesopotamia, such as the Elamites to the east, the Hurrians and Hittites to the north, and the Aramaeans and Israelites to the west.

HISTORICAL DEVELOPMENT

Cultural background. Human occupation of Mesopotamia—"the land between the rivers" (*i.e.*, the Tigris and Euphrates)—seems to reach back farthest in time in the north (Assyria), where the earliest settlers built their small villages some time around 6000 BC. The prehistoric cultural stages of Ḥassūna-Sāmarrā' and Ḥalaf (named after the sites of archaeological excavations) succeeded each other here before there is evidence of settlement in the south (the area that was later called Sumer). There, the earliest settlements, such as Eridu, appear to have been founded around 5000 BC, in the late Ḥalaf period. From then on the cultures of the north and south move through a succession of major archaeological periods that in their southern forms are known as Ubaid, Warka, Protoliterate (during which writing was invented), and Early Dynastic, at the end of which—shortly after 3000 BC—recorded history begins. The historical periods of the 3rd millennium are, in order: Akkad, Gutium, 3rd dynasty of Ur; those of the 2nd millennium: Isin-Larsa, Old Babylonian, Kassite, and Middle Babylonian; and those of the 1st millen-

Periodization of Mesopotamian history

nium: Assyrian, Neo-Babylonian, Achaemenian, Seleucid, and Parthian.

Politically, an early division of the country into small independent city-states, loosely organized in a league with the centre in Nippur, was followed by a unification by force under King Lugalzagesi (*c.* 2375–2350 BC) of Uruk, just before the Akkadian period. The unification was maintained by his successors, the kings of Akkad, who built it into an empire, and—after a brief interruption by Gutian invaders—by Utuhegal (*c.* 2116–*c.* 2110) of Uruk and the rulers of the 3rd dynasty of Ur (*c.* 2112–*c.* 2004 BC). When Ur fell, around 2000 BC, the country again divided into smaller units, with the cities Isin and Larsa vying for hegemony. Eventually Babylon established a lasting national state in the south, while Ashur dominated a similar rival state, Assyria, in the north. From the middle of the 1st millennium onward, Assyria built an empire comprising, for a short time, all of the ancient Middle East. This political and administrative achievement remained essentially intact under the following Neo-Babylonian and Persian kings down to Alexander's conquest (331 BC).

Stages of religious development. The religious development—as indeed that of the Mesopotamian culture generally—was not significantly influenced by the movements of the various peoples into and within the area—the Sumerians, Akkadians, Gutians, Kassites, Hurrians, and Aramaeans (or Chaldeans). Rather it forms a uniform, consistent, and coherent Mesopotamian tradition changing in response to its own internal needs of insights and expression. It is possible to discern a basic substratum involving worship of the forces in nature—often visualized in nonhuman forms—especially those that were of immediate import to basic economic pursuits. Many of these figures belong to the type of the "dying god" (a fertility deity displaying death and regeneration characteristics) but show variant traits according to whether they are powers of fertility worshiped by marsh men, orchard growers, herders, or farmers. This stage may be tentatively dated back to the 4th millennium BC and even earlier. A second stage, characterized by a view of the gods as human in shape and organized in a polity of a primitive democratic cast in which each deity had his or her special offices and functions, overlaid and conditioned the religious forms and characteristics of the earlier stage during the 3rd millennium BC. Lastly, a third stage, characterized by a growing emphasis on personal religion involving concepts of sin and forgiveness and by a change of the earlier democratic divine polity into an absolute monarchical structure dominated by the god of the national state—to the point of pious abstention from all human initiative, in absolute faith and reliance on divine intervention—characterizes the 2nd and 1st millennia BC. As a result of this development, since the ancient Mesopotamians were intensely conservative in religious matters and unwilling to discard anything of a hallowed past, the religious data of any period, and particularly those of the later periods, are a condensed version of earlier millennia that must be carefully analyzed and placed in proper perspective before it can be evaluated.

THE LITERARY LEGACY: MYTH AND EPIC

Present knowledge of ancient Mesopotamian religion rests almost exclusively on archaeological evidence recovered from the ruined city-mounds of Mesopotamia during the last century or so. Of greatest significance is the literary evidence, texts written in cuneiform (wedge-shaped) script on tablets made of clay or, for monumental purposes, on stone. Central, of course, are the specifically religious texts comprising god lists, myths, hymns, laments, prayers, rituals, omen texts, incantations, and other forms; however, since religion permeated the culture, giving form and meaning to all aspects of it, any written text, any work of art, or any of its material remains are directly or indirectly related to the religion and may further scholarly knowledge of it.

Importance of archaeological discoveries

Among the archaeological finds that have particularly helped to throw light on religion are the important discoveries of inscribed tablets with Sumerian texts in copies of Old Babylonian date (*c.* 1800–*c.* 1600 BC) at Nippur and Ur, the Sumerian and Akkadian texts of the 2nd and 1st millennia from Ashur and Sultantepe, and particularly the all-important library of the Assyrian king Ashurbanipal (reigned 668–627 BC) from Nineveh. Of nonliterary remains, the great temples and temple towers (ziggurats) excavated at almost all major sites—*e.g.*, Eridu, Ur, Nippur, Babylon, Ashur, Kalakh (biblical Calah), Nineveh—as well as numerous works of art from various periods, are important sources of information. The Uruk Vase, with its representation of the rite of the sacred marriage, the Naram-Sin stela (inscribed commemorative pillar), the Ur-Nammu stela, and the stela with the Code of Hammurabi (Babylonian king, 18th century BC), which shows at its top the royal lawgiver before the sun god Shamash, the divine guardian of justice, are important works of art that may be singled out. Other important sources are the representations on cylinder seals and on boundary stones (*kudurrus*), both of which provide rich materials for religious iconography in certain periods.

In working with, and seeking to interpret, these varied sources two difficulties stand out: the incompleteness of the data and the remoteness of the ancients from modern man, not only in time but also in experience and in ways of thought. Thus, for all periods before the 3rd millennium, scholars must rely on scarce, nonliterary data only, and, even though writing appears shortly before that millennium, it is only in its latter half that written data become numerous enough and readily understandable enough to be of significant help. It is generally necessary, therefore, to interpret the scarce data of the older periods in the light of survivals and of what is known from later periods, an undertaking that calls for critical acumen if anachronisms are to be avoided. Also, for the later periods, the evidence flows unevenly, with perhaps the middle of the 2nd millennium the least well-documented and hence least-known age.

As for the difficulties raised by differences in the ways of thinking between modern man and the ancients, they are of the kind that one always meets in trying to understand something unfamiliar and strange. A contemporary inquirer must keep his accustomed values and modes of thought in suspension and seek rather the inner coherence and structure of the data with which he deals, in order to enter sympathetically into the world out of which they came, just as one does, for example, in entering the sometimes intensely private world of a poem, or, on a slightly different level, in learning the new, unexpected



Detail of the stela inscribed with Hammurabi's code, showing the king before the god Shamash; bas-relief from Susa, 18th century BC. In the Louvre, Paris.

Giraudon—Art Resource/EB Inc.

meanings and overtones of the words and phrases of a foreign language.

Sumerian literature. Mesopotamian literature originated with the Sumerians, whose earliest known written records are from the middle of the 4th millennium BC. It constitutes the oldest known literature in the world; moreover, inner criteria indicate that a long oral-literary tradition preceded, and probably coexisted with, the setting down of its songs and stories in writing. It may be assumed, further, that this oral literature developed the genres of the core literature. The handbook genres, however, in spite of occasional inclusions of oral formula—*e.g.,* legal or medical—may generally be assumed to have been devised after writing had been invented, as a response to the remarkable possibilities that writing offered for amassing and organizing data.

Functions of Mesopotamian religious literature

The purpose underlying the core literature and its oral prototypes would seem to have been as much magical as aesthetic, or merely entertaining, in origin. In magic, words create and call into being what they state. The more vivid and expressive the words are, the more they are believed to be efficacious—so by its expressiveness literature forms a natural vehicle of such creativity. In ancient Mesopotamia its main purpose appears to have been the enhancement of what was seen as beneficial. With the sole exception of wisdom literature, the core genres are panegyric in nature (*i.e.,* they praise something or someone), and the magical power and use of praise is to instill, call up, or activate the virtues presented in the praise.

That praise is of the essence of hymns, for instance, is shown by the fact that over and over again the encomiast, the official praiser, whose task it was to sing these hymns, closed with the standing phrase: "O [the name of a deity or human hero], thy praise is sweet." The same phrase is common also at the end of myths and epics, two further praise genres that also belonged in the repertoire of the encomiast. They praise not only in description but also in narrative, by recounting acts of valour done by the hero, thus sustaining and enhancing his power to do such deeds, according to the magical view.

In time, possibly quite early, the magical aspect of literature must have tended to fade from people's consciousness, yielding to more nearly aesthetic attitudes that viewed the praise hymns as expressions of allegiance and loyalties and accepted the narrative genres of myth and epic for the enjoyment of the story and the values expressed, poetic and otherwise.

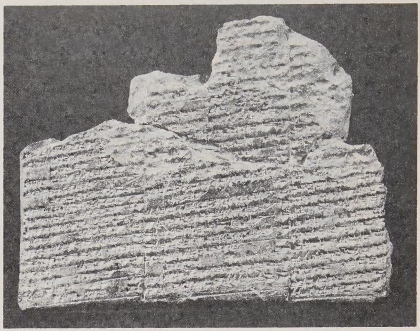
Hymns, myths, and epics all were believed to sustain existing powers and virtues by means of praise, but laments were understood to praise blessings and powers lost, originally seeking to hold on to and recall them magically, through the power in the expression of intense longing for them and the vivid representation of them. The lamentation genre was the province of a separate professional, the elegist. It contained dirges for the dying gods of the fertility cults and laments for temples and cities that had been destroyed and desecrated. The laments for temples—which, as far as is known, go back no earlier than to the 3rd dynasty of Ur—were used to recall the beauties of the lost temple as a kind of inducement to persuade the god and the owner of the temple to restore it.

Penitential psalms lament private illnesses and misfortunes and seek to evoke the pity of the deity addressed and thus to gain divine aid. The genre apparently is late in date, most likely Old Babylonian (*c.* 19th century BC), and in it the element of magic has, to all intents and purposes, disappeared.

The core genres of Mesopotamian literature were developed by the Sumerians apparently as oral compositions.

The significance of writing

Writing, which is first attested at the middle of the 4th millennium BC, was in its origins predominantly logographic (*i.e.,* each word or morpheme was represented by a single graph or symbol) and long remained a highly imperfect means of rendering the spoken word. Even as late as the beginning of the Early Dynastic III period in southern Mesopotamia, in the early 3rd millennium, the preserved written literary texts have the character of mnemonic (memory) aids only and seem to presuppose that the reader has prior oral knowledge of the text.



Tablet recounting the Sumerian story of the Flood, *c.* 2000–1500 BC, excavated from Nippur, Iraq. In the University Museum, University of Pennsylvania, Philadelphia.
By courtesy of the University Museum, University of Pennsylvania, Philadelphia

As writing developed more and more precision during the 3rd millennium BC, more oral compositions seem to have been put into writing. With the 3rd dynasty of Ur a considerable body of literature had come into being and was being added to by a generation of highly gifted authors. Fortunately for its survival, this literature became part of the curriculum in the Sumerian scribal schools. It was studied and copied by student after student so that an abundance of copies, reaching a peak in Old Babylonian times, duplicated and supplemented each other as witnesses to the text of the major works. Fifty or more copies or fragments of copies of a single composition may support a modern edition, and many thousands more copies probably lie unread, still buried in the earth.

Myths. The genre of myths in ancient Mesopotamian literature centres on praises that recount and celebrate great deeds. The doers of the deeds (creative or otherwise decisive acts), and thus the subjects of the praises, are the gods. In the oldest myths, the Sumerian, these acts tend to have particular rather than universal relevance, which is understandable since they deal with the power and acts of a particular god with a particular sphere of influence in the cosmos. An example of such myths is the myth of "Dumuzi's Death," which relates how Dumuzi (Producer of Sound Offspring), the power in the fertility of spring, dreamed of his own death at the hands of a group of deputies from the netherworld and how he tried to hide himself but was betrayed by his friend after his sister had resisted all attempts to make her reveal where he was.

"Dumuzi's Death"

A similar, very complex myth, "Inanna's Descent," relates how the goddess Inanna (Lady of the Date Clusters) set her heart on ruling the netherworld and tried to depose her older sister, the queen of the netherworld, Ereshkigal (Lady of the Greater Earth). Her attempt failed, and she was killed and changed into a piece of rotting meat in the netherworld. It took all the ingenuity of Enki (Lord of Sweet Waters in the Earth) to bring Inanna back to life, and even then she was released only on condition that she furnish a substitute to take her place. On her return, finding her young husband Dumuzi feasting instead of mourning for her, Inanna was seized with jealousy and designated him as that substitute. Dumuzi tried to flee the posse of deputies who had accompanied Inanna, and with the help of the sun god Utu (Sun), who changed Dumuzi's shape, he managed to escape, was recaptured, escaped again, and so on, until he was finally taken to the netherworld. The fly told his little sister Geshtinanna where he was, and she went in search of him. The myth ends with Inanna rewarding the fly and decreeing that Dumuzi and his little sister could alternate as her substitute, each of them spending half a year in the netherworld, the other half above with the living.

A third myth built over the motif of journeying to the netherworld is the myth of "The Engendering of the Moongod and his Brothers," which tells how Enlil (Lord Wind), when still a youngster, came upon young Ninlil (goddess of grain) as she—eager to be with child and disobeying her mother—was bathing in a canal where he would see her. He lay with her in spite of her pretending to protest and thus engendered the moon god Suen. For this offense Enlil was banished from Nippur and took the road to the netherworld. Ninlil, carrying his child, followed him. On the way Enlil took the shape first of the Nippur gatekeeper, then of the man of the river of the netherworld, and lastly of the ferryman of the river of the netherworld. In each such disguise Enlil persuaded Ninlil to let him lie with her to engender a son who might take Suen's place in the netherworld and leave him free for the world above. Thus three further deities, all underworld figures, were engendered: Meslamtaea (He Who Comes Out of the Meslam Temple), Ninazu (Water Sprinkler [?]), and Ennugi (the God Who Returns Not). The myth ends with a paean to Enlil as a source of abundance and to his divine word, which always comes true.

Most likely all of these myths have backgrounds in fertility cults and concern the disappearance of nature's fertility with the onset of the dry season or with the underground storage of food.

As Enlil is celebrated for engendering other gods that embody other powers in nature, so also was Enki in the myth of "Enki and Ninhursag," in which myth Enki lay down with Ninhursag (Lady of the Stony Ground) on the island of Dilmun (modern Bahrain), which had been allotted to them. At that time all was new and fresh, inchoate, not yet set in its present mold. There Enki provided water for the future city of Dilmun, lay with Ninhursag, and left her. She gave birth to a daughter, Ninshar (Lady Herb), on whom Enki in turn engendered the spider Uttu, goddess of spinning and weaving. Ninhursag warned Uttu against Enki, but he, proffering marriage gifts, persuaded her to open the door to him. After Enki had abandoned Uttu, Ninhursag found her and removed Enki's semen from her body. From the semen seven plants sprouted forth. These plants Enki later saw and ate and so became pregnant from his own semen. Unable as a male to give birth, he fell fatally ill, until Ninhursag relented and—as birth goddess—placed him in her vulva and helped him to give birth to seven daughters, whom Enki then happily married off to various gods. The story is probably to be seen as a bit of broad humour.

Not only the birth of gods but also the birth, or creation, of man is treated in the myths. The myth of "Enki and Ninmah" relates how the gods originally had to toil for their food, dig irrigation canals, and perform other menial tasks until, in their distress, they complained to Enki's mother, Nammu, who took the complaints to Enki. Enki remembered the engendering clay of the Apsu (*i.e.*, the fresh underground waters that fathered him), and from this clay, with the help of the womb goddesses and eight midwife goddesses led by Ninmah (another name for Ninhursag), he had his mother become pregnant with and give birth to man so that he could relieve the gods of their toil. At the celebration of the birth, however, Enki and Ninmah both drank too much beer and began to quarrel. Ninmah boasted that she could impair man's shape at will, and Enki countered that he could temper even the worst that she might do. So she made seven freaks, for each of which Enki found a place in society and a living. He then challenged her to alleviate the mischief he could do, but the creature he fashioned—a prematurely aborted fetus—was beyond help. The moral drawn by Enki was that both male and female contribute to the birth of a happy child. The aborted fetus lacked the contribution of the birth goddess in the womb.

The ordering, rather than the creation, of the world is the subject of another myth about Enki, called "Enki and World Order." Beginning with long praises and self-praises of Enki, it tells how he blessed Nippur (Sumer), Ur, Meluhha (Ethiopia), and Dilmun (Bahrain) and gave them their characteristics, after which he turned his attention to the Euphrates and Tigris rivers, to the marshes, the sea, and the rains, and then to instituting one facet after another of the economic life of Sumer: agriculture, housebuilding, herding, and so forth. The story ends with a complaint by Enki's granddaughter Inanna that she has not been given her due share of offices, at which he patiently pointed to various offices she had in fact been given and kindly added a few more.

Another myth about the world order but dealing with it from a very different point of view concerns Enlil's son, the rain god Ninurta, called from its opening word *Lugal-e* ("O King"). This myth begins with a description of the young king, Ninurta, sitting at home in Nippur when, through his general, reports reach him of a new power that has arisen in the mountains to challenge him—*i.e.*, Azag, son of Anu (Sky) and Ki (Earth), who has been chosen king by the plants and is raiding the cities with his warriors, the stones. Ninurta sets out in his boat to give battle, and a fierce engagement ensues, in which Azag is killed. Afterward Ninurta reorganizes his newly won territory, builds a stone barrier, the near mountain ranges or foothills (the *hursag*), and gathers the waters that used to go up into the mountains and directs them into the Tigris to flood it and provide plentiful irrigation water from Sumer. The *hursag* he presents as a gift to his mother, who had come to visit him, naming her Ninhursag (Lady of the *hursag*). Lastly he sits in judgment on the stones who had formed the Azag's army. Some of them, who had shown special ill will toward him, he curses, and others he trusts and gives high office in his administration. These judgments give the stones their present characteristics so that, for example, the flint is condemned to break before the much softer horn, as it indeed does when the horn is pressed against it to flake it. Noteworthy also is the way in which order in the universe, the yearly flood and other seasonal events, is seen—consonantly with Ninurta's role as "king" and leader in war—under the pattern of a reorganization of conquered territories.

Lugal-e

By courtesy of the Trustees of the British Museum



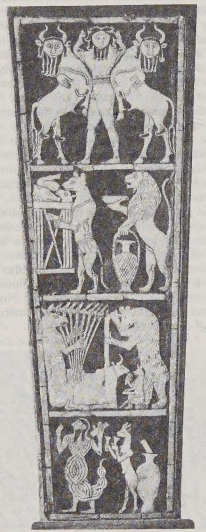
Shamash, the sun god, rising in the morning from the eastern mountains between (left) Ishtar (Sumerian Inanna), the goddess of the morning star, and (far left) Ninurta, the god of thunderstorms, with his bow and lion, and (right) Ea (Sumerian Enki), the god of fresh water, with (far right) his vizier, the two-faced Usmu.

Other myths about Ninurta are *An-gim dim-ma* and a myth of his contest with Enki. The first of these tells how Ninurta, on returning from battle to Nippur, was met by Enlil's page Nusku, who ordered him to cease his warlike clamour and not scare Enlil and the other gods. After long speeches of self-praise by Ninurta, further addresses to him calmed him and made him enter his temple gently. The second tale relates how he conquered the Thunderbird Ansud with Enki's help but missed the powers it had stolen from him, and how, resentful at this, he plotted against Enki but was outsmarted and trapped. Another Sumerian myth, the "Eridu Genesis," tells of the creation of man and animals, of the building of the first cities, and of the flood.

An-gim dim-ma

Epics. The genre of epics appears generally to be younger in origin than that of myths and apparently was linked—in subject matter and values—to the emergence of monarchy at the middle of the Early Dynastic period. The works that have survived seem, however, all to be of later date. A single short Sumerian epic tale, "Gilgamesh and Agga of Kish," is told in the style of primary epic. It deals with Gilgamesh's successful rebellion against his

overlord and former benefactor, Agga of Kish. More in the style of romantic epic are the stories of "Enmerkar and the Lord of Aratta," "Enmerkar and Ensuhkeshdanna," and the "Lugalbanda epic," all of which have as heroes rulers of the 1st dynasty of Uruk (*c.* 3500 BC) and deal with wars between that city and the fabulous city of Aratta in the eastern highlands. Gilgamesh, also of that dynasty, figures as the hero of a variety of short tales; some, such as "Gilgamesh and Huwawa" and "Gilgamesh and the Bull of Heaven," are in romantic epic style, and others, such as "The Death of Gilgamesh" and "Gilgamesh, Enkidu and the Netherworld," concern the inescapable fact of death and the character of afterlife.



Gold and shell-inlay mosaic from the soundbox of a harp found in the Royal Cemetery at Ur (*c.* 25th century BC). The registers show a bull-man wrestling with two bulls, a lion and dog acting as servants, a bear dancing to a harp played by a donkey, and a scorpion-man walking in front of a gazelle. In the University Museum, University of Pennsylvania, Philadelphia.

The University Museum, University of Pennsylvania (neg. no. 22097-99)

Akkadian literature. The first centuries of the 2nd millennium BC witnessed the demise of Sumerian as a spoken language and its replacement by Akkadian. Because of its role as bearer of Sumerian culture, as the language of religion, literature, and many arts, however, Sumerian (much as Latin in the Middle Ages) continued to be taught and spoken in the scribal schools throughout the 2nd and 1st millennia BC. New compositions were even composed in Sumerian. As time passed these grew more and more corrupt in grammar.

Akkadian, when it supplanted Sumerian as the spoken language of Mesopotamia, was not without its own literary tradition. Writing, to judge from Akkadian orthographic peculiarities, was very early borrowed from the Sumerians. By Old Babylonian times (*c.* 19th century BC), the literature in Akkadian, partly under the influence of Sumerian models and Sumerian literary themes, had developed myths and epics of its own, among them the superb Old Babylonian Gilgamesh epic (dealing with the problem of death; see below *Epics*) as well as hymns, disputation texts (evaluations of elements of the cosmos and society), penitential psalms, and not a few independent new handbook genres—*e.g.,* omina, rituals, laws and legal phrasebooks (often translated from Sumerian), mathematical texts, and grammatical texts. There was a significant amount of translation from Sumerian; translations include incantation series such as the *Utukke limnuti* ("The Evil Spirits"), laments for destroyed temples, penitential psalms, and others. The prestige of Sumerian as a literary language, however, is indicated by the fact that translations were rarely, if ever, allowed to supersede the original Sumerian text. The Sumerian text was kept with an interlinear translation to form a bilingual work.

The continued study and copying of literature in the schools, both Sumerian and Akkadian, by the middle of the 2nd millennium led to a remarkable effort of standardizing, or canonizing. Texts of the same genre were collected, often under royal auspices and with royal support, and were then sifted and finally edited in series that from then on were recognized as the canonical form. Authoritative texts were established for incantations, laments, omina, medical texts, lexical texts, and others. In myths and epics, such major and lengthy compositions as the Akkadian creation story *Enuma elish,* the Erra myth, the myth of Nergal and Ereshkigal, the Etana legend, the Gilgamesh epic, and the Tukulti-Ninurta epic were reworked or re-created.

Canonization of Mesopotamian religious literature

Of special interest are philosophical compositions, such as the Akkadian *Ludlul bel nemeqi,* "Let me praise the expert," and theodicies (justification of divine ways) that deal with the problem of the just sufferer, similar to the biblical Job. They constitute a high point in the genre of wisdom literature. From the 1st millennium BC the rise of factual historical chronicles and a spate of political and religious polemical writings reflecting the rivalry between Assyria and Babylonia deserve mention. Very late in the millennium, the first astronomical texts appeared.

Myths. The Akkadian myths are in many ways dependent on Sumerian materials, but they show an originality and a broader scope in their treatment of the earlier Sumerian concepts and forms; they address themselves more often to existence as a whole. Fairly close to Sumerian prototypes is an Akkadian version of the myth of "Inanna's Descent." An Old Babylonian myth about the Thunderbird Ansud, who stole the tablets of fates and was conquered by Ninurta, who was guided by Enki's counsel, is probably closely related to the Sumerian story of Ninurta's contest with Enki.

Also important is an Old Babylonian "Myth of Atrahasis," which, in motif, shows a relationship with the account of the creation of man to relieve the gods of toil in the "Enki and Ninmah" myth, and with a Sumerian account of the Flood in the "Eridu Genesis." The Atrahasis myth, however, treats these themes with noticeable originality and remarkable depth. It relates, first, how the gods originally had to toil for a living, how they rebelled and went on strike, how Enki suggested that one of their number—the god We, apparently the ringleader who "had the idea"—be killed and mankind created from clay mixed with his flesh and blood, so that the toil of the gods could be laid on man and the gods left to go free. But after Enki and the birth goddess Nintur (another name for Ninmah) had created man, man multiplied at such a rate that the din he made kept Enlil sleepless. At first Enlil had Namtar, the god of death, cause a plague to diminish mankind's numbers, but the wise Atrahasis, at the advice of Enki, had man concentrate all worship and offerings on Namtar. Namtar, embarrassed at hurting people who showed such love and affection for him, stayed his hand. Next Enlil had Adad, the god of rains, hold back the rains and thus cause a famine, but, because of the same stratagem, Adad was embarrassed and released the rains. After this, Enlil planned a famine by divine group action that would not be vulnerable as the earlier actions by individual gods had been. Anu and Adad were to guard the heavens, he himself earth, and Enki the waters underground and the sea so that no gift of nature could come through to man. The ensuing famine was terrible. By the seventh year one house consumed the other and people began eating their own children. At that point Enki—accidentally he main-

tained—let through a wealth of fish from the sea and so saved man. With this, however, Enlil's patience was at an end and he thought of the Flood as a means to get rid of humanity once and for all. Enki, however, warned Atrahasis and had him build a boat in which he saved himself, his family, and all animals. After the flood had abated and the ship was grounded, Atrahasis sacrificed, and the hungry gods, much chastened, gathered around the offering. Only Enlil was unrelenting until Enki upbraided him for killing innocent and guilty alike and—there is a gap in the text—suggested other means to keep human numbers down. In consultation with the birth goddess Nintur, Enki then developed a scheme of birth control by inventing the barren woman, the demon Pashittu who kills children at birth, and the various classes of priestesses to whom giving birth was taboo.

The role of Atrahasis as the hero of the Flood

The myth uses the motif of the protest of the gods against their hard toil and the creation of man to relieve it, which was depicted earlier in the Sumerian myth of "Enki and Ninmah," and also the motif of the Flood, which occurred in the "Eridu Genesis." The import of these motifs here is, however, new: they bring out the basic precariousness of man's existence; man's usefulness to the gods will not protect him unless he takes care not to annoy them, however innocently. He must stay within bounds; there are limits set for his self-expression.

A far more trustful and committed attitude toward the powers that rule existence finds expression in the seemingly slightly later Babylonian creation story, *Enuma elish,* which may be dated to the later part of the 1st dynasty of Babylon (*c.* 1894–*c.* 1595 BC). Babylon's archenemy at that time was the Sealand, which controlled Nippur and the country south of it—the ancestral country of Sumerian civilization. This lends political point to the battle of Marduk (thunder and rain deity), the god of Babylon, with the Sea, Tiamat; it also accounts for the odd, almost complete silence about Enlil of Nippur in the tale.

The origin of the gods

The myth tells how in the beginning there was nothing but Apsu, the sweet waters underground, and Tiamat, the sea, mingling their waters together. In these waters the first gods came into being, and generation followed generation. The gods represented energy and activity and thus differed markedly from Apsu and Tiamat, who stood for rest and inertia. True to their nature the gods gathered to dance, and in so doing, surging back and forth, they disturbed the insides of Tiamat. Finally, Apsu's patience was at an end, and he thought of doing away with the gods, but Tiamat, as a true mother, demurred at destroying her own offspring. Apsu, however, did not swerve from his decision, and he was encouraged in this by his page Mummu, "the original (watery) form." When the youngest of the gods, the clever Ea (Sumerian Enki), heard about the planned attack he forestalled it by means of a powerful spell with which he poured slumber on Apsu, killed him, and built his temple over him. He seized Mummu and held him captive by a nose rope.

In the temple thus built the hero of the myth, Marduk, was born. From the first he was the darling of his grandfather, the god of heaven, Anu, who engendered the four winds for him to play with. As they blew and churned up waves, the disturbing of Tiamat—and of a faction of the gods who shared her desire for rest—became more and more unbearable. At last these gods succeeded in rousing her to resistance, and she created a mighty army with a spearhead of monsters to destroy the gods. She placed her consort Kingu ("Task[?]") at the head of it and gave him absolute powers.

When news of these developments reached the gods there was consternation. Ea was sent to make Tiamat desist, and then Anu, but to no avail. Finally Anshar, god of the horizon and king of the gods, thought of young Marduk. Marduk proved willing to fight Tiamat but demanded absolute authority. Accordingly, a messenger was sent to the oldest of the gods, Lahmu and Lahamu ("Silt[?]"), to call the gods to assembly, and in the assembly the gods conferred absolute authority on Marduk, tested it by seeing whether his word of command alone could destroy a constellation and then again make it whole, hailed him king, and set him on the road of "security and obedience," a formula of allegiance that based his power and authority on the pressing need for protection of the moment.

In the ensuing encounter with Tiamat's forces Kingu and his army lost heart when they saw Marduk. Only Tiamat stood her ground, seeking first to throw him off his guard by flattery about his quick rise to leadership, but Marduk angrily denounced her and the older generation: "The sons (had to) withdraw (for) the fathers were acting treacherously, and (now) you, who gave birth to them, bear malice to the offspring." At this Tiamat, furious, attacked, but Marduk loosed the winds against her, pierced her heart with an arrow, and killed her. Kingu and the gods who had sided with her he took captive.

Having thus won a lasting victory for his suzerain, King Anshar, he gave thought to what he might do further. Cleaving the carcass of Tiamat, he raised half of her to form heaven, ordered the constellations, the calendar, the movements of Sun and Moon, and, keeping control of atmospheric phenomena for himself, made the Earth out of the other half of her, arranging its mountains and rivers. Having organized the various administrative tasks, he put their supervision in Ea's hands; to Anu he gave the tablets of fate he had taken from Kingu. His prisoners he paraded in triumphal procession before his fathers, and as a monument to his victory he set up images of Tiamat's monsters at the gate of his parental home. The gods were overjoyed to see him; Anshar rushed toward him and Marduk formally announced to him the state of security he had achieved. He then bathed, dressed, and seated himself on his throne, with the spear "Security and Obedience," named from his mandate, at his side. By now, however, the situation had subtly altered. The old fear and urgent need for protection was gone, but in its stead had come a promise held out by Marduk's organizational powers; so when the gods reaffirmed their allegiance to him as king they used a new formula: "benefits and obedience." From then on Marduk would take care of their sanctuaries and they, in turn, would obey him.

The building of Babylon

Marduk then announced his intention of building a city for himself, Babylon, with room for the gods when they come there for assembly. His fathers suggested that they move to Babylon themselves to be with him and help in the administration of the world he had created. Next, he pardoned the gods who had sided with Tiamat and had been captured, charging them with the building tasks. Grateful for their lives, they prostrated themselves before him, hailed him as king, and promised to do the building.

Pleased with their willingness, Marduk magnanimously wanted to relieve them even from this chore and planned to create man to do the toil for them. At the advice of his father Ea, he then had them indict Kingu as instigator of the rebellion. Kingu was duly sentenced and executed, and from his blood Ea created man. Then Marduk divided the gods into a celestial and a terrestrial group, assigned them their tasks in the cosmos, and allotted them their stipends. Thus freed from all burdens, the gods wanted to show their gratitude to Marduk, and as a token they took, of their own free will, for one last time, spade in hand to build Babylon and Marduk's temple Esagila. In the new temple the gods then assembled and distributed the celestial and terrestrial offices. The "great gods" went into session and permanently appointed the "seven gods of destinies," or better "of the decrees," who would formulate in final form the decrees enacted by the assembly. Marduk then presented his weapons, and Anu adopted the bow as his daughter and gave it a seat among the gods. Lastly, Marduk was enthroned, and after the gods had prostrated themselves before him they bound themselves by oath—touching their throats with oil and water—and formally gave him kingship, appointing him permanently lord of the gods of heaven and earth. After this they solemnly named his 50 names expressive of his power and achievements. The myth ends with a plea that it be handed on from father to son and told to future rulers, that they may heed Marduk: it is the song of Marduk who bound Tiamat and assumed the kingship.

The motifs from which this myth is built up are in large measure known from elsewhere. The initial generation of the gods is a variant form of the genealogy of Anu in

the great god list *An: Anum.* The threat to annihilate the disturbers of sleep are known from the Atrahasis and the Sumerian Flood traditions. The battle of Marduk with Tiamat seems to stem from western myths of a battle between the thunder god and the sea. The organization of the universe after victory recalls the organization of conquered territory in *Lugal-e.* The killing of a rebel god to create man to take over the gods' toil is found in the Atrahasis myth and—without the rebel aspect—in a bilingual creation myth found in Assur. New and original, however, is the way in which they have all been grouped and made dependent on the figure of the young king. The political form of the monarchy is seen as embracing the universe; it was the prowess of a young king that overcame the forces of inertia; it was his organizational genius that created and organized all; and it is he that—like his counterpart on earth, the human king—grants benefits in return for obedience.

The value of the monarchy

The high value set on the monarchy as a guarantor of security and order in the *Enuma elish* can hardly have seemed obvious in Babylonia in the first troubled years of Assyrian rule in the second quarter of the 1st millennium BC. From this period (*c.* 700 BC) comes a myth usually called the Erra epic, which reads almost like a polemic against *Enuma elish.* It tells how the god of affray and indiscriminate slaughter, Erra, persuaded Marduk to turn over the rule of the world to him while Marduk was having his royal insignia cleaned, and how Erra, true to his nature, used his powers to institute indiscriminate rioting and slaughter. Royal power here stands no longer for security and order but for the opposite: license to kill and destroy.

Two other Akkadian myths may be mentioned—both probably dating from the middle of the 2nd millennium—the myth of the "Dynasty of Dunnum" and the myth of "Nergal and Ereshkigal." The first of these tells of succeeding divine generations ruling in Dunnum, the son usually killing his father and marrying, sometimes his mother, sometimes his sister, until—according to a reconstruction of the broken text—more acceptable mores came into vogue with the last generation of gods, Enlil and Ninurta. This myth, as has been mentioned, underlies the Greek poet Hesiod's *Theogony.* The myth of Nergal and Ereshkigal relates the unorthodox way in which the god Nergal became the husband of Ereshkigal and king of the netherworld.

Epics. The quick rise of Sargon, the founder of the dynasty of Akkad (*c.* 2334–*c.* 2154 BC), from obscurity to fame and his victory over Lugalzagesi of Uruk form the theme of several epic tales. The sudden eclipse of the Akkadian empire long after Naram-Sin, which was wrongly attributed to that ruler's presumed pride and the gods' retaliation, is the theme of "The Fall of Akkad." Akkadian epic tradition continues and gives focus to the Sumerian tales of Gilgamesh.

The Gilgamesh epic

The Akkadian epic of Gilgamesh seems to have been composed in Old Babylonian times but was reworked by a certain Sin-leqe-unnini later in the 1st millennium BC. It tells how Gilgamesh, the young ruler of Uruk, drives his subjects so hard that they appeal to the gods for relief. The gods create a wild man, Enkidu, who at first lives with the animals in the desert but is lured away from them and becomes Gilgamesh's friend. Together they vanquish the terrifying Huwawa, set by Enlil to guard the cedar forest in the West, and, when on their return the goddess of Uruk, Ishtar, falls in love with Gilgamesh, is jilted by him, and sends the dread "bull of heaven" to kill him, he and Enkidu manage to kill the bull. At this point, however, their fortunes change. Enlil, angered at the killing of Huwawa, causes Enkidu to fall ill and die, and Gilgamesh, inconsolable at the death of his friend and terrified at the realization that he himself must someday die, sets out to find eternal life.

After many adventures he reaches his ancestor Utnapishtim, to whom the gods have granted eternal life, but his case proves to be a unique one and so of no help to Gilgamesh. Utnapishtim was rewarded for having saved human and animal life at the time of the great Flood. Eventually, just as Gilgamesh is ready to return home, he is told about a plant that rejuvenates and makes old men children again. Gilgamesh finds it and begins his return journey. But, as the day is warm, when he passes an inviting pool he leaves his clothes and the plant on the shore and goes in for a swim. A serpent smells the plant, comes out of its hole, and eats it. Thus Gilgamesh's quest comes to naught. Eternal life is beyond man's grasp. The Gilgamesh epic is perhaps the most moving work in ancient Mesopotamian literature, with its sharp contrast of values: the warrior's disdain of death and danger, which informs the early parts of the epic, and the haunting fear that drives Gilgamesh in the later parts.

Other Akkadian epics that deserve to be mentioned are the Etana epic, which tells how Etana, the first king, was carried up to heaven on the back of an eagle to obtain the plant of birth so that his son could be born. Also important are the epic tales about Sargon of Akkad, one of which, the birth legend, tells of his abandonment in a casket on the river by his mother—much as the Bible tells that Moses was abandoned—and his discovery by an orchardman, who raised him as his son. Another Sargon tale is "The King of Battle," which tells about conquests in Asia Minor to protect foreign trade. Naram-Sin is the central figure in another tale dealing with that king's pride and also relating the destructive invasions by barbarous foes. A late flowering of primary epic is the Assyrian Tukulti-Ninurta (reigned 1243–07 BC) epic that deals with that king's wars with Babylonia.

The birth legend of Sargon

THE MESOPOTAMIAN WORLDVIEW AS EXPRESSED IN MYTH

The more completely a given culture is embraced, the more natural will its basic tenets seem to the people involved. The most fundamental of its presuppositions are not even likely to rise into awareness and be consciously held but are tacitly taken for granted. It takes a degree of cultural decline, of the loosening of the culture's grip on thought and action, before its most basic structural lines can be recognized and, if need be, challenged. Since culture, the total pattern within which man lives and acts, is thus not likely to be conceived of consciously and as a whole until it begins to lose its obvious and natural character, it is understandable that those myths of a culture that may be termed existential—in the sense that they articulate human existence as a whole in terms of the culture and show its basic structure—are rarely encountered until comparatively late in the history of a culture. Before that occurs, it is, rather, the particular aspects and facets of existence that are apt to claim attention.

In ancient Mesopotamia the oldest known materials, the Sumerian myths, have relatively little to say about creation; scholars must, for the most part, turn to the introductions of tales and disputations to infer how things were believed to be in the beginning. Thus, a story about the hero Gilgamesh refers in its introductory lines to the times "after heaven had been moved away from earth, after earth had been separated from heaven." The same notion that heaven and earth were once close together occurs also in a bilingual Sumero-Akkadian text from Ashur about the creation of man. The actual act of separating them is credited to the storm god Enlil of Nippur in the introduction to a third tale that deals with the creation of the first hoe. From similar passing remarks scholars have inferred that the gods, before man came into being, had to labour hard at the heavy works of irrigation agriculture and dug out the beds of the Tigris and the Euphrates.

Cosmogony and cosmology. Though the "Eridu Genesis" may have come close to treating existence as a whole, a true cosmogonic and cosmological myth that deals centrally with the origins, structuring, and functional principles of the cosmos does not actually appear until Old Babylonian times, when Mesopotamian culture was entering a millennium and a half of doubts about the moral character of world government and even of divine power itself. Yet, the statement is a positive one, almost to the point of defiance. *Enuma elish* tells of a beginning when all was a watery chaos and only the sea, Tiamat, and the sweet waters under ground, Apsu, mingled their waters together. Mummu, the personified original watery form, served as Apsu's page. In their midst the gods were

born. The first pair, Lahmu and Lahamu, represented the powers in silt; the next, Anshar and Kishar, those in the horizon. They engendered the god of heaven, Anu, and he in turn the god of the flowing sweet waters, Ea.

An: Anum

This tradition is known in a more complete form from an ancient list of gods called *An: Anum.* There, after a different beginning, Lahmu and Lahamu give rise to Duri and Dari, "the time-cycle"; and these in turn give rise to Enshar and Ninshar, "Lord and Lady Circle." Enshar and Ninshar engender the concrete circle of the horizon, Anshar and Kishar, probably conceived as silt deposited along the edge of the universe. Next was the horizon of the greater heaven and earth, and then—omitting an intrusive line—heaven and earth, probably conceived as two juxtaposed flat disks formed from silt deposited inward from the horizons.

Enuma elish truncates these materials and violates their inner logic considerably. Though they are clearly cosmogonic and assume that the cosmic elements and the powers informing them come into being together, *Enuma elish* seeks to utilize them for a pure theogony (account of the origin of the gods). The creation of the actual cosmos is dealt with much later. Also, the introduction of Mummu, the personified "original form," which in the circumstances can only be that of water, may have led to the omission of Ki, "Earth," who—as nonwatery—did not fit in.

The gods, who in *Enuma elish* come into being within Apsu and Tiamat, are viewed as dynamic creatures, who contrast strikingly with the older generation. Apsu and Tiamat stand for inertia and rest. This contrast leads to a series of conflicts in which first Apsu is killed by Ea; then Tiamat, who was roused later to attack the gods, is killed by Ea's son Marduk. It is Marduk, the hero of the story, who creates the extant universe out of the body of Tiamat. He cuts her, like a dried fish, in two, making one-half of her into heaven—appointing there Sun, Moon, and stars to execute their prescribed motions—and the other half into the Earth. He pierces her eyes to let the Tigris and Euphrates flow forth, and then, heaping mountains on her body in the east, he makes the various tributaries of the Tigris flow out from her breasts. The remainder of the story deals with Marduk's organization of the cosmos, his creation of man, and his assigning to the gods their various cosmic offices and tasks. The cosmos is viewed as structured as, and functioning as, a benevolent absolute monarchy.

The gods and demons. The gods were, as mentioned previously, organized in a polity of a primitive democratic cast. They constituted, as it were, a landed nobility, each god owning and working an estate—his temple and its lands—and controlling the city in which it was located. On the national level they attended the general assembly of the gods, which was the highest authority in the cosmos, to vote on matters of national import such as, for example, election or deposition of kings. The major gods also served on the national level as officers having charge of cosmic offices. Thus, for example, Utu, the sun god, was the judge of the gods, in charge of justice and righteousness generally.

Hierarchy of the gods

Highest in the pantheon—and presiding in the divine assembly—ranked An (Akkadian Anu), god of heaven, who was responsible for the calendar and the seasons as they were indicated by their appropriate stars. Next came Enlil of Nippur, god of winds and of agriculture, creator of the hoe. Enlil executed the verdicts of the divine assembly. Equal in rank to An and Enlil was the goddess Ninhursag (also known as Nintur and Ninmah), goddess of stony ground: the near mountain ranges in the east and the stony desert in the west with its wildlife—wild asses, gazelles, wild goats, etc. She was also the goddess of birth. With these was joined—seemingly secondarily—Enki (Ea), god of the sweet waters of rivers and marshes; he was the cleverest of the gods and a great troubleshooter, often appealed to by both gods and men. Enlil's sons were the moon god Nanna or Sin; the god of thunderstorms, floods, and the plough, Ninurta; and the underworld figures Meslamtaea, Ninazu, and Ennugi. Sin's sons were the sun god and judge of the gods, Utu (the Akkadian Shamash); the rain god Ishkur (the Akkadian Adad); and his daughter, the goddess of war, love, and morning and evening star, Inanna (the Akkadian Ishtar). Inanna's ill-fated young husband was the herder god Dumuzi (the Akkadian Tammuz). The dread netherworld was ruled by the goddess Ereshkigal and her husband Nergal, a figure closely related to Meslamtaea and Ninurta. Earlier tradition mentions Ninazu as her husband.

Demons played little or no role in the myths or lists of the Mesopotamian pantheon. Their domain was that of incantations. Mostly, they were depicted as outlaws; the demoness Lamashtu, for instance, was hurled from heaven by her father An because of her wickedness. The demons attacked man by causing all kinds of diseases and were, as a rule, viewed as wind and storm beings. Consonant with the classical view of the universe as a cosmic state, it was possible for a person to go to the law courts against the demons—*i.e.,* to seek recourse before Utu and obtain judgments against them. Various rituals for such procedures are known.

Man: his origin, nature, and destiny. Two different notions about man's origin seem to have been current in ancient Mesopotamian religions. Brief mentions in Sumerian texts indicate that the first men grew from the earth in the manner of grass and herbs. One of these texts, the "Myth of the Creation of the Hoe," adds a few details: Enlil removed heaven from earth in order to make room for seeds to come up, and after he had created the hoe he used it to break the hard crust of earth in Uzumua ("the flesh-grower"), a place in the Temple of Inanna in Nippur. Here, out of the hole made by Enlil's hoe, man grew forth.

The other notion presented the view that man was created from select "ingredients" by Enki, or by Enki and his mother Nammu, or by Enki and the birth goddess called variously Ninhursag, Nintur, and Ninmah. In the myth of "Enki and Ninmah" recounted above, Enki had man sired by the "engendering clay of the Apsu"—*i.e.,* of the waters underground—and borne by Nammu. The Akkadian tradition, as represented by the "Myth of Atrahasis," had Enki advise that a god—presumably a rebel—be killed and that the birth goddess Nintur mix his flesh and blood with clay. This was done, after which 14 womb goddesses gestated the mixture and gave birth to 7 human pairs. A similar—probably derived—form of this motif is found in *Enuma elish,* in which Enki (Ea) alone fashioned man out of the blood of the slain rebel leader Kingu. The creation of man from the blood shed by two slain gods is yet another version of the motif that appears in a bilingual myth from Ashur.

The divine and earthly nature of man

Man's nature, then, is part clay (earthly) and part god (divine). The divine aspect, however, is not that of a living god but rather that of a slain, powerless divinity. The Atrahasis story relates that the *etemmu* (ghost) of the slain god was left in man's flesh and thus became part of man. It is this originally divine part of man, his *etemmu,* that was believed to survive at his death and to give him a shadowy afterlife in the netherworld. No other trace of a notion of divine essence in man is discernible; in fact, man by himself was viewed as being utterly powerless to act effectively or to succeed in anything. For anything he might wish to do or achieve, man needed the help of a personal god or goddess, some deity in the pantheon who for one reason or other had taken an interest in him and helped and protected him, for "Without his personal god a man eats not."

About man's destiny all sources agree. However man may have come into being, he was meant to toil in order to provide food, clothing, housing, and service for the gods, so that they, relieved of all manual labour, could live the life of a governing upper class, a landed nobility. In the scheme of existence man was thus never an end, always just a means.

INSTITUTIONS AND PRACTICES

City-state and national state. In early dynastic times, probably as far back as historians can trace its history, Mesopotamia was divided into small units, the so-called city-states, consisting of a major city with its surrounding lands. The ruler of the city—usually entitled *ensi*—was

also in charge of the temple of the city god. The spouse of the *ensi* had charge of the temple of the city goddess, and the children of the *ensi* administered the temples of the deities who were regarded as children of the city god and the city goddesses. After the foundation of larger political units, such as leagues or empires, contributions were made to a central temple of the political unit, such as the temple of Enlil at Nippur in the Nippur league. On the other hand, however, the king or other central ruler might also contribute to the shrines of local cults. When, in the 2nd and 1st millennia, Babylonia and Assyria emerged as national states, their kings had responsibility for the national cult, and each monarch supervised the administration of all temples in his domain.

The purpose of man in relation to the gods

Cult. In the cultic practices, humans fulfilled their destiny: to take care of the gods' material needs. They therefore provided the gods with houses (the temples) that were richly supplied with lands, which people cultivated for them. In the temple the god was present in—but not bounded by—a statue made of precious wood overlaid with gold. For this statue the temple kitchen staff prepared daily meals from victuals grown or raised on the temple's fields, in its orchards, in its sheepfolds, cattle pens, and game preserves, brought in by its fishermen, or delivered by farmers owing it as a temple tax. The statue was also clad in costly raiment, bathed, and escorted to bed in the bedchamber of the god, often on top of the temple tower, or ziggurat. To see to all of this the god had a corps of house servants—*i.e.,* priests trained as cooks, bakers, waiters, and bathers, or as encomiasts (singers of praise) and musicians to make the god's meals festive, or as elegists to soothe him in times of stress and grief. Diversions from the daily routine were the great monthly festivals and also a number of special occasions. Such special occasions might be a sudden need to go through the elaborate ritual for purifying the king when he was threatened by the evils implied in an eclipse of the Moon, or in extreme cases there might be a call for the ritual installation of a substitute king to take upon himself the dangers threatening, and various other nonperiodic rituals.

Partly regular, partly impromptu, were the occasions for audiences with the god in which the king or other worshipers presented their petitions and prayers accompanied by appropriate offerings. These were mostly edibles, but not infrequently the costly containers in which they were presented, stone vases, golden boat-shaped vessels, etc., testified to the ardour of the givers. Appropriate gifts other than edibles were also acceptable—among them cylinder seals for the god's use, superhuman in size, and weapons for him, such as maceheads, also outsize.

To the cult, but as private rather than as part of the temple cult, may be counted also the burial ritual, concerning which, unfortunately, little is known. In outgoing Early Dynastic times in Girsu two modes of burial were current. One was ordinary burial in a cemetery; the nature of the other called laying the body "in the reeds of Enki," is not understood. It may have denoted the floating of the body down the river into the canebrakes. Elegists and other funerary personnel were in attendance and conducted the laments seeking to give full expression to the grief of the bereaved and propitiate the spirit of the dead. In later times burial in a family vault under the dwelling house was frequent.

Sacred times. During most of the 2nd millennium each major city had its own calendar. The months were named from local religious festivals celebrated in the month in question. Only by the 2nd millennium did the Nippur calendar attain general acceptance. The nature of the festivals in these various sacred calendars sometimes reflected the cycle of agricultural activities, such as celebrating the ritual hitching up of the plows and, later in the year, their unhitching, or rites of sowing, harvesting, and other activities. The sacred calendar of Girsu at the end of the Early Dynastic period is rich in its accounting of festivals. During some of these festival periods the queen traveled through her domain to present funerary offerings of barley, malt, and other agricultural products to the gods and to the spirits of deceased charismatic human administrators.

The cycles of festivals celebrating the marriage and early death of Dumuzi and similar fertility figures in spring were structured according to the backgrounds of the various communities of farmers, herders, or date growers. The sacred wedding—sometimes a fertility rite, sometimes a harvest festival with overtones of thanksgiving—was performed as a drama: the ruler and a high priestess took on the identity of the two deities and so ensured that their highly desirable union actually took place. In many communities the lament for the dead god took the form of a procession out into the desert to find the slain god in his gutted fold, a pilgrimage to the accompaniment of harps and heart-rending laments for the god.

New Year Festival

Of major importance in later times was the New Year Festival, or Akitu, celebrated in a special temple out in the fields. Originally an agricultural festival connected with sowing and harvest, it became the proper occasion for the crowning and investiture of a new king. In Babylon it came to celebrate the sun god Marduk's victory over Tiamat, the goddess of the watery deep. Besides the yearly festivals there were also monthly festivals at new moon, the 7th, the 15th, and the 28th of the month. The last—when the moon was invisible and thought to be dead—had a distinctly funereal character.

Administration. Supreme responsibility for the correct carrying out of the cult, on which the welfare of the country depended, was entrusted to the city ruler, or, when the country was united, the king. The city ruler and the king were, however, far more than administrators; they also were charismatic figures imparting their individual magic into their rule, thus creating welfare and fertility. In certain periods the king was deified; throughout the 3rd millennium, he became, in ritual action, the god Dumuzi in the rite of the sacred marriage and thus ensured fertility for his land. All the rulers of the 3rd dynasty of Ur (*c.* 2112–*c.* 2004 BC) and most of the rulers of the dynasty of Isin (*c.* 2020–*c.* 1800 BC) were treated as embodiments of the dying god Damu and invoked in the ritual laments for him. As a vessel of sacred power the king was surrounded by strict ritual to protect that power, and he had to undergo elaborate rituals of purification if the power became threatened.

The individual temples were usually administered by officials called *sangas* ("bishops"), who headed staffs of accountants, overseers of agricultural and industrial works on the temple estate, and *gudus* (priests), who looked after the god as house servants. Among the priestesses the highest-ranking was termed *en* (Akkadian *entu*). They were usually princesses of royal blood and were considered the human spouses of the gods they served, participating as brides in the rites of the sacred marriage. Other ranks of priestesses are known, most of them to be considered orders of nuns. The best-known are the votaries of the sun god, who lived in a cloister (*gagûm*) in Sippar. Whether, besides nuns, there were also priestesses devoted to sacred prostitution is a moot question; what is clear is that prostitutes were under the special protection of the goddess Inanna (Ishtar).

Sacred places. Mesopotamian worshipers might worship in open-air sanctuaries, chapels in private houses, or small separate chapels located in the residential quarters of town, but the sacred place par excellence was the temple. Archaeology has traced the temple back to the earliest periods of settlement, and though the very early temple plans still pose many unsolved problems, it is clear that from the Early Dynastic period onward the temple was what the Sumerian (*e*) and Akkadian (*bîtum*) terms for it indicate; *i.e.,* the temple was the god's house or dwelling. In its more elaborate form such a temple would be built on a series of irregular artificial platforms, one on top of the other; by the 3rd dynasty of Ur, near the end of the 3rd millennium, these became squared off to form a ziggurat. On the lowest of these platforms a heavy wall—first oval, later rectangular—enclosed storerooms, the temple kitchen, workshops, and other such rooms. On the highest level, approached by a stairway, were the god's living quarters centred in the cella, a rectangular room with an entrance door in the long wall near one corner. The god's place was on a podium in a niche at the short wall farthest from the entrance; benches with statues of worshipers ran

The structure and function of the temple

along both long walls, and a hearth in the middle of the floor served for heating. Low pillars in front of the god's seat seem to have served as stoppers for a hanging that shielded him from profane eyes. Here, or in a connecting room, would be the god's table, bed, and bathtub.

At a later time in Babylonia the dimensions of the cella with its adjoining rooms were greatly enlarged so that it became an open court surrounded by rooms. Only the section separated by the hanging remained roofed and became a new cella, entered from the middle of its long side and with the god in his niche in the wall directly opposite. The development in Assyria took a slightly different course. There, the original door in the long side moved around the corner to the short side opposite the god, creating a rectangular cella entered from the end wall.

The function of the temple, as of all of the other sacred places in ancient Mesopotamia, was primarily to ensure the god's presence and to provide a place where he could be approached. The providing of housing, food, and service for the god achieved the first of these purposes. His presence was also assured by a suitable embodiment—the cult statue, and, for certain rites, the body of the ruler. To achieve the second purpose, greeting gifts, praise hymns as introduction to petitions, and other actions were used to induce the god to receive the petitioner and to listen to, and accept, his prayers.

In view of the magnitude of the establishment provided for the gods and the extent of lands belonging to them and cultivated for them—partly by temple personnel, partly by members of the community holding temple land in some form of tenure—it was unavoidable that temples should vie in economic importance with similar large private estates or with estates belonging to the crown. This importance, one may surmise, would lie largely in the element of stability that an efficiently run major estate provided for the community. With its capacity for producing large storable surpluses that could be used to offset bad years and with its facilities for production—such as its weaveries—the temple estates could absorb and utilize elements of the population, such as widows, waifs, captives, and others, who otherwise would have perished or become a menace to the community in one way or other. The economic importance of the temple primarily was local. The amount of foreign trade carried on by them apparently was small. The power behind foreign trade seems rather to have been the king.

The magical arts. In the ancient Mesopotamian view, gods and humans shared one world. The gods lived among men on their great estates (the temples), ruled, upheld law and order for humans, and fought their wars. In general, knowing and carrying out the will of the gods was not a matter for doubt: they wanted the practice of their cult performed faultlessly and work on their estates done willingly and well, and they disapproved, in greater or lesser degree, of breaches of the moral and legal order. On occasion, however, humans might well be uncertain: did a god want his temple rebuilt or did he not? In all such cases and others like them, the Mesopotamians sought direct answers from the gods through divination, or, conversely, the gods might take the initiative and convey specific wishes through dreams, signs, or portents.

Belief in divination and astrology

There were many forms of divination. Of interest to students of biblical prophecy is recent evidence that prophets and prophetesses were active at the court of Mari on the Euphrates in Old Babylonian times (*c.* 1800–*c.* 1600 BC). In Mesopotamia as a whole, however, the forms of divination most frequently used seem to have been incubation—sleeping in the temple in the hope that the god would send an enlightening dream—and hepatoscopy—examining the entrails, particularly the liver, of a lamb or kid sacrificed for a divinatory purpose, to read what the god had "written" there by interpreting variations in form and shape. In the 2nd and 1st millennia large and detailed handbooks in hepatoscopy were composed for consultation by the diviners. Though divination in historical times was regularly presented in terms of ascertaining the divine will, there are internal indications in the materials suggesting that it was originally less theologically elaborated. Apparently it was a mere attempt to read the future from "symptoms" in the present, much as a physician recognizes the onset of a disease. This is particularly evident in that branch of divination that deals with unusual happenings believed to be ominous. Thus, if a desert plant sprouted in a city—indicating that desert essence was about to take over—it was considered an indication that the city would be laid waste.

Related to the observation of unusual happenings in society or nature, but far more systematized, was astrology. The movements and appearance of the Sun, the Moon, and the planets were believed to yield information about future events affecting the nation or, in some cases, the fate of individuals. Horoscopes, predicting the character and fate of a person on the basis of the constellation of the stars at his birth, are known to have been constructed in the late 1st millennium, but the art may conceivably be older.

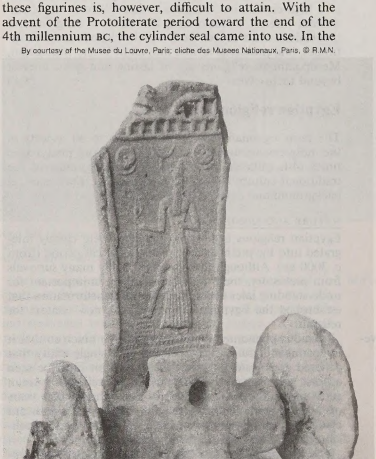
Belief in witchcraft

Witchcraft was apparently at all times considered a crime punishable by death. Frequently, however, it probably was difficult to identify the witch in individual cases, or even to be sure that a given evil was the result of witchcraft rather than of other causes. In such cases, the expert in white magic, the *āšipu* or *mašmašu*, was able to help both in diagnosing the cause of the evil and in performing the appropriate rituals and incantation to fight it off. In earlier times the activities of the magicians seem generally to have been directed against the lawless demons who attacked humans and caused all kinds of diseases. In the later half of the 2nd, and all through the 1st millennium, however, the fear of man-made evils grew, and witchcraft vied with the demons as the chief source of all ills.

RELIGIOUS ART AND ICONOGRAPHY

The earliest periods in Mesopotamia have yielded figurines of clay or stone, some of which may represent gods or demons; certainty of interpretation in regard to these figurines is, however, difficult to attain. With the advent of the Protoliterate period toward the end of the 4th millennium BC, the cylinder seal came into use. In the

By courtesy of the Musee du Louvre, Paris; cliche des Musees Nationaux, Paris, © R.M.N.



Terra-cotta cult chariot from the 2nd millennium BC. At the top are the symbols of Sin, Shamash, and Ishtar. Below, a god stands with one foot on the mountains, holding the symbol of Nergal, god of the underworld, in his hand. In the Louvre Museum, Paris.

designs on these seals—often, it would seem, copies from monumental wall paintings now lost—ritual scenes and divine figures, recognizable from what is known about them in historical times, make their first appearance. To this period also belongs the magnificent Uruk Vase, with its representation of the sacred marriage rite. Until the early centuries of the 2nd millennium the cylinder seal remains one of the most prolific sources of religious motifs and representations of divine figures, but larger reliefs, wall paintings, and sculpture in the round greatly add to modern historians' understanding of who and what is rendered. In the 2nd and 1st millennia, the humble categories of clay plaques and clay figurines often contained representations of deities, and the numerous sculptured boundary stones (*kudurrus*) furnish representations of symbols and emblems of gods, at times identified by labels in cuneiform. To the 1st millennium belong also the magnificent colossal statues of protective genies (spirits) in the shape of lions or human-headed bulls that guarded the entrances to Assyrian palaces, and also, on the gates of Nebuchadrezzar's (d. 562 BC) Babylon, the reliefs in glazed tile of lions and dragons that served the same purpose.

CONCLUSION

A religious development covering four millennia such as one finds in ancient Mesopotamian religions is obviously of interest in and of itself. The tendencies that lead from a central concern with salvation from famine to a concern with salvation from attack, and finally to salvation from a sense of personal guilt, with the attendant deepening and enriching of the concept of the divine, invites close study. So also do the many moving and profound expressions of religious faith in the hymns, laments, and prayers of these religions. As one of the earliest religious systems in history to structure, and be itself structured by, the complexities of a high civilization, Mesopotamian religions are of significant interest to historians, historians of religion, and theologians. As a source from which religious insights, attitudes, and problems flowed into all of Western tradition, Mesopotamian religions are of lasting and great interest beyond themselves. (T.J.)

Egyptian religion

The term Egyptian religion here refers to all aspects of the indigenous religion of ancient Egypt from predynastic times (4th millennium BC) to the disappearance of the traditional culture in the first centuries AD. For historical background and detailed dates, see EGYPT.

NATURE AND SIGNIFICANCE

Egyptian religious beliefs and practices were closely integrated into Egyptian society of the historical period (from *c.* 3000 BC). Although there were probably many survivals from prehistory, these may be relatively unimportant for understanding later times, because the transformation that established the Egyptian state created a new context for religion.

Pervasiveness of religion

Religious phenomena were pervasive, so much so that it is not meaningful to view religion as a single entity that cohered as a system. Nevertheless, religion must be seen against a background of potentially nonreligious human activities and values. During its more than 3,000 years of development, Egyptian religion underwent significant changes of emphasis and practice, but in all periods religion had a clear consistency in character and style.

It is inappropriate to define religion narrowly, as consisting only in the cult of the gods and in human piety. Religious behaviour encompassed contact with the dead, practices such as divination and oracles, and magic, which mostly exploited divine instruments and associations.

There were two essential foci of public religion: the king and the gods. Both are among the most characteristic features of Egyptian civilization. The king had a unique status between humanity and the gods, partook in the world of the gods, and constructed great, religiously motivated funerary monuments for his afterlife. Egyptian gods are renowned for their wide variety of forms, including animal forms and mixed forms with an animal head on a human body. The most important deities were the sun god, who had several names and aspects and was associated with many supernatural beings in a solar cycle modeled on the alternation of night and day, and Osiris, the god of the dead and ruler of the underworld. With his consort Isis, Osiris became dominant in many contexts during the 1st millennium BC, when solar worship was in relative decline.

The Egyptians conceived of the cosmos as including the gods and the present world—whose centre was of course Egypt—and as being surrounded by the realm of disorder, from which order had arisen and to which it would finally revert. Disorder had to be kept at bay. The task of the king as the protagonist of human society was to retain the benevolence of the gods in maintaining order against disorder. This ultimately pessimistic view of the cosmos was associated principally with the sun god and the solar cycle. It formed a powerful legitimation of king and elite in their task of preserving order.

Despite this pessimism, the official presentation of the cosmos on the monuments was positive and optimistic, showing the king and the gods in perpetual reciprocity and harmony. This implied contrast reaffirmed the fragile order. The restricted character of the monuments was also fundamental to a system of decorum that defined what could be shown, in what way it could be shown, and in what context. Decorum and the affirmation of order reinforced each other.

These beliefs are known from monuments and documents created by and for the king and the small elite. The beliefs and practices of the rest of the people are poorly known. While there is no reason to believe that there was a radical opposition between the beliefs of the elite and of others, this possibility cannot be ruled out.

SOURCES AND LIMITATIONS OF ANCIENT AND MODERN KNOWLEDGE

The only extensive contemporaneous descriptions of ancient Egyptian culture from the outside were made by Classical Greek and Roman writers. Their works include many important observations about Egyptian religion, which particularly interested the writers and which until late antiquity was not fundamentally different in type from their own religions. Herodotus (5th century BC) remarked that the Egyptians were the most religious of people, and the comment is apt because popular religious practices proliferated in the 1st millennium BC. Other significant Classical sources include Plutarch's essay on Isis and Osiris (1st century AD), which gives the only known connected narrative of their myth, and writings of Apuleius (2nd century AD) and others about the Isis cult as it spread in the Greco-Roman world.

In other respects, ancient Egypt has been recovered archaeologically. Excavation and the recording of buildings have produced a great range of material, from large monuments to small objects and texts on perishable papyrus. Egyptian monuments are almost unique in the amount of inscription they bear; vast numbers of texts and representations with religious content are preserved, especially from the later 2nd and 1st millennia BC. Much of this material is religious or has religious implications. This dominance may be misleading, partly because many monuments were in the desert where they are well preserved and partly because the lavishing of great resources on religious monuments for the king and the gods need not mean that people's lives were dominated by religion.

In addition to favouring large monuments and the elite, the archaeological record has other important biases. The formal cults of major deities and the realm of the dead are far better known than everyday religious activities, particularly those occurring in towns and villages, very few of which have been excavated. The absence of material deriving from the religious practice of most people in itself constitutes evidence, suggesting both the inequality of society and the possibility, confirmed by other strands of evidence, that many people's religious life did not focus on official cult places and major temples.

Official works of art

Many official works of art present standard conceptions of the divine world and of the king's role in this world and in caring for the gods. Much religious evidence is at the

same time artistic, and the production of works of art was a vital prestige concern of king and elite. Religious activities and rituals are less well known than this formalized artistic presentation of religious conceptions. The status of personal religion in the context of official cults is poorly understood.

Official forms were idealizing, and the untoward, which is everywhere an important focus of religion, was excluded almost entirely from them. The world of the monuments is that of Egypt alone, even though the Egyptians had normal, sometimes reciprocal, relations with other peoples. Decorum affected what was shown. Thus, the king was almost always depicted as the person offering to the gods, although temple rituals were performed by priests. Scenes of offering and of the gods conferring benefits on the king may not depict specific rituals, while the equal form in which king and gods are depicted bears no direct relation to real cult actions, which were performed on small cult images kept inside shrines.

An additional limitation is that knowledge of many central concerns was restricted. The king was stated to be alone in knowing aspects of the solar cycle. Knowledge of some religious texts was reserved to initiates, who would benefit from them both in this life and in the next. Magic evoked the power of the exotic and esoteric. Evidence for some restricted material is preserved, but it is not known who had access to it, while in other cases the restricted knowledge is only alluded to and is now inaccessible.

Death and the next world dominate both the archaeological record and popular modern conceptions of Egyptian religion. This dominance is determined to a great extent by the landscape of the country, since tombs were placed if possible in the desert. Vast resources were expended on creating prestigious burial places for absolute rulers or wealthy officials. Tombs contained elaborate grave goods (mostly plundered soon after deposition), representations of "daily life," or less commonly of religious subjects, and some texts that were intended to help the deceased attain the next world and prosper there. The texts came increasingly to be inscribed on coffins and stone sarcophagi or deposited in burials on papyrus. Some royal tombs included long passages from religious texts, many of them drawn from nonmortuary contexts and hence more broadly valuable as source material.

One crucial area where religion extended beyond narrow bounds was in the ethical instructions, which became the principal genre of Egyptian literature. These are known from the Middle Kingdom (*c.* 1900–1600 BC) to the Roman period (1st century AD). As with other sources, the later texts are more overtly religious, but all show inextricable connections between proper conduct, the order of the world, and the gods.

KING, COSMOS, AND SOCIETY

The king was the centre of human society, the guarantor of order for the gods, the recipient of god-given benefits including life itself, and the benevolent ruler of the world for humanity. He was ultimately responsible for the cults of the dead, both for his predecessors in office and for the dead in general. His dominance in religion corresponded to his central political role: from late predynastic times (*c.* 3100 BC), state organization was based on kingship and on the service of officials for the king. For humanity, the king had a superhuman role, being a manifestation of a god or of various deities on earth.

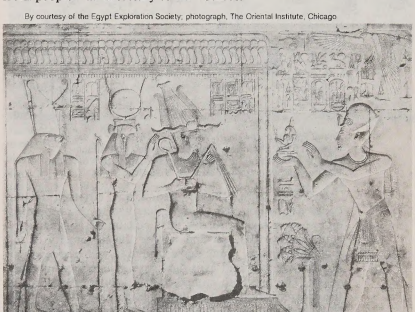
The king's titles and divine status

The king's principal original title, the Horus name, proclaimed that he was an aspect of the chief god Horus, a sky god who was depicted as a falcon. Other identifications were added to this one, notably "Son of Re (the sun god)" and "Perfect God," both introduced in the 4th dynasty (*c.* 2575–2465 BC), when the great pyramids were constructed. The epithet "Son of Re" placed the king in a close but dependent relation with the leading figure in the pantheon. "Perfect God" (often rendered "Good God") indicated that the king had the status of a minor deity, for which he was "perfected" through accession to his office; it restricted the extent of his divinity and separated him from full deities.

In his intermediate position between humanity and the gods, the king could receive the most extravagant divine adulation and was in some ways more prominent than any single god. In death he aspired to full divinity but could not escape the human context. Although royal funerary monuments differed in type from other tombs and were vastly larger, they too were pillaged and vandalized, and few royal mortuary cults were long-lasting. Some kings, notably Amenhotep III (1390–53 BC), Ramses II (1279–13 BC), and several of the Ptolemies, sought deification during their own lifetimes, while others, such as Amenemhet III (1818–*c.* 1770 BC), became minor gods after their deaths, but these developments show how restricted royal divinity was. The divinized king coexisted with his mortal self, and as many nonroyal individuals as kings became deified after death.

The gods, the king, humanity, and the dead existed together in the cosmos, which the creator god had brought into being from the preexistent chaos. All living beings, except perhaps the creator, would die at the end of time. The sun god became aged and needed to be rejuvenated and reborn daily. The ordered cosmos was surrounded by and shot through with disorder, which had to be kept at bay. Disorder menaced most strongly at such times of transition as the passage from one year to the next or the death of a king. Thus, the king's role in maintaining order was cosmic and not merely social. His exaction of service from people was necessary to the cosmos.

By courtesy of the Egypt Exploration Society; photograph, The Oriental Institute, Chicago



King Seti I offering a figure of *ma'at* to Osiris, Isis, and Horus; relief in the temple of King Seti I, Abydos, early 13th century BC.

Ma'at

The concept of *ma'at* ("order") was fundamental in Egyptian thought. The king's role was to set *ma'at* in place of *izfet* ("disorder"). *Ma'at* was crucial in human life and embraced notions of reciprocity, justice, truth, and moderation. *Ma'at* was personified as a goddess and the creator's daughter and received a cult of her own. In the cult of other deities, the king's offering of *ma'at* to a deity (see illustration) encapsulated the relationship between humanity, the king, and the gods: as the representative of humanity, he returned to the gods the order that came from them and of which they were themselves part. *Ma'at* extended into the world of the dead: in the weighing of the heart after death, shown on papyri deposited in burials (see illustration), the person's heart occupies one side of the scales and a representation of *ma'at* the other. The meaning of this image is deepened in the accompanying text, which asserts that the deceased behaved correctly on earth and did not overstep the boundaries of order, declaring that he or she did not "know that which is not"—that is, things that were outside the created and ordered world.

This role of *ma'at* in human life created a continuity between religion, political action, and elite morality. Over the centuries, private religion and morality drew apart from state concerns, paralleling a gradual separation of king and temple. It cannot be known whether religion and

morality were as closely integrated for the people as they were for the elite, or even how fully the elite subscribed to these beliefs. Nonetheless, the integration of cosmos, king, and *ma'at* remained fundamental.

THE GODS

Egyptian religion was polytheistic. The gods who inhabited the bounded and ultimately perishable cosmos varied in nature and capacity. The word *netjer* ("god") described a much wider range of beings than the deities of monotheistic religions, including what might be termed demons. As is almost necessary in polytheism, gods were neither all-powerful nor all-knowing. Their power was immeasurably greater than that of human beings, and they had the ability to live almost indefinitely, to survive fatal wounds, to be in more than one place at once, to affect people in visible and invisible ways, and so forth.

By courtesy of the Metropolitan Museum of Art, New York, Museum Excavations, 1928–29 and Rogers Fund, 1930



The judgment of the dead. While Osiris, the ruler of the dead, watches from his throne, the jackal-headed god Anubis weighs the heart of the deceased against the figure of *ma'at*. Funerary papyrus from Thebes, *c.* 1025 BC.

Most gods were generally benevolent, but their favour could not be counted on, and they had to be propitiated and encouraged to inhabit their cult images so that they could receive the cult and further the reciprocity of divine and human. Some deities, notably such goddesses as Neith, Sekhmet, and Mut, had strongly ambivalent characters. The god Seth embodied the disordered aspects of the ordered world, and in the 1st millennium BC he came to be seen as an enemy who had to be eliminated (but would remain present).

The characters of the gods were not neatly defined. Most had a principal association, such as that of Re with the sun or that of the goddess Hathor with women, but there was much overlap, especially among the leading deities. In general, the more closely circumscribed a deity's character, the less powerful that deity was. All the main gods acquired the characteristics of creator gods. A single figure could have many names: among those of the sun god, the most important were Khepri (the morning form), Re-Harakhty, and Atum (the old, evening form). There were three principal "social" categories of deity: gods, goddesses, and youthful deities, mostly male.

Cult centres

Gods had regional associations, corresponding to their chief cult places. The sun god's cult place was Heliopolis, Ptah's was Memphis, and Amon's was Thebes. These were not necessarily their original cult places. The principal cult of Khnum, the creator god who formed people from clay like a potter, was Elephantine, and he was the lord of the nearby First Cataract. His cult is not attested there before the New Kingdom, however, even though he was important from the 1st dynasty (*c.* 2925–2775 BC). The main earlier sanctuary there belonged to the goddess Satet, who became Khnum's companion. Similarly, Mut, the partner of Amon at Thebes, seems to have originated elsewhere.

Deities had principal manifestations, and most were associated with one or more species of animal. For gods the most important forms were the falcon and bull, and for goddesses the cow, cobra, vulture, and lioness. Rams were widespread, while some manifestations were as modest as the millipede of the god Sepa. Some gods were very strongly linked to particular animals, as Sebek was with the crocodile and Khepri with the scarab beetle. Thoth had two animals, the ibis and the baboon. Some animal cults were only partly integrated with specific gods, notably the Ram of Mendes in the Delta and the Apis and Mnevis bulls at Memphis and Heliopolis, respectively. Animals could express aspects of a deity's nature: some goddesses were lionesses in their fiercer aspect but were cats when mild.

These variable forms relate to aspects of the person that were common to gods and people. The most significant of these were the *ka*, which was the vital essence of a person that was transmitted from one generation to the next, the *ba*, which granted freedom of movement and the ability to take on different forms, principally in the next world, and the *akh*, the transfigured spirit of a person in the next world.

The chief form in which gods were represented was human, and many deities had only human form. Among these deities were very ancient figures such as the fertility god Min and the creator and craftsman Ptah. The cosmic gods Shu, of the air and sky, and Geb, of the earth, had human form, as did Osiris, Isis, and Nephthys, deities who provided a model of human society. In temple reliefs the gods were depicted in human form, which was central to decorum. Gods having animal manifestations were therefore shown with a human body and the head of their animal. The opposite convention, a human head and an animal body, was used for the king, who was shown as a sphinx with a lion's body. Sphinxes could receive other heads, notably those of rams and falcons, associating the form with Amon and Re-Harakhty. Demons were represented in more extravagant forms and combinations; these became common in the 1st millennium BC. Together with the cult of animals, they were mocked by Greek and Roman writers.

Minor deities

Apart from major deities—gods who received a cult or had a significant cosmic role—there were important minor figures. Several of these marginal beings had grotesque forms and variable names. The most prominent were Bes, a helpful figure with dwarf form and a masklike face, associated especially with women and children, and Taurt, a goddess with similar associations whose physical form combined features of a hippopotamus and a crocodile. Among demons, the most important figure was Apopis, shown as a colossal snake, who was the enemy of the sun god in his daily cycle through the cosmos. Apopis existed outside the ordered realm; he had to be defeated daily, but, since he did not belong to the sphere of existence, he could not be destroyed.

Groupings of deities. The number of deities was large and was not fixed. New ones appeared and some ceased to be worshiped. Deities were grouped in various ways. The most ancient known grouping is the ennead, which is probably attested from the 3rd dynasty (*c.* 2650–2575 BC). Enneads were groups of nine deities, nine being the "plural" of three (in Egypt the number three symbolized plurality in general); not all enneads consisted of nine gods.

The principal ennead was the Great Ennead of Heliopolis. This was headed by the sun god and creator Re or Re-Atum, followed by Shu and Tefnut, deities of air and moisture; Geb and Nut, who represented earth and sky; and Osiris, Isis, Seth, and Nephthys. This ordering incorporated a myth of creation, to which was joined the myth of Osiris, whose deeds and attributes ranged from the founding of civilization to kinship, kingship, and succession to office. The ennead excluded the successor figure, Horus son of Osiris, who is essential to the meaning of the myth. Thus, the ennead has the appearance of a grouping that brought together existing religious conceptions but was rather arbitrary and inflexible, perhaps because of the significance of the number nine.

Other numerical ordering schemas included the Ogdoad (group of eight gods) of Hermopolis, which embodied the inchoate world before creation and consisted of four pairs of male and female deities with abstract names such as Darkness, Absence, and Endlessness. Here, too, the number was significant in itself, because at least six different

pairs of names are known although eight deities are listed in any occurrence. The major god Amon, whose name can mean "He who is hidden," was often one of the ogdoad with his female counterpart, Amaunet.

The most common grouping, principally in the New Kingdom and later, was the triad. The archetypal triad of Osiris, Isis, and Horus exhibits the normal pattern of a god and a goddess with a youthful deity, usually male. Most local centres came to have triads, the second and third members of which might be devised for the sake of form. Thus, one triad worshiped in the Greco-Roman-period temple at Kawm Umbū (Kôm Ombo) consisted of Haroeris (the "elder Horus"), the goddess Tsenetnofret ("the perfect companion"), and the youthful god Pnebtawy ("the lord of the two lands"). The last name, which is an epithet of kings, is revealing, because youthful gods had many attributes of kings. As this case indicates, triads resemble a minimal nuclear family, but deities were rarely spouses. The notion of plurality and the bringing together of the essential types of deity may have been as important to the triads as the family analogy.

Syncretism

Another important ordering of deities was syncretism, a term with a special meaning for Egyptian religion. Two or more names of gods were often combined to form a composite identity; many combinations included the name of Re. Prominent examples are Amon-Re, a fusion of Amon and Re, and Osiris-Apis, a fusion of Osiris with the Apis Bull. Although composite forms such as Amon-Re became the principal identities of some gods, the separate deities continued to exist, and sometimes, as in the case of Re, to receive a cult. In part, these syncretisms expressed the idea of Amon in his aspect as Re; they were thus analogous to the multiple manifestations of individual deities. Through syncretism many major deities came to resemble one another more closely.

Myth. Myths are poorly known. Religious discourse was recorded in hymns, rituals, temple scenes, and specialized texts, but rarely in narrative, which only slowly became a common written genre and never had the highest literary prestige. In addition, much religious activity focused on constant reiteration or repetition rather than on development. A central example of this tendency is the presentation of the cycle of the sun god through the sky and the underworld, which was an analogy for the creation, maturity, decay, and regeneration of an individual life and of the cosmos. This is strikingly presented in the underworld books. These pictorial and textual compositions, which probably imparted secret knowledge, were inscribed in the tombs of New Kingdom kings. They describe the solar cycle in great detail, including hundreds of names of demons and of deities and other beings who accompanied the sun god in his barque on his journey through night and day. The texts are in the present tense and form a description and a series of tableaux rather than a narrative.

The fact that mythical narratives are rare does not imply that myths or narratives did not exist. There is reason to think that some myths underlay features of enneads and therefore originated by the Early Dynastic period (*c.* 3000 BC). Mythical narratives preserved from the New Kingdom and later include episodes of the rule of the sun god on earth, tales of the childhood of Horus in the delta marshes, and stories with themes similar to the Osiris myth but with differently named protagonists. The rule of the sun god was followed by his withdrawal into the sky, leaving people on earth. The withdrawal was motivated by his age and by the lack of tranquility in the world. One narrative recounts how Isis obtained a magical substance from Re's senile dribbling and fashioned from it a snake that bit him; to make her still the agony of the snakebite, he finally revealed to her the secret of his "true" name. A myth with varied realizations recounts how Re grew weary of humanity's recalcitrance and dispatched his daughter or "Eye" to destroy them. Regretting his action later, he arranged to have the bloodthirsty goddess tricked into drunkenness by spreading beer tinted the colour of blood over the land. This myth provides an explanation for the world's imperfection and the inaccessibility of the gods. In Greco-Roman times it was widespread in Lower Nubia, where it seems to have been related to the winter retreat of the sun to the Southern Hemisphere and its return in the spring.

THE CULT

Most cults centred on the daily tending and worship of an image of a deity and were analogous to the pattern of human life. The shrine containing the image was opened at dawn, and then the deity was purified, greeted and praised, clothed, and fed. There were several further services, and the image was finally returned to its shrine for the night. Apart from this activity, which took place within the temple and was performed by a small group of priests, there were numerous festivals, at which the shrine and image were taken out from the sanctuary on a portable barque, becoming visible to the people and often visiting other temples. Thus, the daily cult was a state concern, whose function was to maintain reciprocity between the human and the divine, largely in isolation from the people. This reciprocity was fundamental because deities and humanity together sustained the cosmos. If the gods were not satisfied, they might cease to inhabit their images and retreat to their other abode, the sky. Temples were constructed as microcosms whose purity and wholeness symbolized the proper order of the larger world outside.

The priesthood

The priesthood became increasingly important. In early periods there seem to have been no full-time professional priests; people could hold part-time high priestly offices, or they could have humbler positions on a rotating basis, performing duties for one month in four. The chief officiant may have been a professional. While performing their duties, priests submitted to rules of purity and abstinence. One result of this system was that more people were involved in the cult and had access to the temple than would have been the case if there had been a permanent staff. Although most priestly positions were for men, women were involved in the cult of the goddess Hathor, and in the New Kingdom and later many women held the title of "chantress" of a deity (perhaps often a courtesy title); they were principally involved in musical cult performances.

Festivals allowed more direct interaction between people and the gods. Questions were often asked of a deity, and a response might be given by a forward or backward movement of the barque carried on the priests' shoulders. Oracles, of which this was one form, were invoked by the king to obtain sanction for his plans, including military campaigns abroad and important appointments. Although evidence is sparse, consultation with deities may have been part of religious interaction in all periods and for all levels of society.

Apart from this interaction between deities and individual people or groups, festivals were times of communal celebration, and often of the public reenactment of myths such as the death and vindication of Osiris at Abydos or the defeat of Seth by Horus at Idfū. They had both a personal and a general social role in the spectrum of religious practice.

Nonetheless, the main audience for the most important festivals of the principal gods of state held in capital cities may have been the ruling elite rather than the people as a whole. In the New Kingdom these cities were remodeled as vast cosmic stages for the enactment of royal-divine relations and rituals.

PIETY, PRACTICAL RELIGION, AND MAGIC

Despite the importance of temples and their architectural dominance, the evidence for cult does not point to mass participation in temple religion. The archaeological material may be misleading, because in addition to major temples there were many local sanctuaries that may have responded more directly to the concerns and needs of those who lived around them. From some periods numerous votive offerings are preserved from a few temples. Among these are Early Dynastic and Old Kingdom provincial temples, but the fullest evidence is from New Kingdom temples of Hathor at Thebes and several frontier sites, and from the Late and Ptolemaic periods (664–30 BC).

Although votive offerings show that significant numbers

of people brought gifts to temples, it is difficult to gauge the social status of donors, whose intentions are seldom indicated, probably in part for reasons of decorum. Two likely motives are disinterested pious donation for the deity, and offering in the hope of obtaining a specific benefit. Many New Kingdom offerings to Hathor relate to human fertility and thus belong to the second of these categories. Late period bronze statuettes are often inscribed with a formula requesting that the deity represented should "give life" to the donor, without stating a specific need. These may be more generally pious donations, among which can also be counted nonroyal dedications of small parcels of land to temples. These donations are recorded on stelae from the New Kingdom onward. They parallel the massive royal endowments to temples of land and other resources, which resulted in their becoming very powerful economic and political institutions.

Animal cults

Apart from the donation of offerings to conventional cult temples, there was a vast Late period expansion in animal cults. These might be more or less closely related to major deities. They involved a variety of practices centring on the mummification and burial of animals. The principal bull cults, which gave important oracles, focused on a single animal kept in a special shrine. The burial of an Apis bull was a major occasion involving vast expenditure. Some animals, such as the sacred ibis (connected with Thoth) were kept, and buried, in millions. The dedication of a burial seems to have counted as a pious act. The best-known area for these cults and associated practices is the necropolis of northern Ṣaqqārah, which served the city of Memphis. Numerous species were buried there, and people visited the area to consult oracles and to spend the night in a temple area and receive a healing dream. A few people resided permanently in the animal necropolis in a state akin to monastic seclusion.

There are two further important groups of evidence for pious and reciprocal relations between people and gods. One is proper names of all periods, the majority of which are meaningful utterances with religious content. For example, names state that deities "show favour" to or "love" a child or its parents. From the end of the New Kingdom (*c.* 1100 BC), names commonly refer to consultation of oracles during pregnancy, alluding to a different mode of human-divine relations. The second source is a group of late New Kingdom inscriptions recounting episodes of affliction that led to people's perceiving that they had wronged a god. These texts, which provide evidence of direct pious relations, are often thought to show a transformation of religious attitudes in that period, but allusions to similar relations in Middle Kingdom texts suggest that the change was as much in what was written down as in basic attitudes.

Piety was one of many modes of religious action and relations. Much of religion concerned attempts to comprehend and respond to the unpredictable and the unfortunate. The activities involved often took place away from temples and are little known. In later periods, there was an increasing concentration of religious practice around temples; for earlier times evidence is sparse. The essential questions people asked, as in many religious traditions, were why something had happened and why it had happened to them, what would be an appropriate response, what agency they should turn to, and what might happen in the future. To obtain answers to these questions, people turned to oracles and to other forms of divination, such as consulting seers or calendars of lucky and unlucky days. From the New Kingdom and later, questions to oracles are preserved, often on such mundane matters as whether someone should cultivate a particular field in a given year. These cannot have been presented only at festivals, and priests must have addressed oracular questions to gods within their sanctuaries. Oracles of gods also played an important part in dispute settlement and litigation in some communities.

A vital focus of questioning was the world of the dead. The recently deceased might exert influence on the living for good or for bad. Offerings to the dead, which were required by custom, were intended, among other purposes, to make them well disposed. People occasionally deposited with their offerings a letter telling the deceased of their problems and asking for assistance. A few of these letters are complaints to the deceased person, alleging that he or she is afflicting the writer. This written communication with the dead was confined to the very few literate members of the population, but it was probably part of a more widespread oral practice. Some tombs of prominent people acquired minor cults that may have originated in frequent successful recourse to them for assistance.

Letters to the dead

Offerings to the dead generally did not continue long after burial, and most tombs were robbed within a generation or so. Thus relations with dead kin probably focused on the recently deceased. Nonetheless, the dead were respected and feared more widely. The attitudes attested are almost uniformly negative. The dead were held accountable for much misfortune, both on a local and domestic level and in the broader context of the state. People were also concerned that, when they died, those in the next world would oppose their entry to it as newcomers who might oust the less recently dead. These attitudes show that, among many possible modes of existence after death, an important conception was one in which the dead remained near the living and could return and disturb them. Such beliefs are rare in the official mortuary literature.

A prominent aspect of practical religion was magic. There is no meaningful distinction between Egyptian religion and magic. Magic was a force present in the world from the beginning of creation and was personified as the god Heka, who received a cult in some regions. Magic could be invoked by using appropriate means and was generally positive, being valuable for counteracting misfortune and in seeking to achieve ends for which unseen help was necessary. Magic also formed part of the official cult. It could, however, be used for antisocial purposes as well as benign ones. There is a vast range of evidence for magical practice, from amulets to elaborate texts. Much magic from the Greco-Roman period mixed Egyptian and foreign materials and invoked new and exotic beings. Preserved magical texts record elite magic rather than general practice. Prominent among magical practitioners, both in folklore and, probably, in real life, were "lector priests," the officiants in temple cults who had privileged access to written texts. Most of the vast corpus of funerary texts was magical in character.

THE WORLD OF THE DEAD

The majority of evidence from ancient Egypt comes from funerary monuments and burials of royalty, of the elite, and for the Late period of animals; relatively little is known of the mortuary practices of the mass of the population. Reasons for this dominance of the tomb include both the desert location of burials and the use of mortuary structures for display among the living. Alongside the fear of the dead, there was a moral community between the living and the dead, so that the dead were an essential part of society, especially in the 3rd and 2nd millennia BC.

The basic purpose of mortuary preparation was to ensure a safe and successful passage into the hereafter. Belief in an afterlife and a passage to it is evident in predynastic burials, which are oriented to the west, the domain of the dead, and which include pottery grave goods as well as personal possessions of the deceased. The most striking development of later mortuary practice was mummification, which was related to a belief that the body must continue intact for the deceased to live in the next world. Mummification evolved gradually from the Old Kingdom to the early 1st millennium BC, after which it declined. It was too elaborate and costly ever to be available to the majority.

Mummification

This decline of mortuary practice was part of the more general shift in the focus of religious life toward the temples and toward more communal forms. It has been suggested tentatively that belief in the afterlife became less strong in the 1st millennium BC. Whether or not this is true, it is clear that in various periods some people voiced skepticism about the existence of a blessed afterlife and the necessity for mortuary provision, but the provision nevertheless continued to the end.

It was thought that the next world might be located in

the area around the tomb (and consequently near the living); on the "perfect ways of the West," as it is expressed in Old Kingdom invocations; among the stars or in the celestial regions with the sun god; or in the underworld, the domain of Osiris. One prominent notion was of the "Elysian Fields," where the deceased could enjoy an ideal agricultural existence in a marshy land of plenty. The journey to the next world was fraught with obstacles. It could be imagined as a passage by ferry past a succession of portals, or through an "Island of Fire." One crucial test was the judgment after death, a subject often depicted from the New Kingdom onward. The date of origin of this belief is uncertain, but it was probably no later than the late Old Kingdom. The related text, Chapter 125 of the Book of the Dead, responded magically to the dangers of the judgment, which assessed the deceased's conformity with *ma'at*. Those who failed the judgment would "die a second time" and would be cast outside the ordered cosmos. In the demotic story of Setna (3rd century BC), this notion of moral retribution acquired overtones similar to those of the Christian judgment after death.

INFLUENCE ON OTHER RELIGIONS

Egyptian culture, of which religion was an integral part, was influential in Nubia as early as predynastic times, and in Syria in the 3rd millennium BC. During the New Kingdom, Egypt was very receptive to cults from the Middle East, while Egyptian medical and magical expertise were highly regarded among the Hittites, Assyrians, and Babylonians. The chief periods of Egyptian influence were, however, the 1st millennium BC and the Roman period. Egypt was an important centre of the Jewish diaspora starting in the 6th century BC, and Egyptian literature influenced the Hebrew Bible. With Greek rule there was significant cultural interchange between Egyptians and Greeks. Notable among Egyptian cults that spread abroad were those of Isis, which reached much of the Roman world as a mystery religion, and of Sarapis, a god whose name probably derives from Osiris-Apis, who was worshiped widely in a non-Egyptian iconography and cultural milieu. With Isis went Osiris and Horus the child, but Isis was the dominant figure. Many Egyptian monuments were imported to Rome to provide a setting for the principal Isis temple in the 1st century AD.

The cults of Isis and Sarapis

The cult of Isis was probably influential on another level. The myth of Osiris shows some analogies with the Gospel story and, in the figure of Isis, with the role of the Virgin Mary. The iconography of the Virgin and Child has evident affinities with that of Isis and the infant Horus. Thus, one aspect of Egyptian religion may have contributed to the background of early Christianity, probably through the cultural centre of Alexandria. Egypt also was an influential setting for other religious and philosophical developments of late antiquity such as Gnosticism, Manicheism, Hermetism, and Neoplatonism, some of which show traces of traditional Egyptian beliefs. Some of these religions became important in the intellectual culture of the Renaissance. Finally, Christian monasticism seems to have originated in Egypt and could look back to a range of native practices, among which were seclusion in temple precincts and the celibacy of certain priestesses. Within Egypt, there are many survivals from earlier times in popular Christianity and Islām. (J.R.Ba.)

Syrian and Palestinian religions

The religions of Syria and Palestine between 3000 and 300 BC are usually defined by the languages of those who practiced them: *e.g.*, Amorite, Hurrian, Ugaritic, Phoenician, Aramaic, and Moabite. The term "Canaanite" is often used broadly to cover a number of these, as well as the religion of early periods and areas from which there are no written sources. Knowledge of the religions of these groups is very uneven; it usually consists of mere glimpses of one or another aspect. Only from the city-state of Ugarit (14th–13th centuries BC) is there a wide range of religious expression. For historical background on the region, see the articles ISRAEL, JORDAN, LEBANON, PALESTINE, and SYRIA.

NATURE AND SIGNIFICANCE

Internally, the landscape of Syria and Palestine is broken into many different regions. In consequence, the population was generally divided among many polities, each of which had its own official religion. Externally, Syria-Palestine formed a land bridge between the great civilizations of Mesopotamia and Egypt and faced westward across the Mediterranean Sea toward the cultures of the Aegean. Syria and Palestine were subject to influences from these cultures and in their turn contributed to them. As a result, the official religions of the area were often syncretistic and sometimes cosmopolitan. Particular cults and myths were carried westward and adopted by the Egyptians of the New Kingdom (1539–1075 BC), by the Greeks and their antecedents, and later by the Romans. Despite their many different outer forms, and the individual stamp given them by the various political powers, the religions of Syria and Palestine appear to have been typologically similar. Out of them, however, emerged the ultimately quite distinctive religion of Israel, from which in turn Judaism, Christianity, and, less directly, Islām were formed.

The evidence available is primarily the product of the small, wealthy, ruling elites of these societies. It bears witness primarily to their religion, giving only indirect testimony to the beliefs or practices of the vast majority of the population. This official religion is polytheistic, the anthropomorphic gods as a whole being referred to as an extended family, or an assembly, or by other collective terms. Most earlier sources come from more cosmopolitan contexts and reflect that fact in their attention to a variety of gods. The sources from the 1st millennium suggest a greater concentration on a few gods or indeed on one supreme god.

Some divine names appear through most of the period from 3000 to 300 BC. In other cases, different names appear in different periods and in different regions or languages, and often titles are used instead of names. Consequently, it is sometimes not possible to determine to what extent new names have been assigned to gods whose cult is continuous across these boundaries and to what extent different gods may lie behind the same title. In general it appear that a few types prevailed and persisted over the centuries.

The most pervasive type was the storm god (Hadad, Baal, Teshub), who was associated with rain, thunder, and lightning—and thus with fertility and war. Another type was a more patriarchal creator god, bearing the simple name El ("God"). The major female deities appear to have been of either the belligerent type (Anath, Astarte) or the matriarchal type (Asherah). These often, but not always, served as the respective consorts of the two male types. Also prominent throughout the period were a solar and a lunar deity.

Types of deities

Consistent with the sources of documentation, the monarch emerges as a significant medium between god and people, acting on the people's behalf in the cult of the god and on the god's behalf in the care of the people. The cult was generally practiced in a "house" of the god, where a professional priesthood attended to the daily needs of the god, represented in effigy.

The most recurrent concerns in the written sources are (1) the good relations between monarch and god and the well-being of the monarch and his family (alive and deceased), on which the order of society depended, and (2) the natural conditions—rainfall, sunshine, fertility of soil, flocks, and herds—on which most people depended directly for survival and on which the agrarian economy as a whole depended.

SOURCES OF MODERN KNOWLEDGE

Until the late 19th century most of the information about pre-Hellenistic Syria and Palestine came from the Hebrew Bible and from various Greek and Latin sources.

While the Hebrew Bible was largely completed by 300 BC, its attitude toward contemporary religions of the area was generally quite hostile, so that its references to these religions may not only devalue them but also exaggerate or distort various aspects of them. On the other hand, Israelite religion was itself an outgrowth of, as well as a

reaction to, the religions of its neighbours, so that many features of Israelite religion found in the Hebrew Bible exemplify the religions of the larger area. The only sure guide to making such discriminations is the knowledge gained from indigenous documents.

Greek and Latin sources may be less hostile, but they are also much later, from the Roman period. While they may be more reliable in their description of the contemporary character of the religions of the area, that character may have been significantly different after several centuries of Hellenism from what it had been even in the middle of the preceding millennium. Notable among the Greek and Latin sources are *De Dea Syra* ("About the Syrian Goddess") from the 2nd century AD, attributed to Lucian of Samosata, and the section of Eusebius of Caesarea's *Praeparatio evangelica* ("Preparation for the Gospel"; 4th century AD) that cites extracts from a history of Phoenicia by Philo of Byblos (*c.* AD 100); Philo himself claimed to be translating the work of an early Phoenician priest, Sanchuniathon. While indigenous sources now confirm isolated elements of this allegedly early description of Phoenician religion, its distortions also have become more demonstrable. Philo's history is in fact an attempt to recount early Phoenician history by constructing a systematic chronological sequence of events out of the various local traditions of his time and interpreting the latter euhemeristically—that is, by treating gods and myths as representative of historical individuals and events.

Beginning in the late 18th century, the finds of early explorers of the area and subsequently of archaeologists engaged in more systematic excavation have produced a rapidly increasing number of firsthand sources. Successive generations of epigraphers and philologists have deciphered the texts and attained an increasingly sophisticated understanding of the languages. Unfortunately, the texts that are best understood tend to be formulaic and yield only the most external kinds of information about the religion, while the more distinctive texts, which seem more interesting and promise to be more revealing, are usually more difficult to penetrate.

Cuneiform archives from various 2nd-millennium sites and from the 3rd millennium at Ebla in northwestern Syria provide some documentation of the religion. The most abundant documentation comes from the 14th- and 13th-century remains of the city of Ugarit (modern Ras Shamra), on the Mediterranean coast of Syria. This includes the only native examples of extended religious narrative. It also comprises the widest range of genres, including myths, legends, liturgical texts, god lists, omens, and correspondence.

Ugarit

From the 1st millennium come scores of Phoenician inscriptions, both from the Phoenician coast and from other areas of the eastern Mediterranean; neo-Hittite hieroglyphic inscriptions and Aramaic inscriptions from northern Syria, almost all from the 9th and 8th centuries; and Moabite, Ammonite, and Hebrew inscriptions. These are very limited in genre, and relatively few are more than a few lines long.

Uninscribed materials from excavated sites throughout Syria and Palestine supplement the picture: they include the foundations of temples, temple furnishings, figurines, images of gods and their emblems, and scenes of gods, myths, and religious activities on reliefs and seals. However, criteria for identifying religious materials have not always been carefully considered, nor has discriminating attention been given to the question of the reflection of religious life in material remains in general. It is often difficult to correlate with confidence written and unwritten materials.

In spite of these new and ever-growing sources of knowledge, the resulting picture is still very irregular. While there is an unparalleled variety of sources, covering a century and a half, from the large cosmopolitan city of Ugarit, other written materials give a much more limited picture. For many periods, areas, and topics there are no written remains. Descriptions of the religion of any one period or area (with the exception of Ugarit) are extremely limited and superficial. Generalizations about the religions of Syria and Palestine may well prove to have significant exceptions as some of these gaps are filled by new discoveries.

INSTITUTIONS AND PRACTICES

The temple typically occupied a dominating site in the city along with the palace. Like the palace, it had political, administrative, and economic functions, as well as its distinctive religious functions. The temple, or the temple and palace together, were often raised and/or walled off in a separate precinct or acropolis. The temple was the "house" of the god—often so in both name and form. It was also a storehouse for the god's treasures and hence sometimes particularly thickly walled. The temple staff played a leading role in the life of the city.

In the early 3rd millennium the temples were built on the same plan as houses: a rectangle with the entrance on one of the long sides, with a small altar or a niche for the cult statue opposite the entrance. Sometimes there were benches around the three uninterrupted walls. An outer court contained the main altar, where the larger community could participate in worship. At the beginning of the 2nd millennium the house of the god was extended by the expansion of the niche into an additional room ("cella") and of the entrance into a porch—the form later used by the Phoenician architects of Solomon's Temple in Jerusalem. There were also outdoor shrines, such as the "high place" at Gezer (near modern Ramla, Israel) with its row of standing stones and monumental stone basin (and surviving charred animal remains). Over the centuries there was an increasing variety of forms at different sites. At particular sites, however, the plans of temples often remained virtually identical, even after previous superstructures had been destroyed.

Temple architecture

Israel Exploration Society—Hazor Expedition



Standing stones and seated deity from the high place at Hazor, dating from the 13th century BC.

Typical temple furniture included the cult statue, standing stones, bowls and their stands, altars, and benches around the walls. Hazor, in the Jordan Valley north of the Sea of Galilee, has yielded a 13th-century statue of a male deity on a bull-shaped base. In another temple a set of cultic objects, also from the 13th century, was found behind a stone slab: a seated male figure and a group of standing stones, the central one of which has engraved on it a vertical pair of arms with hands outstretched toward a disk and crescent.

The palace too might have a chapel. The palace at Mari, on the Euphrates in eastern Syria, housed a statue of a goddess holding a vase from which she dispensed flowing ("living") water; the water was channeled through the statue to the vase. Wall paintings in the palace depict the same image, as well as scenes of the king being presented to a god and making offerings to a god.

A common religious object, not confined to sacred places, is the "Astarte" figurine, depicting a nude woman, often with exaggerated breasts and genitalia, and sometimes holding a child. This was perhaps a fetish representing the mother goddess and used to stimulate conception, childbirth, or lactation.

The temple was staffed by cultic personnel (priests) under a "chief of priests," and by practitioners of the various other skills required by the functions of the temple. These included singers and other musicians, diviners, scribes, and other specialists, depending on the size of the temple. The temple staff was sustained by some of the sacrifices, by supplies from the estates of the temple or palace, or by direct contributions imposed on the surrounding population. Its essential religious function was the care of the cult statue, the offering of sacrifices, and the performance of other rituals for the welfare of god, monarch, and community.

Typically the monarch and sometimes other members of the royal family played a leading role in the most significant cultic acts and festivals. A king of Sidon refers to himself as "priest of Astarte." One text from a town near Ugarit concerns a sacrifice by the queen.

In tombs formed from subterranean caves beneath the western palace of Ebla during the second quarter of the 2nd millennium, skeletal remains and treasures suggest a cult of deceased monarchs. From Mari and Ugarit researchers have learned of a significant cult of former rulers (called "Healers" at Ugarit)—from putative or mythical figures to the most recently deceased—who supported the reigning monarch with divine blessings. The monarch's expectations of life after death are expressed in an inscription on an 8th-century monumental effigy of the god Hadad from Zincirli (ancient Sam'al) in south-central Turkey. King Panammu directs that his future heir, when making sacrifice to Hadad, pray that Panammu's soul may eat and drink with the god. Phoenician kings of Sidon later refer to a resting place with the Healers, and the same word is used by the Israelites to refer to all the dead.

Sacrifice

People attempted to influence the gods through animal sacrifices, petitions, and vows (promises of gifts contingent on the deity's response to a request for help). Sacrifice was central to the cult. Domestic animals were the main victims—cattle, sheep, and goats—and also birds. There is clear evidence for two types of sacrifice: simple gifts and whole burned offerings. There also is scattered evidence of human sacrifice, probably limited to situations of unusual extremity (contrast the account of the sacrifice of his eldest son by the king of Moab in 2 Kings 3:26–27 with the more abundant evidence of child sacrifice from Carthage and other Phoenician colonies in the west.)

The will of the gods was discovered in various ways. Use of the Mesopotamian technique of liver divination (hepatoscopy) is evidenced by the discovery of clay liver models (sometimes inscribed with omens) at such sites as Ugarit and Hazor, as well as by abundant written testimony at sites closer to Mesopotamia, such as Mari. Ugarit also had a list of omens based on abnormal births. King Idrimi of Alalakh refers to divining by observation of the flight of released birds.

The correspondence from Mari abundantly testifies to the institution of prophecy—spontaneous pronouncements by cult personnel and occasionally others, delivering messages from the deity. By this means the deity disclosed his or her wishes or gave divine warnings or promises to the king. The Aramaean king Zakir records that he appealed to his god in desperation during a siege and that the god answered him through prophets with promises of deliverance—obviously fulfilled, since the king makes so much of this in his inscription. According to the Egyptian "Report of Wen-Amun," a young man of Byblos went into a trance and resolved a diplomatic deadlock by announcing that the Egyptian envoy whom the local king had refused to see had indeed been sent by the Egyptian god Amun. Biblical narratives portray similar prophetic phenomena in Israel. The gods also revealed themselves through dreams, which again were carefully reported to the monarch by his officers at Mari.

According to later classical sources a central focus of Syrian religion was the rituals surrounding the myth of the dying god. The myth, according to these sources, variously draws on other Middle Eastern or Egyptian traditions but essentially tells of the deity's death and subsequent sojourn in the underworld and of an accommodation reached between the queen of the underworld and the goddess associated with the god that allows him to return to earth for six months of the year. Associated rituals include the sacrifice of a male pig, mourning for the dead god in a funeral procession, cultivating "gardens" in small pots and baskets, and a threshing rite.

GODS, MYTHOLOGY, AND WORLDVIEW

There are significant differences between the divine names used in personal names, those of literary myths and epics, and those of more official pantheons, as found in cultic and political texts.

Personal names

Personal names are probably the most conservative of these sources. Some of the deities referred to in personal names are not mentioned in other contemporary sources. They may also preserve the memory of old family or clan cults. The piety expressed in personal names shows that people often saw themselves (or their children) as related to a god especially by kin or service. At Ugarit the god was variously conceived as father, mother, brother, sister, mistress, king, or judge, and the person named could be the son, daughter, offspring, servant, boy, or man of the god. The names also refer to individuals as the "gift" or "beloved" of the god. In personal names the relationship between an individual and a god is more important than the particular deity's role in traditional mythology or the official cult.

The projection of anthropomorphic features onto the gods and the need to explain things—from specific rituals to the nature of the world—led to the telling of stories about the gods. The written versions of such myths and epics often preserve older traditions and may figure as their chief divine actors gods other than those prominent in the current official pantheon. The only source of such native Syro-Palestinian religious literature is 14th-century Ugarit.

In the Ugaritic myths, El is depicted as a bearded old man, kindly and wise. In the legend of King Keret (or Kirta; *k-r-t*), El is the sole benefactor of Keret in that king's various sufferings: he responds to Keret's misery at his lack of a family by appearing to him in a dream and giving him detailed directions for getting a certain princess as his wife. When Keret has successfully followed these directions, El appears at his wedding and pronounces a blessing, promising them many children. After the children are born, Keret becomes sick because of failure to fulfill a vow. No mortal or deity is able to help him until finally El again intervenes and creates a creature for the specific task of healing him. No sooner has Keret recovered and resumed his duties than he faces another crisis—his son proposes to take over from him—but the sequel (a third intervention by El?) has not been preserved. In the text El is called "the Father of humankind." He is the patriarch of the gods, the final power and authority, though he does not always act decisively and he is not always treated with due respect. As the creator god, "the Creator of Creatures" (though no creation myth has been

preserved) and the king of the gods, he is the owner and chief executive of the world. Even the forces of chaos, Yamm and Mot ("Sea" and "Death"), are his beloved children. El is called "the Bull" and is represented iconographically by a bull. His consort is Elat, usually known as Asherah, the "Progenitress of the Gods." She is also called simply Qudshu, "Holiness." Asherah is associated with the sea and with serpents.

Baal (Hadad) is regularly denominated "the son of Dagan," although Dagan (biblical Dagon) does not appear as an actor in the mythological texts. Baal also bears the titles "Rider of the Clouds," "Almighty," and "Lord of the Earth." He is the god of the thunderstorm, the most vigorous and aggressive of the gods, the one on whom mortals most immediately depend. Baal resides on Mount Zaphon, north of Ugarit, and is usually depicted holding a thunderbolt. He is the protagonist of a cycle of myths from Ugarit. These tell of a challenge from Yamm ("Sea"), to which Baal responds. Armed with magical weapons made by the craftsman god, Kothar, Baal manages to overcome Yamm. Another major episode is instigated by Baal's lack of a house. With the assistance of Asherah and Anath, Baal gets El's approval to build a house; Kothar accomplishes the construction; and Baal celebrates by inviting the gods to a feast. The other major story concerns Baal's relations with Mot ("Death"), whom he initially defies, but to whom he eventually succumbs. The attempt to find a god adequate to assume Baal's role fails. Anath disposes of Mot, and then El learns in a dream that Baal is again alive. Mot also reappears, and he and Baal fight until the sun goddess warns Mot of the consequences. There is apparently a final definition of their respective spheres of influence.

The Baal cycle

After Baal is swallowed up by Mot, his sister Anath, called "the Maiden," longs for him like a mother. She finds Baal and buries him. She then defeats Mot and disposes of his body as if it were grain, grinding him up and scattering him over land and sea. Elsewhere in the text Anath refers to her victories over various monstrous enemies in single combat, and she is depicted in scenes of bloody slaughter. She is the "villain" of the tale of Aqhat, also from Ugarit. In this story the gods grant the childless Danel a son, Aqhat, on whom Danel confers a bow made by the craftsman god, Kothar. Anath offers Aqhat riches and immortality in exchange for the bow, but Aqhat refuses her offers. After bullying El into letting her have her way with Aqhat, she proceeds, with the aid of her henchman Yutpan, to have Aqhat killed. Danel performs various rites to try to remove the consequent blight on the land, until he is informed of his son's murder. He then seeks his remains and buries him, curses the towns closest to the site of the murder, and mourns for seven years, after which he gives his blessing to his daughter's proposed mission to avenge Aqhat's death. She sets out and comes to the camp of Yutpan, where the two of them start drinking—at which point the preserved portion of the tale ends. Anath is often associated with Athtart (later Hebrew Ashtoreth, Greek Astarte). Both are renowned for their beauty, and both are closely associated with Baal.



Limestone stela of Baal, often called "Baal with the lightning." The god is shown wearing a helmet, with a club in his right hand and a lance in his left. In the Louvre Museum, Paris.

By courtesy of the Musée du Louvre, Paris; cliche des Musees Nationaux, Paris, © R.M.N.

Another group of gods play important subordinate roles in the myths. The sun goddess, Shapash, "Light of the Gods," helps Anath in her retrieval of the dead Baal and intervenes in the final conflict between Baal and Mot. The craftsman god, known as both Kothar ("Skilled") and Hasis ("Clever"), makes the weapons with which Baal disposes of Yamm and builds the palace for Baal. He is the source of Aqhat's bow, coveted by Anath. The Kathirat are goddesses of marriage and pregnancy, who appear before the conception of Aqhat and in a brief myth about the marriage of Yarikh ("Moon") and his Mesopotamian consort Nikkal. Shahar and Shalim are the gods of dawn and dusk, whose conception and birth are recounted in a liturgical myth.

While the great cycle of narratives about Baal from Ugarit in its present form is clearly a literary work rather than a myth, it is doubtlessly composed of religiously significant mythic material. It depicts the prevailing order of things as the result of struggles among the gods—successive bids for power in which Yamm and Mot are confined to their present bounds and Baal and Anath (associated with fertility and military prowess, respectively) prevail. Having descended into the underworld and survived Death, Baal embodies the assertiveness and continuity of life.

It is the official documents of religious practice—god lists, sacrificial lists, and temple rituals, as well as the inscribed monuments—that disclose most directly the gods favoured by the authorities of the time. While virtually all the gods of the myths are Semitic in name, the gods of the cult are much more diverse. This official pantheon presumably included the gods of leading families within this cosmopolitan state and the gods of allied neighbouring states.

The religion of Ebla

At 3rd-millennium Ebla the most important god was Dagan, "Lord of Gods" and "Lord of the Land." Other gods of Ebla included El, Resheph, the storm god, Ishtar, Athtart, Chemosh, and the sun goddess. The gods of the city included several referred to by their Sumerian names. The great rivers of northern Syria were also deified, so that their local names remain unknown. Personal or family gods were referred to as "the god of my father" and "the god of the ruler."

In the early 2nd millennium the great goddess, Ishtar, was widely portrayed in contemporary northern Syria as both warrior and fertility goddess. A standing stone from Ebla depicts her in a winged shrine, standing on a bull. Dagan was also popular—there are references to the local Dagan of various towns: Dagan of Terqa, Dagan of Tuttul, and so on. The royal establishments of Mari and Ugarit owed special allegiance to a deity called "The Lady of the Palace."

The Indo-European gods Varuṇa, Mitra, and Indra were recognized in the kingdom of Mitanni in northeastern Syria, where a Hurrian population was ruled by an Indo-Aryan aristocracy in the third quarter of the 2nd millennium. Little is known of the religion of the Hurrians beyond the names and general character of their chief gods: Teshub, a storm god, and his consort Hepat; their son, Sharruma, also a storm god; the goddess Shaushka,

identified with the Mesopotamian Ishtar; and Kushukh and Shimegi, lunar and solar deities, respectively. Hurrian mythology is known only through Hittite versions (see below *Religions of Asia Minor: Religions of the Hittites, Hattians, and Hurrians*.)

King Idrimi of Alalakh designates himself "servant of the storm god; of Hepat; and of Ishtar, the Lady of Alalakh, my lady." He acknowledges his dependence on the storm god in his adventures and concludes his autobiographical inscription by invoking deified Heaven and Earth, the gods of heaven and earth, the storm god "the lord of heaven and earth," and the great gods. Thus an individual king of the mid-2nd millennium pays tribute specifically to the storm god and then to the two major goddesses of his world, and he acknowledges the rest by means of collectives.

The documentation at Ugarit attests to a more explicit and specific comprehensiveness. Several god lists have been recovered from Ugarit. The most "official" one, which has survived in two Ugaritic copies and one Akkadian translation, consists of 33 items, beginning with a generalized ancestral deity, Ilib, "God of the Father." (One version prefixes the "God of [Mount] Zaphon"—presumably the deity of the mountain north of Ugarit, which is later referred to directly as a god.) Then comes El, followed by Dagan, Baal of Zaphon, and six other Baals. (El, Ilib, or Baal of Ugarit variously come at the head of other god lists.) There follows a small group of gods and goddesses bracketed by Earth-and-Heaven and Mountains-and-Valleys, including the Kathirat, Yarikh, Mount Zaphon, Kothar, and Athtar. Then comes a group of major goddesses, led by Asherah, Anath, and Shapash and concluding with Athtart. The list ends with another group beginning with "the gods who are Baal's auxiliaries," and including the assembly of the gods. This group includes Resheph, Yamm, and Shalim.

Figurines from throughout the area and from a period of many centuries represent an enthroned couple (corresponding to El and Asherah) and a belligerent pair (corresponding to Baal and Anath or Athtart). These figurines are probably replicas of life-size (or larger-than-life) cult images. In any case, they attest to the ongoing official significance of these four types of deity under whatever names.

Developments in the 1st millennium

In the 1st millennium the written documentation shrinks to formulaic inscriptions, very occasionally developed into more expressive literary miniatures. Gods are often referred to in these texts by titles or by new names, so that it is often difficult to ascertain their relationship to the deities of the 2nd millennium, or indeed to determine their individuality in relation to one another. It appears that there was a tendency in this millennium to concentrate all divine power in one deity, as has been noted of Mesopotamia and as is most obviously and extremely the case in Israel.

The storm god, Hadad, appears as the chief god of the Aramaeans in northern Syria in the 9th and 8th centuries. The moon god (under the name Sahar) also is prominent in this area. Some rulers speak of their own dynastic deity. A king who owes his position to the Assyrian emperor refers to the latter and the dynastic deity equally as "my master."

It is clear that several different deities are referred to by the form Baal-X ("Lord of X"). Hadad is probably represented by Baal-Shamen ("Lord of the Heavens"). El appeared under the tile Baal-Hammon—rarely on the mainland, but abundantly in the Phoenician colonies of Africa; under this name he becomes the chief deity of Carthage. In the Phoenician heartland the supreme goddess of Byblos—presumably Asherah—is called simply Baalat Gubl ("the Lady of Byblos"). Anath becomes much less visible during the 1st millennium than at Ugarit. Athtart (Astarte), on the other hand, becomes more prominent. At Sidon, as earlier at Ugarit, she is referred to as "the Name of Baal," perhaps indicating that she was called upon as a mediator with the supreme Baal (Hadad). Alongside other long-familiar deities such as Resheph and Shamash appeared certain new names, including Eshmun (especially at Sidon), Melqart ("king of the [underworld] city"; especially at Tyre), and, of course, Yahweh (in Israel—but also represented at least in personal names at Hamath and Larnaca). According to the Hebrew Bible, Asherah and Astarte were both worshiped in Israel during the first half of the millennium, and Hebrew inscriptions attest to a pairing of Yahweh and Asherah.

Chemosh, known from Ebla and Ugarit, reappears as the national god of Moab. King Mesha of Moab interprets Israel's occupation of his country as a consequence of Chemosh's anger with his land. He claims that, at Chemosh's direction, he reconquered land occupied by Israel, and he attributes his success to Chemosh. He reports that he dedicated the Israelite inhabitants to Chemosh by slaughter and says that Chemosh will henceforth dwell in these territories. This is recorded on the Moabite Stone (now in the Louvre, Paris) a stela that commemorates these events and Mesha's building of a sanctuary for Chemosh in gratitude. The formal identity of these expressions and this kind of religious interpretation of events with those found in some of Israel's literature encourages the surmise that they may also have been shared by the Ammonites with respect to their national god, Milcom.

Philistine religion

The Philistines, traditionally believed to have originated in Crete, were one group of the Sea Peoples that moved from the Aegean Sea to the southeastern Mediterranean. They settled in southeastern Palestine after being repulsed by the Egyptians. Their religion, while it retains some Aegean and Egyptian elements from the Philistines' origins and route of migration, appears largely indistinguishable from Canaanite religion in general. The Bible refers to the gods of the Philistines by the familiar Canaanite names Dagon, Baalzebub, and Ashtart. The name of Asherah has been found inscribed on storage jars in a cultic room at Ekron. (S.B.P.)

Arabian religions

The description of the religions of Arabia given here comprises the polytheistic beliefs and practices that existed before the rise of Islām in the 7th century AD in Arabia, in the broad sense of the term, including the confines of the Syrian desert. The religion of Palmyra, which belongs to the Aramaic sphere, is excluded from this account. The monotheistic religions that had already spread in Arabia before the arrival of Islām are also mentioned briefly. For historical background, see ARABIA.

NATURE AND SIGNIFICANCE

In the polytheistic religions of Arabia most of the gods were originally associated with heavenly bodies, to which were ascribed powers of fecundity, protection, or revenge against enemies. Aside from a few deities common to various populations, the pantheons show a marked local particularism. But many religious practices were in general use. The study of these practices is instructive in view of their similarities with those of the biblical world and also with those of the world of Islām, for, while firmly repudiating the idolatry of the pre-Islāmic period, which it calls the "Age of Ignorance" (Jāhiliyah), Islām has nevertheless taken over, in a refined form, some of its practices.

SOURCES OF MODERN KNOWLEDGE

Knowledge of pre-Islāmic Arabia rests mainly on original archaeological and epigraphic data from the region itself. Countless pre-Islāmic sites are scattered over the whole Arabian Peninsula: ancient lines of circles of raised stones, cairns, graveyards, and so on. In addition there are more recent constructions such as fortified towns and ruins of temples and irrigation systems. Many rock faces are covered with incised drawings. The oldest drawings, barely visible under a dark patina, date back to several millennia BC and provide evidence, for instance, of an ancient cult for the bull and the ostrich. These ancient drawings also depict queer ritual scenes that refer to a still obscure mythology. More explicit and much later (at least no earlier than the end of the 2nd millennium BC) are tens of thousands of alphabetic rock graffiti in ancient Arabian dialects, written in related local alphabets. These graffiti were clustered predominantly along the natural routes

followed by nomads and caravaneers, as well as less numerous monumental inscriptions from the sites formerly occupied by a sedentary population.

The written graffiti are short inscriptions scratched on the rock. The author gives his name and his patronymic and/or his tribal affiliation and genealogy. Short messages, such as a description of an incident, a sad evocation of a dead relative, or an invocation to a god, may follow. Thanks to their considerable number, such texts, which may be rather insignificant in themselves, provide valuable information on the gods and their attributes and on their worshipers.

Monumental inscriptions

The monumental inscriptions are much more elaborate and meaningful, both because they belong to the complex institutions of a sedentary culture and because they appear in an archaeological context. They are carefully engraved, so that the state of evolution of the script allows them to be dated approximately, even when no explicit date is given. They are utilitarian in character and are usually concerned with the construction of buildings, the dedication of objects to a god, or arrangements relating to irrigation. They may also describe military campaigns. So far only traces of a true religious literature have been recovered. But several specimens of a hitherto unknown type of document, excavated since 1970 in Yemen, contradict the unilateral character of the inscriptions. These are records from private archives (personal letters, contracts, and so on), finely engraved in a cursive writing on small wooden sticks. Iconographic documents such as statues and reliefs, seals, and coins also reveal aspects of the religion.

Yet another source is the Muslim tradition. Next to the pre-Islāmic poetry, belatedly put into writing, it comprises the Qur'ān, the sacred book of the Muslims transmitted by its Prophet Muḥammad, which takes a stand against idolatry. Historical traditions have been transmitted by early Muslim annalists and geographers; more specific data on the ancient folklore and religion appear, for instance, in "The Book of the Idols" (*Kitāb al-Aṣnām*), by the Iraqi genealogist Ibn al-Kalbī (8th–9th century AD), and in "The Crown" (*al-Iklīl*), by the Yemeni encyclopaedist and geographer al-Hamdānī (9th–10th century AD), which describes the pre-Islāmic antiquities of Yemen.

External sources are scanty: Arabia has remained little known to its neighbours. From the 9th to the 7th century BC Assyrian kings report their campaigns against North Arabian kings (or queens) and tribes and occasionally name their gods. The annals of Sargon for the year 718 BC and those of his son Sennacherib name two successive sovereigns of Saba' who sent them a "tribute" of aromatics. The Book of Kings of the Bible describes the legendary visit in Jerusalem of a queen of Sheba, bringing presents of gold and frankincense, during the reign of Solomon (10th century BC). In the middle of the 6th century BC the Neo-Babylonian king Nabu-na'id (Nabonidus) conquered the oasis of Taymā' in the Hejaz (Al-Ḥijāz). He boasts of having settled populations from Babylonia there and in neighbouring oases such as Dedān, Khaybar, and Yathrib (Medina), which are known to have been inhabited since ancient times by Jewish populations. It is quite probable that Jews of the Babylonian Exile were among those forced settlers and initiated at that time the Jewish presence in Arabia.

Some classical authors, from Herodotus (5th century BC) to Claudius Ptolemy (2nd century AD), provide information on the religion of the Arabs and on the geography of the Arabian Peninsula. Several Byzantine authors report conflicts between Jews and Christians in Yemen in the 6th century AD.

For many subsequent centuries Arabia remained practically closed to European penetration. Important discoveries of monuments and inscriptions occurred only from about the middle of the 19th century. It was only after World War II, and indeed mostly since the late 1970s, that major archaeological surveys and excavations began in various parts of the peninsula.

THE HISTORICAL SETTING

South Arabia. From the middle of the 2nd millennium BC a sedentary agrarian civilization developed in Yemen in the oases along the edge of the desert. The people of this civilization had gradually mastered techniques enabling them to accumulate water from seasonal mountain rivers and distribute it into extensive irrigation systems. At the end of the 8th century appeared the oldest monumental inscriptions so far recorded, displayed on the walls of buildings. A total of about 8,000 such texts, whole or fragmentary, which correspond to 13 centuries of South Arabian history, have been discovered.

The main South Arabian kingdoms

The texts from the 6th century BC mention the main South Arabian kingdoms, which were spaced out from the northwest to the southeast in the oases along the edge of the desert. There were successively Ma'īn, the kingdom of the Minaeans; Saba', the most important, with its capital, Mārib; Qatabān and Awsān (both located in the area of former Aden Territory [Yemen]); and finally Ḥaḍramawt (the eastern part of the former Aden Protectorate), extending inland from and along the coast of the Gulf of Aden toward Oman; its capital was Shabwa. The coastal area of Ḥaḍramawt was the nearly exclusive biotope of the wild tree from which was extracted the best kind of frankincense, which was the most precious aromatic in the Middle East used for the cult of the gods and of the dead. Along with other aromatics, frankincense was carried inland northwestward on the caravan route through Yemen to a place north of Yemen, where the route bifurcated, running through the oases of the Hejaz (on the Red Sea coast of the Arabian Peninsula) toward Egypt and Syria, and through Qaryat al-Fa'w on the caravan route to central Arabia toward the Persian Gulf and Mesopotamia. Minaean merchants, established in Dedān in the Hejaz and in Qaryat al-Fa'w, were in control of that trade. During the following centuries Saba' struggled with Qatabān for hegemony. About the beginning of the Common era the rise of overseas trade between Egypt and India disrupted the political and economic balance in South Arabia and resulted in a period of general conflict. At the end of the 3rd century AD, Saba', which had meanwhile conquered Ma'īn, Qatabān, and finally Ḥaḍramawt, was in turn conquered, with the whole of South Arabia, by Ḥimyar, a little kingdom that had risen in the southwestern corner of Yemen. This political unification hastened the decay of the overly diversified polytheistic beliefs. After about AD 350 monotheistic invocations to *Raḥmānān*, "the Merciful" (an epithet of Aramaic origin used for God by both Jews and Christians), or to the "Lord of Heaven and Earth," take the place of former polytheistic formulas and dedications. These early monotheistic texts probably emanated from Jewish immigrants from the oases of the Hejaz, although Christianity had already been introduced in South Arabia by Byzantine and Syrian missionaries.

About AD 523 Yūsuf As'ar Yath'ar (nicknamed Dhū Nuwās by the Muslim tradition), a Ḥimyarite king of Jewish faith, persecuted and killed numerous monophysite Christians in Najrān on the northern frontier of Yemen. He also killed Byzantine merchants elsewhere in his kingdom. Outraged by the massacre and pressed by the Christian world to intervene, the Negus of Ethiopia gathered a fleet and landed with troops in Yemen. Having killed the Ḥimyarite king in battle, the Negus appointed an indigenous Christian as his viceroy and sailed back home. Somewhat later Abraha, a former Ethiopian general, took power. The Muslim tradition credits him with a fruitless military expedition with elephants (alluded to in the title, "the Elephant," of chapter 105 of the Qur'ān), directed in 570 against Mecca and its polytheistic shrine. About the end of the 6th century the famous Mārib dam finally collapsed after several major dam bursts. This was a symptom rather than the cause of the long decline of the South Arabian culture, which had led to the emigration northward of several Yemeni tribes. About 572 South Arabia came under Persian occupation. This lasted until 628, when the local satrap in charge embraced Islām, thus opening his province to the new faith and to the Islāmic culture.

North and central Arabia. There are various populations to consider, differing in their languages and systems of writing, in their pantheons, and above all in their ways of life. Sedentary populations of merchants and farmers were settled in towns and oases, which were centres of

developed civil and religious institutions. In sharp contrast with them were the breeders of sheep and goats—semi-nomads living in precarious shelters in the vicinity of sedentary settlements—and true nomads: camel breeders and caravaneers, capable of crossing the desert, moving with their herds over great distances toward seasonal pastures, and living under tents. Their places of worship were rocky high places; portable idols followed the peregrinations of the tribe.

Among the oases or towns of which the local gods are known appears in the first place the oasis of Dūmat al-Jandal, halfway between the Sinai and Babylon; the Assyrian king Esarhaddon names its gods (see below). In the North Arabian oasis of Taymā', stelae written in Aramaic and dated to the 5th century BC name the local deities. In the 5th century BC, the oasis of Dedān (al-'Ulā) was the capital of a short-lived Dedānite kingdom; then, from the 4th century to the 1st century BC, it was the capital of the kingdom of Liḥyān, which for nearly two centuries was home to a colony of Minaean tradesmen from South Arabia. Dedān and the neighbouring site of Al-Ḥijr (Ḥegrā') were occupied from the north in about 25 BC by the Nabataean kingdom.

The Nabataeans

The Nabataeans were originally a nomadic tribe from the land of Madiān in the northern Ḥejaz who settled in North Arabia, the Negev, and southern Jordan as far north as the Dead Sea, from which they extracted bitumen. Their capital, Petra, north of the Gulf of Aqaba, is historically attested from the beginning of the 4th century BC. In spite of their Arab origin, they used an Aramaic dialect as their written language. At the time of their greatest wealth and power, under Aretas IV (8 BC–40 AD), their territory extended from Al-Ḥijr in the south, northward past Petra, along the northern route east of the Jordan River as far as the Ḥawrān region south of Damascus. The Nabataean territory—except for its southern part—was incorporated into the Roman Provincia Arabia in AD 106. The last dated Nabataean text dates from AD 356.

The so-called "Thamūdic" graffiti are named after Thamūd, one of several Arabian tribes named in the Assyrian annals. Thamūdaeans are named about AD 169 in a Greek inscription on a Nabataean temple in the northeastern Ḥejaz, and in a 5th-century Byzantine source, as members of a cameleer corps on the northeastern Egyptian frontier. The Muslim tradition wrongly ascribes to the Thamūd the Nabataean tombs carved in the rock in Al-Ḥijr. The name "Thamūdic" was first given to a type of alphabetic graffiti found in the region of Taymā', because what may be mentions of the tribal name Thamūd occur in some of these texts. Later the name was incorrectly applied to various types of graffiti found throughout Arabia, dating from the 4th century BC to the 3rd or 4th century AD.

The Ṣafaitic graffiti (1st century BC to the 4th century AD) are so called because they belong to a type first discovered in 1857 in the basaltic desert of Ṣafā', southwest of Damascus. Many thousands of such texts, scattered over an area including eastern Syria and Jordan and northern and northeastern Saudi Arabia, have so far been collected and in part published.

From the disruption of the Arabian sphere in the 3rd and 4th centuries, owing in part to the penetration of Christianity and to the emigration of south and central Arabian tribes toward Syria and lower Iraq, emerged during the 4th and 5th centuries some buffer states, vassals of the Byzantine and Persian empires and of the Ḥimyarite kingdom. The Ghassānids were settled in Syria, the Lakhmids in Al-Ḥīrah on the Euphrates, and the Kindites in central Arabia. In the 5th and 6th centuries they were closely involved in the hostilities between Byzantium and Persia.

PRE-ISLĀMIC DEITIES

South Arabia. The astral basis of the South Arabian pantheon emerges from such divine names as Shams ("Sun") and Rub' ("Moon-Quarter"). The epithets "Mother of 'Athtar," "Mother of [the] goddesses," "Daughters of [the god] Il" allude to still-obscure theogonic myths.

The name of the Venus god 'Athtar corresponds to that of the Mesopotamian goddess Ishtar (Venus). Hawbas, a goddess, was his consort (but seems to have been locally a masculine deity). As head of the South Arabian pantheon, 'Athtar had superseded the ancient supreme Semitic god Il or El, whose name survives nearly exclusively in theophoric names. 'Athtar was a god of the thunderstorm, dispensing natural irrigation in the form of rain. When qualified as Sharīqān, "the Eastern One" (possibly a reference to Venus as the Morning Star), he was invoked as an avenger against enemies.

National deities

Next to 'Athtar, who was worshiped throughout South Arabia, each kingdom had its own national god, of whom the nation called itself the "progeny" (*wld*). In Saba' the national god was Almaqah (or Ilmuqah), a protector of artificial irrigation, lord of the temple of the Sabaean federation of tribes, near the capital Ma'rib. Until recently Almaqah was considered to be a moon god, under the influence of a now generally rejected conception of a South Arabian pantheon consisting of an exclusive triad: Father Moon, Mother Sun (the word "sun" is feminine in Arabic), and Son Venus. Recent studies underline that the symbols of the bull's head and the vine motif that are associated with him are solar and Dionysiac attributes and are more consistent with a sun god, a male consort of the sun goddess. In Ma'in the national god Wadd ("Love") originated from North Arabia and probably was a moon god: the magic formula *Wd'b*, "Wadd is [my?] father," written on amulets and buildings, is often accompanied by a crescent Moon with the small disk of Venus. In Ḥaḍramawt the national god Syn was also a sun god: the current identification with the Mesopotamian moon god Sin (Suen) raises phonetic objections, and the symbolic animal of Syn, shown on coins, was the eagle, a solar animal. In Qatabān the national god 'Amm, "paternal uncle," may have been a moon god. The sun goddess Shams was the national deity of the kingdom of Ḥimyar. She appears also, in a minor role, in Saba'. Other aspects of Shams are certainly concealed in some of the many and still obscure South Arabian female divine epithets.

Lesser deities

Among various lesser or local deities, the nature and even the sex of many of whom remain unknown, the better-documented are listed here. In Qatabān, Anbay and Ḥawkam are invoked together as (the gods) "of command and decision(?)." The name Anbay is related to that of the Babylonian god Nabu, while Ḥawkam derives from the root meaning "to be wise." They probably represent twin aspects (as Evening and Morning Star?) of Babylonian Nabu-Mercury, the god of fate and science and the spokesman of the gods. In Ḥaḍramawt, Ḥawl was probably a moon god; his name apparently alludes to the lunar cycle. Some tribes worshiped their own "patron" (*shym*). Ta'lab was the patron of Sum'ay, a Sabaean federation of tribes. In Ma'īn, Nikraḥ was a healer patron; his shrine, located on a hillock in the middle of a large enclave marked by pillars, was an asylum for dying people and women in childbirth.

Among other North or central Arabian gods worshiped in South Arabia, Dhū-Samāwī ("the Heavenly One"), was presented by Bedouin tribes with votive statuettes of camels to ensure the well-being of their herds. Kāhil, the national god of the central Arabian kingdom of Qaḥṭān in Qaryat al-Fa'w, was assimilated there to Dhū-Samāwī. He was also known in South Arabia. Conversely, the Sabaean god 'Athtar Sharīqān appears in Qarya under the Arabic transcription *'Athar* [sic] *a(sh)-Sharīq*.

The South Arabian deities are usually evoked by a symbol, as, for instance, a bull's head, snake, or thunderbolt. Seldom (and later) do they appear in human form, inspired by late Hellenistic iconography: for example, seated Demeter with cornucopia, Dionysus-Sabazios, and the Dioscuri.

North Arabia. North Arabian gods are named for the first time in the annals of the 7th-century BC Assyrian king Esarhaddon, in which he reports having returned to the oasis of Adumatu (Dūmat al-Jandal) the idols previously confiscated as war booty by his father, Sennacherib. Among the gods named by Esarhaddon are 'Atarsamāin, 'Atarqurumā, Nukhay, and Ruldayu. Herodotus wrote that the Arabs worshiped as sole deities Alilat, whom he identifies with both Urania and Aphrodite, and Orotalt,

identified with Dionysus. Both accounts concur: Ruldayu and Orotalt are phonetic transcriptions of the same name, Ruḍā, a sun god often named in the Thamūdic inscriptions and in Ṣafaitic (in Ṣafaitic, Ruḍā eventually becomes a goddess). In the Nabataean kingdom the counterpart of Dionysus was the great god nicknamed dū-Sharā (Dusares), "the one of Sharā" from the name of the mountain overlooking Petra. This epithet replaced the secret name (probably Ruḍā) of that god, a rival to Shay' al-Qawm, "the Shepherd of the People," he "who drinks no wine, who builds no home," the patron of the nomads, represented as Lycurgus and also worshiped by the Liḥyānites. Nukhay, perhaps a solar god, was worshiped by the Thamūdaeans and Ṣafaites.

Al-Ilāt or Allāt ("the Goddess"), was known to all pantheons. She is a daughter or a consort, depending on the region, of al-Lāh or Allāh ("the God"), Lord of the Ka'bah in Mecca; he is also named in Thamūdic texts. Al-Ilāt formed a trio with the goddesses al-'Uzzā ("the Powerful") and Manāt (or Manawat, "Destiny"). Among the Nabataeans al-'Uzzā was assimilated to Venus and Aphrodite and was the consort of Kutbā' or al-Aktab ("the Scribe"; Mercury); among the Thamudaeans, however, she was assimilated to 'Attarsamay (or 'Attarsam). Manāt was depicted as Nemesis in the Nabataean iconography. The three goddesses were called the "Daughters of Allāh" in pre-Islāmic Mecca, and they are mentioned in the Qur'ān (53: 19–22). In South Arabia they are called the "Daughters of Il," and al-Ilāt and al-'Uzzā are mentioned in Sabaean inscriptions.

In Taymā', in the northern Hejaz, Aramaic inscriptions of the 2nd half of the 5th century BC mention the gods Ṣalm, Ashimā', and Shingalā'. Only the first name can be identified with the figure of a bull's head with a solar disk between the horns represented in the inscriptions. Ṣalm is also named in some Thamūdic graffiti with similar drawings, found in a rock sanctuary near Taymā'.

The secret name of the Liḥyānite god nicknamed dhū-Ghābat, "the One of the thicket," is unknown. Other Liḥyānite gods were han-Aktab, "the Scribe," and Ba'alshamīn, "the Lord of Heavens," and 'Aglibōn, a fertility bull god, both of whom were borrowed from Palmyra.

SANCTUARIES, CULTIC OBJECTS, AND RELIGIOUS PRACTICES AND INSTITUTIONS

The sanctuaries, sometimes carved in the rock on high places, consisted of a *ḥaram*, a sacred open-air enclosure, accessible only to unarmed and ritually clean people in ritual clothes. There the baetyl, a "raised stone," or a statue of the god, was worshiped. The Nabataeans originally represented their gods as baetyls on a podium, but later they gave them a human appearance.

Petra

Of the Nabataean high places that are carved from the rock, the best-known overlooks the site of Petra. On a summit measuring roughly 215 by 65 feet (65 by 20 metres) are carved a large triclinium for ritual meals, a podium with baetyls, a sacrificial altar, and a basin. The stone-built temples of the Nabataeans and South Arabians were more elaborate structures, consisting of a rectangular walled enclosure, near one end of which was a stone canopy or a closed cella or both, which contained the altar for sacrifices or the idol of the god. Other rooms and a cistern might be added. The Ka'bah in Mecca, which became the sacred shrine of the Muslims, has a similar structure: it is a closed cella (which was full of idols in pre-Islāmic times) in a walled enclosure, with a well. A baetyl, the Black Stone, is inserted in the wall of the Ka'bah; it is veiled by a cloth cover (the *kiswah*), reminiscent of the leather cover of the Ark of the Covenant. Numerous South Arabian temples have been surveyed. The temple of Almaqah in Mārib had an unusual shape, that of an ellipse with a major axis about 345 feet long, with a strong wall about 28 feet high, built of fine limestone ashlars. A small temple, in front of which were eight standing pillars, comprises a gallery supported by pillars around a rectangular court; it served as a peristyle to the main temple, in the wall of which it was inserted.

To the gods were offered, on appropriate altars, sacrifices of slaughtered animals, libations and fumigations of aromatics, votive objects, or persons dedicated to serve in the temple. A ritual slaughter of enemies in gratitude for a military victory is mentioned at the rock sanctuary of the sun goddess of Ḥimyar. Normally the dedicator of a sacrifice performed the slaughtering of the animal.

In addition to the northwestern Arabian *Kāhin*, "soothsayer," several kinds of priests and temple officials appear in Liḥyānite, Nabataean, and South Arabian inscriptions, but their respective functions are not clear. North Arabian queens and ancient Qatabānian rulers bore priestly titles. In Saba', some priests (*rshw*) of 'Athtar, recruited on a hereditary basis from three clans, took office in turn for seven years as eponyms (*kabir*) in charge of the collection of the tithe and of the rites aimed at obtaining rain.



A marble relief, the dedication or epitaph of a woman. The inscription, in South Arabian script of the 3rd century AD, reads as follows: "Image of Ghallat, daughter of Mufidat; may 'Athtar crush whomever breaks it." In the upper register a goddess plays a musical instrument; two women bring offerings. The arch above the scene is formed by the necks of twin dragons whose heads appear in the upper corners with a bunch of grapes; this is a symbol of immortality. The scene represents the other world. In the lower register a woman, probably Ghallat, reclines on a couch; her outstretched arm points toward the small representation of a gazelle or horse. A standing woman touches her head. This scene may be a representation of oneiromancy. In the British Museum.

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The priests interpreted the oracles, which, throughout Arabia, were mostly obtained by cleromancy (*istiqsām*): the answer (positive, negative, expectative, and so on) to a question asked of the god was obtained by drawing lots from a batch of marked arrows or sticks. Many Sabaean texts mention the oracles, but only one inscription mentions arrows in connection with them. A bunch of sticks possibly used for that purpose was found in 1987 in a Sabaean temple. Among the many other forms of divination known from pre-Islāmic Arabia, only oneiromancy, or divination by means of dreams (possibly after incubation in the temple), is well attested in Sabaean texts.

Pilgrimages

Throughout pre-Islāmic Arabia, "truces of God" allowed people to attend in security the yearly pilgrimages to important shrines. The rites included purification and the wearing of ritual clothing, sexual abstinence, abstention from shedding blood, and circuits performed (*ṭawāf, dawār*) around the sacred object; they were concluded by the slaughter of animals, which were eaten in collective feasts. Today such practices still form the core of the Islāmic pilgrimage to Mecca. The classical, Nabataean, Liḥyānite, and Sabaean sources mention pilgrimages.

In South Arabia pilgrims were entertained in the temples on the proceeds of the tithe. The sanctuary of Jabal al-Lawdh, in al-Jawf of northern Yemen, consisted of two temples: the first, at the foot of the mountain, was connected to another one near the summit, some 3,000 feet higher up, by a 3.7-mile processional way. Open courtyards contained many rows of low masonry benches, more than 30 feet long, which were probably used for the ritual meals mentioned in the texts found at the site. Among the Nabataeans, sacral brotherhoods (*mrzḥ;* "thiasoi") held ritual meals in the temples or in burial rooms of the dead.

The sovereigns of Saba' performed a rite called "hunting the game of 'Athtar and the game of Kurūm." The gazelle was the symbol animal of 'Athtar, and Kurūm is now known to be a hypostasis or a consort of 'Athtar (this explains the name 'Atarqurumā of an idol in Dūmat al-Jandal, mentioned above). This rite was aimed at obtaining rain, and that is also the aim of a formal tribal ibex hunting still performed today in Ḥaḍramawt. *Istisqā'*, a collective rogation for rain with magical rites, in times of acute drought, is mentioned by the Muslim tradition and in two Sabaean texts. The rite is still part of the Islāmic ritual.

South Arabian texts confessing offenses against ritual cleanliness, along with data from classical sources and the Muslim tradition on pre-Islāmic customs, contribute to outline an ancient Arabian code of ritual cleanliness similar to that of the Leviticus and of Muslim jurisprudence, although some Islāmologists, unaware of the pre-Islāmic Arabian epigraphic material, have attributed the Muslim code on ritual cleanliness (*ṭahārah*) to a Jewish influence on early Islām in Medina.

Burials

The dead were buried under a mound of stones or in burial chambers carved from the rock. The Ṣafaite Bedouin used to add a stone, possibly bearing a written expression of grief, to the heap marking the grave of a friend or relative. Some excavated heaps have yielded dozens of such texts. An ancient Arab custom was to tie the mount of a dead warrior to the tomb of its master and leave it to die there. There is probably no relationship between this custom and the discovery, in 1985 in Ḥaḍramawt, of tombs of ritually beheaded kneeling camels. Collective burial chambers were carved in the rock underground or from cliffs in various parts of Arabia. Liḥyānite, Nabataean, and South Arabian inscriptions may mark the entrance, name the occupants and their respective share of ownership, and threaten any intruder or usurper. Surgically prepared mummies were discovered for the first time in 1983 in North Yemen, in burial chambers carved in a cliff. In the Nabataean capital, Petra, and in Madā'in Ṣaliḥ, the necropolis of their city of Al-Ḥijr, in the Hejaz, many dozens of rock burial chambers show a great variety of elaborate facades carved in high relief in the red sandstone. (J.R.)

Religions of Asia Minor

This account covers the beliefs and practices of the ancient peoples and civilizations of Turkey and Soviet Armenia, including the Hittites, Hattians, Luwians, Hurrians, Assyrian colonists, Urartians, and Phrygians. For historical background, see TURKEY AND ANCIENT ANATOLIA.

SOURCES OF MODERN KNOWLEDGE

Until comparatively recent times, the pre-Christian religions of Asia Minor were known only through the works of classical writers. For the Greeks and Romans, Asia Minor was above all the home of the religion of Cybele, the Great Mother of the Gods, whose cult was centred in Phrygian Pessinus. A monument such as the colossal, but much weathered, figure of a Hittite goddess carved high up on the slopes of Mount Sipylus (near Manisa) was of necessity ascribed by the 2nd-century-AD Greek traveler and geographer Pausanias to the Mother of the Gods, since no other ancient Anatolian goddess was known to him.

During the 19th century many such pre-classical rock reliefs and inscribed monuments were reported by travelers, but it was the discovery of the royal Hittite archives at Boğazköy (ancient Hattusa) in 1907 that made available for the first time a mass of indigenous literary evidence for an Anatolian civilization belonging to the 2nd millennium BC, before the arrival of the Phrygians. Because of the discovery of these archives, written on clay tablets, the religion of the Hittites necessarily predominates in any account of the early religions of Asia Minor. Later Hittite history has been further clarified by the decipherment of the Hittite hieroglyphic inscriptions on monuments dating for the most part from the early centuries of the 1st millennium BC, after the downfall of Hattusa. For the same period, the cuneiform inscriptions of the kingdom of Urartu in the region of Lake Van contain some information on the religion of that area, though they are mostly concerned with other matters.

Boğazköy

The clay tablets of Assyrian commercial colonists found at Kültepe, Aliṣar, and Boğazköy belong to the period immediately preceding the rise of the kingdom of Hattusa, but they contain little information bearing on the life of the indigenous population. For all earlier periods, scholars are dependent on the inarticulate data of archaeology—isolated finds, the interpretation of which leaves a large element of uncertainty.

PREHISTORIC PERIODS

The earliest evidence of religious beliefs has come to light at the mound of Çatal Hüyük, to the south of modern Konya. Here in four seasons of excavations (1961–65), James Mellaart discovered remains of a Neolithic village of mud-brick houses, many of which could be identified as shrines. They are dated by radiocarbon to about 6500–5800 BC (calculated with a half-life of 5,730 years). Huge figures of goddesses in the posture of giving birth, leopards, and the heads of bulls and rams are modeled in high relief on the walls of some of these shrines. Others contain frescoes showing elaborate scenes such as the hunting of deer and aurochs, or vultures devouring headless human corpses. A series of stone and terra-cotta statuettes found in these shrines represent a female figure, sometimes accompanied by leopards and, from the earlier levels of excavation, a male either bearded and seated on a bull or youthful and riding a leopard. The main deity of these Neolithic people was evidently a goddess, a mistress of animals, with whom were associated both a son and a consort. Her character is vividly shown by a schist plaque carved to represent two scenes, a sacred marriage and a mother with child. The dead appear to have been excarnated in a mortuary outside the village by exposure to vultures, as shown in the painting, before being buried under the platforms in the houses.

Cults of goddesses

At Hacilar, near Lake Burdur, a somewhat later culture was unearthed by the same excavator, and here again were found statuettes of goddesses associated with felines; but, as in the later levels at Çatal Hüyük, the son or consort is absent.

Entirely different and far removed in time and place are the discoveries at Alaca Hüyük and Horoztepe in northern Anatolia. Here, dating from the latter half of the 3rd millennium BC (*c.* 2400–2200), were found royal tombs richly furnished with artifacts in bronze and precious metals. Beside the heads of skeletons lay female figurines; one such figure found in a grave at Horoztepe represents a mother nursing her child. Many of the objects found in these graves must have had ritual significance. At Horoztepe a bronze sistrum, or rattle, was found. But the outstanding feature of the graves at both sites is the occurrence of bronze standards, which may have been carried on poles. They are openwork objects of circular or occasionally rhomboid form and are adorned with figures of animals (bulls, stags, and, in one instance, felines), birds, flowers, and swastikas and other geometric patterns. Other standards, consisting of simple statuettes of stags or bulls, also occur.

The archaeological finds of central Anatolia follow immediately after the period of these royal tombs from the Pontic region. Kültepe, near Kayseri, became in the 19th century BC the centre of Assyrian trading outposts (*kārum*); but from the mound itself, from a level just prior to the foundation of the Assyrian colonies, have come a series of remarkable statuettes. The majority of these are abstract,

disk-shaped idols without limbs; many of them have two, three, or even four heads, and others bear on their chests small male figures in relief, in one case accompanied by a lion. There can be little doubt that here again is a representation of a divine family—a mother goddess with consort and child or children. From a level at Boğazköy contemporary with Kültepe comes a limestone mold of a "mistress of animals," a nude goddess standing on a pair of felines and holding aloft an animal in either hand. Molds for a pair of figures, a bearded god and a goddess—the god carries various weapons or emblems, the goddess in most instances holds a baby—have been found at several sites at a somewhat later level.

Though the Old Assyrian tablets are concerned exclusively with commercial matters, the seal impressions that they bear contain a new and elaborate system of religious symbolism (iconography) that later reached its maturity under the Hittites. Here a whole pantheon of deities, some recognizably Mesopotamian, others native Anatolian, are distinguished by such features as dress, attendant animals, weapons, actions, and attitudes. Among them are several weather gods, all associated with a bull, but distinguished in various ways; the weather is depicted in the form of rain falling above the god. A bull alone, carrying an enigmatic pyramid upon its back, sometimes surmounted by a bird, is a particularly common motif and probably symbolizes a weather god. Other deities are a war god holding various weapons, a hunting god holding a bird or hare, a god in a horse-drawn chariot, another in a wagon drawn by boars, a goddess enthroned and surrounded by animals, a nude goddess, and several composite beings. On many seals the deity—and especially the bull with the pyramid—is shown receiving ritual offerings.

Weather gods

RELIGIONS OF THE HITTITES, HATTIANS, AND HURRIANS

An interval of only a few decades separates the end of the Assyrian colony period from the earliest records of the kingdom of Hatti, and for the next five centuries (*c.* 1700–1200 BC) the history of Asia Minor is well documented. The texts reveal a country inhabited by a number of distinct peoples. The Hittites in the centre, the Luwians in the south and west, and the Palaians in the north were speakers of related Indo-European languages. In the southeast were the Hurrians, comparatively late arrivals from the region of Lake Urmia. The Hattians, whose language appears to have become extinct, were most probably the earliest inhabitants of the kingdom of Hatti itself.

Each of these nations had its own pantheon, and individual cult centres had their own names for deities. The result is a bewildering number of divine names, and even when a deity is denoted not by a name but by a logogram (sign or signs standing for a word) to indicate weather god, sun god, moon god, and so forth, it seems that the deity of each city was regarded by the Hittite theologians as a distinct personality. There are even special weather gods, such as the weather god of the lightning, the weather god of the clouds, the weather god of the rain, the weather god of the palace, the weather god of the royal person, the weather god of the sceptre, and the weather god of the army, each again conceived as a separate personality. To us these are simply manifestations or aspects of a single deity, and this is reflected to some extent in the iconography, the pattern of religious symbolism, in which, as in the preceding period, there is a well-defined and limited number of divine types. Often deities were represented by a symbol on clubs and other weapons. An example is the rock carving of a sword deity in Yazılıkaya (Inscribed Rock) near Boğazköy. A human head tops the hilt, which is carved in the form of four crouching lions.

Types of gods

The pantheon. The most widely worshiped deity of Hittite Anatolia was clearly the weather god, as befits a country dependent on rain for its fertility; and under the title "weather god of Hatti" he became the chief deity of the official pantheon, a great figure who bestowed kingship, brought victory in war, and probably represented the nation in its dealings with foreign powers. Thus the treaty with Egypt is said to be "for the purpose of making eternal the relations which the sun-god [of Egypt] and the weather-god [of Hatti] have established for the Land of Egypt and the Land of Hatti." His name in Luwian, and probably also in Hittite, was Tarhun (Tarhund); in Hattic he was called Taru, and in Hurrian, Teshub. He is associated with the sacred bull and appears on monuments either attended by a pair of divine bulls or driving over mountains in a chariot drawn by bulls. In the cult itself Tarhun might even be represented by a bull.

As Tarhun's spouse, the great goddess of the city of Arinna was exalted as patroness of the state. (Arinna has not been located, but it was situated somewhere in the heartland of the Hittite kingdom, within a day's journey of the capital.) Her name in Hattic was Wurusemu, but the Hittites worshiped her under the epithet Arinnitti. She is always called a sun goddess, and sun disks appear as emblems in her cult, but there are indications that she may originally have had chthonic, or underworld, characteristics. As "sun goddess of the earth" she might be identified with Lelwani, the ruler of the netherworld. The king and queen were her high priest and priestess.

The weather god of another city, Nerik, was regarded as the son of this supreme pair, and they had daughters named Mezzulla and Hulla and a granddaughter, Zintuhi. Telipinu was another son of the weather god and had similar attributes. He was a central figure in the Hittite myths.

There was also a male sun god, distinct from the sun goddess of Arinna, a special form of whom was the "sun god in the water," probably the sun as reflected in the waters of a lake. His name in Hittite was Istanu, borrowed from the Hattic Estan (Luwian Tiwat, Hurrian Shimegi). There was also a moon god (Hittite and Luwian Arma, Hurrian Kushukh), but he plays little part in the texts. In the iconography, the sun god was represented in the robes of the king, whose title was "My Sun"; the moon god was shown as a winged figure with a crescent on his helmet, sometimes standing on a lion. According to official theology there also existed a sun god or goddess of the underworld. In this place resided the Sun on its journey from west to east during the night.

Solar and lunar deities

The god of hunting appears frequently on Hittite monuments; he holds a bird and a hare, as on the Kültepe seals, and he stands on a stag, his sacred animal. From descriptions of the statues it appears that this is the deity denoted in the texts by the logogram KAL, to be read Kurunda or Tuwata, later Ruwata, Runda. The war god also appears, though his Hittite name is concealed behind the logogram ZABABA, the name of the Mesopotamian war god. His Hattic name was Wurunkatti, his Hurrian counterpart Hesui. His Hattic name meant "king of the land."

The Hittite goddess of love and war is similarly disguised under the logogram of the Babylonian ISHTAR; she was evidently much revered and was the special protectress of Hattusilis III. Her Hurrian name was Shaushka. As a warrior goddess she was represented as a winged figure standing on a lion with a peculiar robe gathered at the knees and accompanied by doves and two female attendants.

There was a mother goddess, Hannahanna "the grandmother," closely associated with birth, creation, and destiny, but the theologians appear to have regarded her as a minor deity.

It is impossible to enumerate the lesser deities, many of whom are mere names to us. Among them were many mountains, rivers, and springs, and the spirits of past kings and queens who had "become gods" at death. Demons are conspicuous by their absence; sickness and misfortune were ascribed either to sorcery or to divine retribution.

During the later years of the Hittite kingdom, the state cult came under strong Hurrian influence. The sun goddess of Arinna and the weather god of Nerik were identified with the Hurrian queen of the gods, Hebat, and her son, Sharruma; and at Yazılıkaya, where a rocky outcrop forming a natural open chamber was adorned with a series of 64 bas-reliefs that represented the national pantheon, every identifiable deity bears a Hurrian name written in Hittite hieroglyphs. The central group is recognizable as the family of the sun goddess, but she is named Hepatu, her son Sharruma. They both stand on felines, she, perhaps, on a lion or lioness, and he on a panther. The Hittites had here already begun a process of assimilation.

Influence of Hurrian religion

Gods and men. The gods were imagined to have their

own lives, though also needing the service of their worshipers, who in turn were dependent on the gods for their well-being. They lived in their temples, where they had to be fed, clothed, washed, and entertained. Part of their time, however, might be spent in heaven or in roaming the sea or the mountains. They might withdraw in anger and so cause life on Earth to wither and cease. One of the most characteristic rituals of the Hittites was the invocation by which a god who had absented himself was induced to return and attend to his duties by a combination of prayer and magic.

The relation between man and god resembled that between servant and master. "If a servant has committed an offence and confesses his guilt before his master, his master may do with him whatever he pleases; but because he has confessed his guilt . . . his master's spirit is appeased and he will not call that servant to account." Confession and expiation form the main theme of the extant royal prayers.

Divination. Divination, through which the cause of divine displeasure was ascertained, was mainly of three kinds: augury (divination by flight of birds), haruspicy (divination by examining the entrails of sacrificial animals), and an enigmatic procedure using tokens with symbolic names, arts said to be practiced respectively by the "bird-watcher," the seer, and the "old woman." The omens, as interpreted by these experts, were either favourable or unfavourable and would give a yes or no answer according to the sense of the question put to them. In this way, by a lengthy process of elimination, it was possible to determine the precise offence that required expiation. Haruspicy was a science inherited by the Hittites from the Babylonian seers. The other two methods of divination seem to have been indigenous to Asia Minor.

The cult. The Hittite records at Boğazköy give abundant evidence for a state religious cult. The king himself and all important state matters, including royal decrees and treaties, were placed under the protection of national deities.

Sacrifices and festivals

The proper conduct for temple personnel was laid down in a tablet of instructions that gives some insight into the organization of a temple. Divine vengeance is threatened against those who misappropriate food or drink brought for sacrifice, who admit unclean animals or unauthorized persons into the temples, who purloin vessels or implements belonging to the god, who fail to celebrate festivals at the proper time, and who desert their posts to spend the night with their wives.

Many extant texts consist of descriptions of festivals in which the king or queen is the chief officiant. These festivals were numerous, but their names are largely unintelligible. Many of them were seasonal. The preliminary details, such as the robing of the king and his entry into the temple, accompanied by various dignitaries and by musicians playing their instruments, differed little from one festival to another. Owing to the very large number of fragmentary texts, it has not yet been possible to discern special characteristics of the festivals. They invariably culminated in libations and frequently in a cultic meal. One such festival lasted 38 days and involved celebrations in a dozen different cities.

Burial customs. The tablets from Boğazköy have yielded much information about the burial practices of the Hittites. There was a burial ritual for a king or queen that lasted 13 days and in which the body was cremated and the fire extinguished with potable liquids. The bones were then dipped in oil or fat and wrapped in cloth. A feast followed their placement on a stool in a stone chamber. Although cremations were practiced, burial of the body in an earthen grave was not uncommon. In 1952 Kurt Bittel excavated two sites near Yazılıkaya, close to a natural rock outcrop. One site contained 72 burials, 50 of which were cremations. The other site contained only cremations, and the presence of some precious objects among them suggests that these might be burials of privileged persons.

Mythology. In Anatolia itself myth seems to have remained on a rather primitive level. Such myths are found embedded in magical or ritual texts, aimed at curing diseases, ensuring good fortune, and the like.

A particularly well-attested type of myth occurs in connection with the invocation of an absent god and tells how the god once disappeared and caused a blight on Earth, how he was sought and found, and eventually returned to restore life and vigour. In one such myth the weather god withdraws in anger and the search is conducted by the sun god (whose messenger is an eagle), the father of the weather god, his grandfather, and his grandmother Hannahanna. In another, it is Telipinu who is angry, and the gods who search are the sun god, the weather god, and Hannahanna, the grandfather being omitted. In both these versions, the missing god is found by a bee sent forth by Hannahanna. In another similar story, the sun god and Telipinu are both missing, not from anger, but because they have been seized by "Torpor," which has paralyzed nature. In yet another version, the weather god of Nerik is said to have gone down to the netherworld through a hole in the ground, apparently the hole from which the river Marassantiya (modern Kızıl Irmak) gushed forth, which suggests that this weather god may really have been a god of the underground waters.

"The Slaying of the Dragon"

Another myth, "The Slaying of the Dragon," connected with the Hattian city Nerik, was apparently recited at a great annual spring festival called Purulli. It tells how the weather god fought the dragon and was at first defeated, but subsequently, by means of a ruse (of which there are two quite distinct versions), succeeded in getting the better of him and killing him.

Other mythological tales of Hittite and Hattian deities existed, but they are too fragmentarily preserved to give any connected story.

The elaborate epic of the struggle against Ullikummi, and the *Theogony,* though written in Hittite, are Hurrian in origin and refer to Hurrian and even Mesopotamian deities. The *Theogony* tells of the struggle for kingship among the gods. Alalu, after holding the kingship for nine years, was defeated by Anu (the Babylonian sky god) and went down to the netherworld. Anu in his turn, after nine years, gave way to Kumarbi, a Hurrian god, and went up to heaven. Eventually the weather god Teshub was born, and though the god KAL apparently reigned for a period, and the end of the tale is lost, it is certain that Teshub was the final victor, for there are many allusions to the "former gods" who were banished to the netherworld by him. The conception itself derives from Babylonia.

The "Song of Ullikummi" tells of a plot by Kumarbi to depose Teshub from his supremacy by begetting a monstrous stone as champion. Ullikummi, the stone monster, grows in the sea, which reaches his waist, while his head touches the sky; he stands on the shoulder of Upelluri, an Atlas figure who carries heaven and earth. Teshub is warned of the danger and goes out to battle in his chariot drawn by bulls, but he fails and appeals for help to Ea (Babylonian god of wisdom). The latter orders the "former gods" to produce the ancient tool by which heaven and earth had once been cut apart (the only surviving hint of a Hittite creation myth), and with this he severs Ullikummi from the giant and so destroys his power. Again the end is lost, but it is certain that the final victory went to Teshub.

RELIGIONS OF SUCCESSOR STATES

When Hattusa fell, in about 1180 BC, the Luwians moved eastward and southward into Cappadocia, Cilicia, and North Syria. Here they formed a number of small successor kingdoms. Shortly afterward the Phrygians crossed the Bosporus from Thrace and occupied the centre of the Anatolian plateau, cutting off in the extreme southwest a remnant of the Luwian people, who became known as the Lycians and maintained their reverence for the Luwian gods Tarhun, Runda, Arma, and Santa into classical times.

The East Luwians, whose rulers used the Hittite hieroglyphic script to record their deeds, worshiped these same deities; but their chief goddess was Kubaba, who hardly appears in the archives of Hattusa except as the local goddess of Carchemish in Syria. Her prominence was due to political factors, for Carchemish was then the leading Hittite city.

Developments in iconography

The traditional Hittite iconography survived but was gradually permeated by Aramaic and Assyrian influences. Orthostats (stone slabs set at the base of a wall) from

Malatya on the Euphrates show Tarhun in his bull-drawn chariot receiving libations from a king dressed in his traditional robes, and there is a relief showing his battle with the dragon. At Carchemish was found a representation of the winged moon god with the sun god, both standing on a single lion. Kubaba appears enthroned, the throne resting on a lion. Runda (the Hittite Kurunda or KAL) is regularly symbolized by a stag's head or antler.

Urartu. In the far east of Anatolia, the Hurrian nation formed around Lake Van a new kingdom, which rose to considerable power, from about 900 to 600 BC. With few exceptions, the cuneiform inscriptions of this kingdom of Urartu are historical and reveal nothing of its religion, except the names of deities. The national god was Haldi, and he is associated with a weather god, Tesheba, a sun goddess, Shiwini (compare Hurrian Teshub and Shimegi), and a goddess, Bagbartu (or Bagmashtu). Haldi is represented standing on a lion, Tesheba on a bull, Shiwini holding a winged sun disk above her head. The cult was practiced not only in temples (one of which is shown in detail on an Assyrian relief) but also in front of rock-hewn niches in the form of gates through which the deity was probably believed to manifest himself.

The Phrygians. Little would be known of the religion of the Phrygians but for the fact that in 204 BC the Roman Senate, on the instructions of the priests, who had consulted the Sibylline books, had the sacred black stone of the Phrygian Mother goddess, Cybele, or Cybebe, transported from Pessinus, together with her priests, and installed in a temple on the Palatine. As a result, there is much information about the cult and its mythology, though it must be remembered that during 200 years of Persian rule Anatolia had been exposed to many alien influences from the east, which may have affected this cult.

The high priest of Cybele was given the name of Attis, and—at least in later times—she was attended by a band of fanatical devotees called *galli*, whose orgiastic dancing, at the climax of which they castrated themselves in their ecstasy, was notorious.



Group statue of Cybele and attendant musicians; the upper body of the goddess is a modern reconstruction. The statue is from a gateway at Boğazköy; it probably dates from the late 7th or early 6th century BC. In the Museum of Anatolian Civilizations, Ankara, Tur.

By courtesy of the Anadolu Medeniyetleri Müzesi Müdürlüğü, Ankara, Turkey

The cult myth of these rites told how Cybele (known at Pessinus as Agdistis, from Mount Agdos [or Mount Agdistis] in the vicinity) loved a beautiful youth named Attis. According to the earliest version, Attis was killed, as was the Syrian Adonis, by a boar. All later versions, however, refer to wild revelry and castration. Agdistis is a bisexual monster who is trapped by Bacchus and castrated; Attis is betrothed to a daughter of Midas (or Gallus, the king of Pessinus); the wedding guests are driven mad by Cybele, and first Midas, then Attis, castrates himself, the latter as he lies beneath a pine tree; in one version Attis is turned into a pine tree. A poem by Catullus describes how a young Greek wanderer named Attis was caught up in the revels and sacrificed his virility, only to be prostrated later with remorse. The "Phrygian rites" introduced into Rome by Claudius included the ceremonious felling of a pine tree to represent the dead youth and its transport in procession to the temple. Still later, the sacrifice of a bull and the belief in the resurrection of Attis were added to the cult.

How much of this myth belonged to the original cult of the Phrygian Mother goddess is questionable. Herodotus, in describing the celebration of the rites by the legendary Scythian sage Anacharsis, mentions only that he did so in a grove, that he carried a timbrel (a small hand drum or tambourine), and that he fastened images about his person. There is no suggestion of orgiastic rites.

In Asia Minor itself, the cult of Cybele is marked by carved rock facades with niches or by rock-hewn thrones, on which the statue would be set; in front of these, the rites were celebrated in the open air. Cybele was a goddess of the mountains, out of which she was believed to manifest herself to her devotees. Representations of the goddess show her in her niche, sometimes flanked by lions, draped in a long garment and wearing a high polos (cylindrical crown or headdress) or with bared breasts and flanked by musicians. Her name and her association with the lion cannot be separated from the Hittite Kubaba, whose cult had spread from Carchemish to the borders of Phrygia, but the process by which this matronly figure was transformed into the Mountain Mother of the Phrygians can only be surmised.

Representations of Cybele

The goddess Ma of Comana, despite her name (Mother), was regarded at least by the Romans as a deity distinct from Cybele and was identified with the war goddess Bellona. Her relationship to the ancient Hittite-Hurrian goddess Hebat of Kummanni (=Comana) remains obscure, for there is no evidence that the latter was a goddess of war.

The god Men, who appears on numerous monuments of the Hellenistic period, was an equestrian moon god, later identified with Attis and with the Thracian Sabazius. He is basically the Persian moon god Mao, as (Artemis) Anaitis is the Persian Anahita.

CONCLUSION

Asia Minor shows a remarkable continuity in its worship. From the Neolithic Period, for 6,000 years, the population venerated a divine pair, mother goddess and weather god, the former in association with the lion, the latter with the bull; a divine son, associated with the panther; and a god of hunting whose symbolic animal was the stag. To the ancients, for whom the essence of a thing lay in its name, this continuity was less obvious than it is today. The many names under which the deities were known at different times and places appear to us of less significance, in a religious sense, than the constancy of the types. (O.R.G.)

Ancient Iranian religions

The religions of ancient Iran are the diverse beliefs and practices of a culturally and linguistically related group of peoples who inhabited the Iranian Plateau and its borderlands as well as areas of Central Asia from the Black Sea to Khotan (modern Ho-t'ien, China). The northern Iranians (referred to generally as Scythians [Saka] in classical sources), who occupied the steppes, differed significantly from the southern Iranians. In religion and culture both

the northern and southern Iranians had much in common with the ancient Indo-Aryans, although there was much borrowing from Mesopotamia as well, especially in western Iran. From at least the time of the rise of the Median empire, Iranian religion and culture has had a profound influence upon the Middle East, as also the Middle East upon Iran. This account will take the conquest of the Achaemenian Empire by Alexander the Great as a somewhat arbitrary date for the close of the period of ancient Iranian religion, even though these influences have continued through later history and some forms of Iranian religion have persisted to the present day. It will also treat ancient Iranian religion, insofar as possible, apart from Zoroastrianism. Unless otherwise indicated, all spellings of Iranian names and terms are given in reconstructed forms that often differ from the Avestan spellings of the Zoroastrian canon.

For a full account of that religion, see ZOROASTRIANISM AND PARSIISM. For historical background, see IRAN.

SOURCES OF KNOWLEDGE

Modern understanding of ancient Iranian religion is impeded by the limitations of the available sources, which are inevitably of two sorts: textual and material.

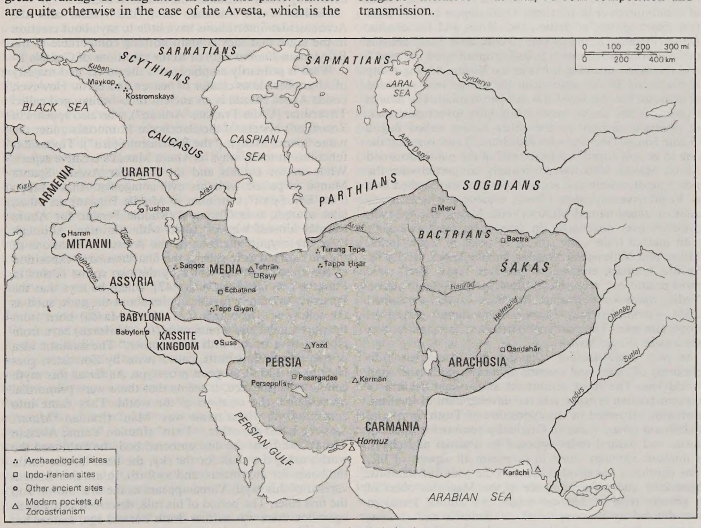
Textual sources are both indigenous and foreign, the latter being primarily Greek, although for purposes of historical reconstruction the ancient Indian Vedic literature is indispensable. The main problem with the Greek sources, the most important of which is Herodotus, is that the information they contain is not always very reliable, either because it is outright erroneous or because it is based on misunderstandings. The main indigenous sources are the Achaemenian royal inscriptions in the Old Persian language (with Akkadian, Elamite, and Aramaic translations) and the Avesta, the sacred scriptures of Zoroastrianism, in a language called Avestan. The royal inscriptions, especially those of Darius (522–486 BC) and his son Xerxes (486–465 BC), for the most part eloquent pieces of propaganda, are rich in references to religion. In addition to the information they contain, they have the great advantage of being fixed in time and place. Matters are quite otherwise in the case of the Avesta, which is the principal source of knowledge of ancient Iranian religions.

Indigenous sources

Like the Bible, the Avesta is a collection of a variety of texts composed over what appears to be a considerable span of time by different authors, which has endured editing and redaction at several points during the history of its development. The text that is now extant represents only a fragment of what remained in the 9th century of the late Sāsānian Avesta compiled under the direction of Khosrow I (AD 531–579). Summaries of the contents of the Sāsānian Avesta show that it was an enormous collection containing texts in Avestan as well as in—and predominantly so—Pahlavi, the language of Sāsānian Zoroastrianism. In spite of the relatively recent date of the existing Avesta, it contains matter of great antiquity, of which the *Gāthās* (or "Songs" of Zoroaster) and much of the *Yashts* are among the oldest. The *Gāthās* contain expressions of Zoroaster's religious vision which, in many ways, is a complicated reinterpretation of inherited Iranian religious ideas. The *Yashts* are collections of verses dedicated to the various deities. Most of the *Yashts*, though touched up with Zoroastrian terminology and ideas, have little to do with anything specifically Zoroastrian. The gods invoked are essentially the gods of pre-Zoroastrian Iran. Unfortunately, there is little agreement as to when Zoroaster lived, though most scholars agree that he lived some time between about 1200 and 600 BC. It does not seem possible to date the *Yashts* much more precisely, except to believe that their redaction (not necessarily composition) may have first taken place in the 5th century BC.

As mentioned above, the earliest religious texts of the closely related Indo-Aryans (principally the Rigveda) are indispensable for making historical reconstructions of the development of Iranian religion. The Rigveda, a collection of more than 1,000 hymns to various deities, can be dated to a period from approximately 1300 to 900 BC. Apart from the Achaemenian inscriptions, there is no secure evidence that religious compositions were reduced to writing until the late Arsacid or early Sāsānian periods. Thus, unlike the other religions of the Middle East, the Iranian religions had no written texts in the ancient period. All religious "literature" was oral, in both composition and transmission.

The Rigveda



Significant religious sites and sites containing religious artifacts of ancient Indo-Iranian peoples, including those of peoples of adjacent areas and modern Zoroastrians.

Material sources are much more limited and are, for the most part, restricted to western Iran. The remains of Achaemenian architecture and art, by far the most important of the material sources, provide abundant evidence of imperial articulation of religious symbols and show a thorough dependence on Middle Eastern precedents.

ORIGIN AND HISTORICAL DEVELOPMENT

During the second half of the 2nd millennium two groups of culturally and linguistically related peoples who called themselves "Arya" migrated from the steppes down into the Middle East, the Iranian Plateau, and the northwestern part of the Indian subcontinent. One group, the Indo-Aryans, settled in Anatolia and in India. The other, the Iranians, settled in greater Iran. These people were originally seminomadic pastoralists whose chief economic base was cattle, primarily bovines but also sheep and goats. They bred horses which they used for riding and pulling chariots in warfare and sport. It is not at all clear how rigidly their society was originally segmented. There were specialists in religious matters, and men who could afford horses and chariots were reckoned as warriors and leaders. By the Achaemenian period there developed a more rigid division of society into four basic classes: priests, nobles, farmers/herdsmen, and artisans. Society generally was patriarchal, and male dominance was strongly reflected in the religion. Like the ancient Israelites, as the Iranians occupied the land they became increasingly dependent upon agriculture and settled in villages and towns. During this process they were certainly influenced by the indigenous populations, of whose religion almost nothing is known, except by inference from elements of Iranian religion that have no reflex in the Veda or among other Indo-Europeans.

Owing to their common origin, Iranian and Indo-Aryan religions are very similar. From a comparative study of both groups, it is possible to reconstruct, in general features, the early forms of Iranian religion for which there is no direct documentation. The pantheon, similar to those of other Indo-European peoples, embraced a large number of deities, both female and, predominantly, male. Some of these were personifications of natural phenomena, others of social norms or institutions. There appear to have been two major groups of deities, the *daivas* and the *ahuras*. *Daiva* (literally "heavenly one"; Vedic *deva*, Latin *deus*) is derived from the common Indo-European word for "god," and this is the meaning it has in the Vedas. Among many Iranians and in Zoroastrianism the *daivas* were regarded as demons, but this belief was not pan-Iranian. The *ahuras* ("lords"; Vedic *asura*) were certain lofty sovereign deities, in contradistinction to the other deities called *bagha* (Vedic *bhaga*, "the one who distributes") and *yazata* ("the one to be worshiped"). At the head of the pantheon stood Ahura Mazdā, who was particularly connected with the principle of cosmic and social order and truth called *arta* in Vedic (Avestan *asha*). Closely associated with him was another *ahura* named Mithra (Vedic Mitra), the god who presided over covenants. In Iran there were two gods with martial traits quite similar to those of Vedic Indra, Mitra, and Vrthraghna. Among female deities the Earth, Spantā Aramati, and the sacred river, Ardvī Sūrā, were most prominent. A sacrificial ritual *yazna* (Avestan *yasna*, Vedic *yajña*) was performed in which fire and the sacred drink *hauma* (Avestan *haoma*, Vedic *soma*) played an important part. The principal officiant at the sacrifice was the *zautar* (Vedic *hotar*).

Daivas and *ahuras*

As with other ancient religions, the cosmological dichotomy of chaos and cosmos figured in both myth and worldview. The most prominent and unique feature of ancient Iranian religion was the development of dualism, primarily expressed in the opposition of Truth (*arta*) and Falsehood (*drug*, *drauga*). Originally confined to ideas of social and natural order opposed by disorder and chaos, a dualistic ideology came to permeate all aspects of life. The pantheon was divided between the gods and demons. Especially under the influence of the Magi, members of a priestly tribe of Median origin, the animal kingdom was divided up between beneficent animals and noxious creatures. Even in vocabulary there developed a system of "ahuric" and "daivic" words for such things as body parts: for example, the word *zasta* was used for the hand of a righteous person, and *gava* for the hand of an evil person. It is important to note that this was not a Gnostic system, like those that flourished in the Middle East during the early centuries of the Common era, as there was no myth of evil matter coming into being through the corruption and fall of a spiritual being.

Except for a mostly legendary line of eastern Iranian kings, the *kavis*, the last of whom was Zoroaster's patron Vishtāspa (Greek Hystapes), the only historical information on the relation of religion to political authority comes from the Achaemenian period in western Iran. The ideology of kingship was closely tied to the supreme deity, Ahura Mazdā, through whose will the kings ruled. The Achaemenian kings had to contend with the power of the Median priesthood, the Magi. Their origin is unclear, but according to classical sources they presided at all religious ceremonies where they chanted "theogonies." That they were deeply involved in politics is seen from the attempt of the magus Gaumāta to seize the throne upon the death of Cambyses II. Although Darius persecuted the Magi, they remained powerful and eventually became the official priesthood of the empire. They were probably responsible for articulating a thoroughly dualist ideology and contributing to Zoroastrianism its zealous preoccupation with ritual purity. In addition, they were famous throughout the ancient world as wonder-workers.

The Magi

MYTHOLOGY AND COSMOLOGY

Since all the sources for Iranian myths, whether classical authors or indigenous texts, are post-Zoroastrian, it is often difficult to discern what elements of the myths are Zoroastrian innovations and what elements are inherited. It is particularly hard to resolve this problem owing to the nature of Zoroastrianism itself as a religion that has always drawn heavily on already existing ideas and that has accommodated itself to various forms of Iranian religions. As is the case with ancient religions generally, Iranian religions did not possess one unified collection of myth. What one finds are fragments of a wide variety of myths exhibiting many variations on common themes.

Creation of the cosmos. Both the Avesta and the Achaemenian inscriptions have little to say about creation in the sense that they contain nothing comparable to the Babylonian *Enuma elish* or to the traditions of Genesis 1–3. What is primarily emphasized is the power and majesty of Ahura Mazdā as creator of heaven and earth. However, beside Ahura Mazdā is an ancient Indo-Iranian god called Thvarshtar (Vedic Tvaṣṭar; "Artisan"), who also appears in Zoroaster's system of the Beneficent Immortals under the name Spanta Manyu ("the Beneficent Spirit"). Thvarshtar functions in many ways as Ahura Mazdā's creative aspect. While in the *Gāthās* and the Younger Avesta, Spanta Manyu is paired with his evil antagonist Ahra Manyu ("the Evil Spirit"; Ahriman in Middle Persian), in other, later sources, it is Ohrmazd (Middle Persian for Ahura Mazdā) himself who is paired with Ahriman. Although there are cryptic allusions in the Avesta to creations of the two antagonistic spirits, the first discursive exposition of the creation of the world by the two spirits occurs in Plutarch (*De Iside et Osiride* 47), where he says that the Persians "tell many mythical tales about the gods, such as the following. Oromazes (*i.e.*, Ahura Mazdā) born from the purest light, and Areimanios (*i.e.*, Ahriman) born from gloom, strive in war with one another." The dualistic idea of two primordial spirits, called twins by Zoroaster, goes back to an Indo-European prototype. As far as this myth can be reconstructed, it seems that there were primordial twins before the creation of the world. They came into conflict. One, whose name was "Man" (Iranian **Manu*, "man"), killed the other, "Twin" (Iranian Yama; Avestan Yima), and from the dismembered body he fashioned the world, using the skull for the sky, the flesh for the earth, the bones for mountains, and so forth. In another Iranian variant of this myth Yama appears as the first mortal and the first ruler. The period of his rule, described as a golden age when there was neither death nor old age, neither hot nor cold, and so on, comes to an end when falsehood enters Yama's speech. The royal Glory (Khvarnah) flees

The myth of primordial twins

from Yama and takes refuge in the cosmic sea. Yama is then overthrown by a serpentine tyrant named Azhi Dahāka ("Dahāka the Snake"), whose rule ushers in a period of drought, ruin, and chaos. In turn, Azhi Dahāka is defeated by the hero Thraitauna, who establishes the legendary line of kings called *kavis*.

Zoroaster seems to have been the first religious thinker to conceive an eschatological myth concerning a future saviour who will rescue the world from evil, an idea that has been greatly elaborated in Zoroastrianism. It may have been influential in the development of the concept of the Messiah in postexilic Judaism. Iranian religion also had a variant of the Noah's Ark myth. In this myth, Yama appears as the first herdsman and leader of humankind. After a long rule during which he has to enlarge the earth three times owing to overcrowding, Ahura Mazdā tells him that a great winter is coming and advises him to prepare for it by building a gigantic three-story barnlike structure (*vara*) to hold pairs of animals and seeds of plants. From the fragmentary version of the myth that has survived, it appears that the *vara* is actually a sort of paradise or island of the blessed, though this story originated as a pastoralist myth about the building of the first winter cattle station by the culture hero.

Cosmography. The Iranians conceived of the cosmos as a three-tiered structure consisting of the earth below, the atmosphere, and the stone vault of heaven above. Beyond the vault of heaven was the realm of the Endless Lights, and below the earth was the realm of darkness and chaos. The earth itself rested on the cosmic sea called Varu-Karta. In the centre of the earth was the cosmic mountain Harā, down which flowed the river Ardvi. The earth was divided into six continents surrounding the central continent, Khvaniratha, the locus of Aryāna Vaijah, the Aryan land (*i.e.*, Iran).

CULTIC PRACTICES, WORSHIP, AND FESTIVALS

In sharp contrast to the peoples of the Middle East, the Iranians did not make images of their deities, nor did they build temples to house them, preferring to worship in the open. Worship of the gods was performed primarily in the context of a central ritual called *yazna*, which corresponds in a great many details to the Vedic *yajña*. It is interesting to note that both rituals, though they have undergone some changes over the millennia, are still performed by Zoroastrians and Hindus in what must be the oldest continuously enacted ritual known. The plan of the *yazna*, as far as it can be reconstructed, was essentially that of a highly stylized festive meal offered to an honoured guest, the sacrificer being the host and the deity the guest. Although it is not known precisely when or how frequently the *yazna* was held (in Zoroastrianism it became a daily ritual), the reason for holding a *yazna* was to enter into communion with a divine being either for a specific purpose (to obtain offspring or a victory, and so on) or for general welfare, or as an expression of piety. As a ritual meal, the *yazna* followed the established rules of hospitality: the guest was sent an invitation; on his arrival from afar he was greeted, shown to a comfortable seat, given meat and a refreshing and invigorating drink, and entertained with song extolling his great deeds and virtues. Finally, the guest was expected to return the hospitality in the form of a gift.

The *yazna*

Of utmost importance was fire. In ancient Iran, fire was at once a highly sacred element and a deity. Thus, the word *ātar* denoted simultaneously "fire" and "Fire," every instance of fire being a manifestation of the deity. Since burned offerings were not made, the role of Ātar, like that of his Vedic counterpart Agni, was principally that of intermediary between heaven and earth, between humans and gods. Beyond the sphere of the *yazna*, fire was always treated with utmost care as a sacred element. Whether in the household hearth or, at a later period, in fire temples, the sacred fire had to be maintained with proper fuel, kept free from polluting agents, and above all never permitted to go out or be extinguished.

More important than the meat offering of an animal victim was the preparation of the divine drink *hauma* (Vedic *soma*). As with fire, *hauma* was regarded as both a sacred drink and as a powerful deity. Probably the greatest part of the *yazna* was devoted to the pressing of the *hauma*. Although there have been a number of proposals for the identification of the plant whose juices were extracted for the ritual drink, all have fallen short of absolute proof, and some, such as the toxic mushroom *Amanita muscaria*, are not worth consideration. In any case, an understanding of the religious meaning of *hauma* does not depend on a botanic identification. The word *hauma* itself derives from a verb "to press, extract" and thus literally means the thing that has been pressed out of the stems or stalks (*āsu*) of whatever plant was being used—*i.e.*, juice. In this process the stalks were first soaked in water, then pounded. In Zoroastrianism this has been done with a metal mortar and pestle, but originally the stalks were pounded between two pressing stones, a lower and an upper. The juice, described as yellow, was filtered and mixed with milk, to cut the bitter taste, and perhaps with water too. Since the resulting drink was consumed immediately, it is clear that it was not alcoholic but rather was a mind-altering drug. The *Yasht* to Hauma says, "All other intoxicants are accompanied by Wrath with the horrible club, but that intoxication which is Hauma's is accompanied by gladdening Truth (*arta*)." This brief statement can be amplified by the far more extensive descriptions of the Rigveda, where *soma* is not only offered to the gods but also taken by poets to enhance their insight and creative powers in their search for truth. Also, *hauma*, invoked for victory, was taken as a stimulant by warriors going into battle, and various heroes of Iranian myth and legend are remembered as primary practitioners of its cult.

The preparation of *hauma*

As mentioned above, a comfortable seat was provided for the god or gods invited to *yazna*. Originally this consisted of special grasses strewn on the ground in front of the altar. In Vedic terminology this seat was called the *barhiṣ* (Avestan *barzish*, "cushion"), while in Zoroastrianism a cognate word, Avestan *barəsman* (Iranian *barzman*), is used for a bundle of sticks—later thin metal rods—that is manipulated by the priest.

It is likely that from a very early period a priest, the *zaotar* (Vedic *hotar*), was required to properly carry out the *yasna*. The *zaotar* might be assisted by a number of other ritual specialists. With the priest or priests acting on behalf of the sacrificer, the god or gods were invoked through the intermediary of Fire. The sacred drink was prepared and the victim led up. When the god arrived he was seated on the *barzman* and given food (parts of the slaughtered victim) and drink, after which he was entertained with song. Finally, the host-sacrificer put in a request for a return gift: heroic sons, long life, health, or victory, for example. In a certain sense, then, the entire ritual followed the old Latin dictum *do ut des* ("I give so that you may give"), in providing a means of inducing the powerful deities to act with favour toward human beings. Yet it also made possible communion between the divine and human realms. Deities could also be addressed directly in prayer with the supplicant standing erect with upraised arms; prostration was unknown.

Of further importance is the song of praise directed to the divine guest. Much of the poetic portions of the Avesta and almost all of the Rigveda must be understood in this ritual context. That is to say, ancient Indo-Iranian poetry was religious in nature and specifically composed for those ritual occasions when the gods required songs of praise to make them well disposed to their worshipers. The obscurity of Zoroaster's *Gāthās* and of many Vedic hymns can best be understood when it is realized that the intended audience was not humans but rather the gods.

During the year there were various festivals, mostly relating to the agricultural and herding cycles. By far the most important was that of the New Year, which is still celebrated by Iranians with great festivity.

HUMAN NATURE

In the Zoroastrian formulation of the myth of creation, humans are created for the noble purpose of aiding in the repulsion of the Evil Spirit. Whether or not this concept is pre-Zoroastrian, it shows that in Iranian religion human nature was held to be essentially good, in the sense

that there was no myth about the baseness of the human condition such as that found in Babylonian mythology (for example, in the *Enuma elish*). Humans have free will and determine their own destinies as a result of their ethical choices.

Spiritual elements or Souls

In addition to the body (*tanū*), it was held that an individual consisted of a number of spiritual elements that loosely fall under the category of souls. These are (1) the animating force (*ahu*), (2) the breath of life (*vyāna*), (3) mind/spirit (*manah*), (4) the soul (*ruvan;* Avestan *urvan*), (5) the protective spirit (*fravarti;* Avestan *fravashi*), and (6) the spiritual double (*dainā;* Avestan *daēnā*). In Zoroastrianism, where belief in the day of judgment is central, it is the *ruvan* that is held accountable for a person's actions during life and that suffers reward or punishment in the life to come. At the time of judgment the *ruvan* encounters the *dainā,* which is an embodiment of the sum of its deeds during life, manifested as either a beautiful maiden or an ugly hag. Depending on how these deeds are weighed, the soul either crosses safely the Chinvat Bridge to the other world or falls into the abyss. The *fravarti* is a deity who acts as a protective spirit of each individual and is also an ancestor spirit; together all the *fravartis* form a warrior band, similar in some ways to the Vedic Maruts.

MAJOR DEITIES

Ahura Mazdā. Ahura Mazdā ("Wise Lord") was probably the chief god of the pre-Zoroastrian pantheon. In both the religion of Zoroaster and that of Darius and Xerxes, he was worshiped as the supreme god, almost to the exclusion of all others. First of all he is the creator of the universe and the one who establishes and maintains the cosmic and social order, *arta.* Darius proclaims him as "the great god . . . who created this earth, who created yonder heaven, who created man, who created happiness for man, who made Darius king." Throughout his inscriptions, Darius speaks not only of the source of the authority of the kingship as deriving from Ahura Mazdā, but also makes it clear that his own establishment of political stability over the chaos of rebellion and his maintenance of order through law imitates the divine model set by the Creator. Using the ancient Indo-European poetic device of interrogative discourse, Zoroaster asks, "Who is the original father of *arta*? Who established the paths of the sun and the stars? Who is it through whom the moon now waxes now wanes? Who supports the earth below and (keeps) the heavens (above) from falling down? Who yokes the two steeds to the wind and the clouds? . . . Who fashioned honoured Devotion together with Dominion? Who made . . . a son respectful of his father?"

In neither the Avesta nor the Achaemenian inscriptions is Ahura Mazdā identified with a natural phenomenon. Since, however, in the hymn to the goddess Rti (Reward), Ahura Mazdā is identified as her father and Spanta Aramati (Earth) as her mother, it is implied that he has taken over, to some extent, the role of the Indo-European Father Heaven (*Dieus Pater, Vedic Dyāus Pitar), who is mythologically paired with Mother Earth. Furthermore, the Greek historian Herodotus seems to have made this identification when he wrote, "Zeus, in their (the Persians') system, is the whole circle of the heavens." Other Greek sources commonly equate Zeus with Oromazes (Ahura Mazdā), because of Ahura Mazdā's position as father and chief god of the pantheon. As his name implies, he seems to have been sought by his worshipers for wisdom and insight, and, to judge by the intense experiences of Darius (whether or not his professions are genuine) and of Zoroaster, he was probably the object of a personal devotion that appears to have been lacking with other deities.

Identification of Zeus and Ahura Mazdā

Mithra. Beside Ahura Mazdā, Mithra is the most important deity of the ancient Iranian pantheon and may have even occupied a position of near equality with him. In the Achaemenian inscriptions Mithra, together with Anāhitā, is the only other deity specifically mentioned. Although the ancient pantheon contained an individual sun god, Hvar Khshaita, in the eastern Iranian traditions reflected in the Avesta, Mithra has a hint of connection with the sun, more specifically with the first rays of dawn as he drives forth in his chariot. In western Iran the identification was complete, and the name Mithra became a common word for "sun." In spite of his connection with the sun, Mithra functioned preeminently in the ethical sphere. The word *mithra* was a common noun that meant "covenant, contract, treaty" and, as such, Mithra was the god Covenant, the celestial deity who oversaw all solemn agreements that people made among themselves and who severely punished anyone who broke the terms of a covenant, whether it was between individuals or between countries or other sociopolitical entities. In his capacity to find out the covenant breaker, he is described as sleepless, ever-waking, having 1,000 ears, 10,000 eyes, and a wide outlook. He is portrayed as a great warrior brandishing his mace while driving in his chariot to battle, where he intervenes on behalf of those faithful to treaties by throwing the treaty-breakers (*mithra-drug*) into panic and defeat. As a sovereign deity, Mithra bore the standing epithet *varu-gavyūti,* meaning "one who (presides over) wide pasture lands"—*i.e.,* one who keeps under his protection (another of his epithets was *pāyu,* "protector") the territories of those who worship him and abide by their covenants. It should be mentioned that Mithra gave his name to a mystery religion, Mithraism, which was popular throughout the Roman Empire, but whose Iranian origins are difficult to trace.

Anāhiti. One of the longest Avestan *Yashts* is to the powerful goddess whose full name is given as Ardvī Sūrā Anāhitā, literally "the damp, strong, untainted." In fact, the long name seems to combine two originally separate names and, hence, two deities. First, Ardvī Sūrā is the Iranian name of the heavenly river goddess who in the Rigveda is called Sarasvatī. In this role, she brings fresh water to the earth, filling streams, rivers, and seas as she flows from Mount Hukarya to the Varu-Karta sea. Second, Anāhiti is a separate goddess of uncertain origin whose cult seems to have been popular originally in northeastern Iran. The name probably meant "untaintedness, purity (both moral and physical)." It is interesting that the Greek Anaitis (Ἀναΐτις) preserves the Old Iranian form of the name, while Anāhit(a), of the Avestan and Old Persian, shows a more recent linguistic form. Unlike any other Iranian deity, she is described in great detail in the *Yashts,* especially in respect to her clothing and ornamentation, to such an extent that one assumes a dressed cult image must be the source of the description. This is confirmed by the fact that Artaxerxes II mentions her. Then, too, the Babylonian historian Berosus reports that this king had many images of her made and distributed. Since the Iranians did not traditionally make images, it may be assumed that Anāhiti's cult borrowed heavily from Mesopotamian models. The Mesopotamian goddess Ishtar probably provided the clearest model, though the details of Anāhiti's dress, her beaver coat, for example—show significant differences. There were other striking similarities: Ishtar was the goddess of war and patroness of the palace, while the greater part of Anāhiti's *Yasht* is devoted to her martial traits and her patronage of Iranian heroes and legendary rulers (in post-Achaemenian Iran Anāhiti was intimately connected with kingship and the shah). In addition, both goddesses were important for fertility.

Influence of the Mesopotamian goddess Ishtar

Vrthraghna. The mighty deity of war Vrthraghna had martial traits in common with Mithra and with the Vedic war god Indra. In post-Achaemenian times he was syncretistically equated with Hercules and was a favourite deity of monarchs, some of whom took his name. The name Vrthraghna means "the smashing of resistance or obstruction," and in his capacity as the god who guaranteed his people the ability to overcome all enemy resistance, his name came to be understood in the general sense of "Victory." In connection with rulership and the granting of victory, he bore the epithet *bara-khvarnah,* "bearing the Glory." Like Mithra in his martial aspects, Vrthraghna represented an ideal type of warrior. For the earliest immigrants onto the Iranian Plateau he personified the aspirations of the Aryans seeking to win new territory from an entrenched indigenous population, while for later populations he became the divine manifestation of the will to world conquest.

Among all the deities Vrthraghna preeminently possesses

the power to undergo various transformations, both anthropomorphic and theriomorphic. Rich mythologies may have existed concerning these avatars, but only 10 forms have been recorded: the Wind (the god Vāyu), bull, stallion, rutting camel, wild boar, a 15-year-old man (15 was considered to be the ideal age), falcon, ram, goat, and hero. All have in common aggressive force and virility, while in some violence is conspicuous. Particularly graphic is the description of him as the "ferocious wild boar with sharp teeth and tusks, a boar that kills at one blow . . . who, overtaking his opponent . . . strikes (him) down with a toss of his head . . . until he smashes the vertebrae, the pillars of life, . . . (and) mixes on the ground the bones, hair, brains, and blood."

Rashnu. Like Mithra, with whom he was often associated, Rashnu was an ethical deity, the divine judge who ultimately presided over legal disputes among men. His name, derived from the same Indo-European verb, **reg* ("to be, make straight, direct, judge"), as are the German words for "judge," *Richter,* and "law," *Recht.* In particular, he appears to have been the god of oaths and ordeals administered during trials. In many ways he carried out the judicial functions of the Vedic god Varuṇa, who among other things, was the ultimate judge presiding over oaths, and who was frequently inseparable from the Vedic Mitra. While it remains unclear whether or not Ahura Mazdā exercised any judicial function, together Rashnu and Mithra seem to have acted in complementary areas of law: Mithra was concerned specifically with covenants of all sorts, while Rashnu had more general jurisdiction over legal matters, especially those of a criminal nature, in that he is invoked as the one who "best smite(s), who best destroy(s) the thief and the bandit at this trial."

Tishtrya and Tiri. Astral deities seem to have figured much more prominently in ancient Iranian religion than in Vedic religion, and this may well be attributed to the influence of Babylonian science on the Iranians, particularly the western groups. In the Avesta such stars and constellations as Ursa Major, the Pleiades, Vega, Fomalhaut, and the Milky Way are mentioned, but the most important astral deities seem to have been Tishtrya and Tiri. An entire *Yasht* is devoted to Tishtrya, who, for reasons that remain obscure, is identified with the star Sirius. Even though the heliacal rising of Sirius would have occurred at the season of drought, his principal myth involves a battle with a demonic star named Apausha ("Nonprosperity") over rainfall and water. In a combat that was reenacted in a yearly equestrian ritual, Tishtrya and Apausha, assuming the forms of a white stallion and a horse of horrible description, respectively, battle along the shores of the Varu-Karta sea. Initially Apausha is victorious, but after receiving worship Tishtrya conquers him, driving him away "along a path the length of a race course." At this point Tishtrya causes the cosmic sea to surge and boil, and then another star, Satavaisa (Fomalhaut), rises with the cloud-forming mists that are blown by the bold Wind in the form of "rain and clouds and hail to the dwelling and the settlements (and) to the seven continents." As one of the stars "who contains the seeds of waters" (*i.e.,* who cause rain), Tishtrya was also intimately connected with agriculture. He battled and defeated the shooting stars, identified as witches, especially one called "Bad Crop" (Duzhyāryā). In Zoroastrianism, Tishtrya was at some point, probably in late Achaemenian times, identified with the western Iranian astral deity, Tiri (Mercury in Sāsānian astronomy), about whom little is known save that a very important agricultural festival, the Tiragān, as well as the 4th month and the 13th day of the Zoroastrian calendar, bears his name. (W.W.M.)

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(C.H.G./T.J./J.R.Ba./S.B.P./J.R./O.R.G./W.W.M.)

Milan

Milan (Italian Milano) is a city of riches, both cultural and economic. This wealth derives from its long history as the political and commercial centre of Italy's richest agricultural region, the Po Basin. While it preserves a remarkable artistic and architectural heritage, contemporary Milan also is one of the world's leading centres of fashion and industrial design. The economic and financial centre of Italy and the headquarters of the country's most important publishing and media firms, Milan also forms the core of the country's largest metropolitan area and plays a prominent role in Italian intellectual and cultural life.

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Physical and human geography

CHARACTER OF THE CITY

Fiscally, contemporary Milan is the richest city in Italy and one of the richest in Europe. When the Milanese proclaim their city the "moral capital" of Italy, they not only express the ancient regionalism typical of all Italy, but they refer to Milan's cultural and intellectual leadership and especially to its role as the motor of the country's extraordinary economic development in the 20th century. As Italy's economic heart—the headquarters of its most important banks and corporations, a leading international centre of fashion and design, and the capital of work, innovation, production, and efficiency—Milan has long claimed a kind of supremacy among Italian cities. In contrast, the Milanese see the country's political capital, Rome, as the parasitical capital of taxation, state spending, and party skullduggery. Milan's economic contributions far exceed, even on a statistical basis, those of all other Italian cities; however, since Italy's unification, the city has remained relatively politically insignificant. Yet its political subordination to Rome has not been a consequence of its physical distance from much of the rest of Italy, which makes it peripheral geographically, since many European capitals lie far from the centre of the country they rule.

Competition with Rome

Regardless, many of the most important political and cultural developments in Italy had their roots in Milan. Reformist socialism was born there, as was Fascism, and the Futurists were based in the city. During World War II, Milan claimed the title of "capital of the Resistance," and during Italy's postwar boom, known as the economic miracle, Milan was undoubtedly the "capital of the miracle." The student and workers' movements also flourished in Milan during and after 1968. With the city's transformation to a post-industrial centre in the 1980s and '90s, Italy's political centre of gravity shifted away from Rome and toward Milan, especially under the premierships of the Milanese Bettino Craxi (1983–87) and Silvio Berlusconi (1994). Culturally, the city has been home to many of Italy's leading architects, designers, visual artists, novelists, and filmmakers. Italy's most important publishing and media enterprises are based there. Milan has always had La Scala, the greatest opera house in the world, and some of the most important educational institutions in Europe, from Bocconi University to the Politecnico. Finally, Milan has two of the greatest football (soccer) teams in the world—AC Milan and Inter Milan—and one of its most imposing stadiums, San Siro.

Its extraordinary mix of intellectuals, designers, industrialists, and financiers enabled Milan to become an international centre of excellence for economic sectors from sports cars to fashion design. Over the years, this versatility and dynamism have combined with the characteristic *operosità* ("industriousness") of the Milanese. The old saying "Milan says and Milan does" has been adopted by the hundreds of thousands of migrants (first from within Italy—from both north and south—and, since the 1980s, from abroad) who have contributed to the success of the city. The integration of these migrants has never been easy, but Milan has always been willing to accept those who contribute to its rich and varied economic structure.

THE LANDSCAPE

Site. Milan is set in the heart of the Po Basin of northern Italy, halfway across the immense plain spreading between the Ticino and Adda rivers. The site is 400 feet (122 metres) above sea level. To the north lies the great sweep of the southern flank of the Alps. Between this semicircle of mountains and the course traced by the Po River to the south, there lies a zone that is arid toward the north, but swampy near the Po, where it turns into an expanse of marshy groves and rice fields. It is at the line of demarcation between these two areas, which are strongly differentiated, that Milan has risen, although now only swamplands mark the site of the ancient city. The earliest inhabitants reinforced their defenses by means of the small watercourses of the Sèveso, the Nirone, the Lambro, and the Olona.

Climate. Milan's climate is continental, with damp, chilly winters and hot, humid summers. Snow falls between December and February, and springtime is generally rainy. In winter temperatures range between 30° and 50° F (−1° and 10° C) and in summer between 68° and 86° F (20° and 30° C). Characteristic of the Po Basin, the city is often shrouded in fog in winter, but this has decreased with the drainage of the rice fields to the south. The growth of an almost uninterrupted built-up area around the city has reduced local air circulation, and pollution from vehicular exhausts often covers the city in smog.

The city plan. Each period of historical crisis, advance, and consolidation has been reflected in the organic structure of Milan. For a thousand years the core of the city was located just southwest of the present cathedral, the Duomo, and was made up of the rectangular, four-gated city of Mediolanum, with roads thrusting out from each gate to the surrounding countryside, together with an irregular outer defense consolidated in Carolingian times. This core has influenced the city plan down to modern times. The period of dynastic struggle and the imposition of transalpine authority brought further changes. After the city was razed in 1162, an enlarged oval was constructed, the course of its outer walls still traceable in contemporary streets. Spanish domination brought the erection of still another outer ring resulting from the 16th-century

reconstructions. This, too, can be traced in contemporary boulevards. Within the city centre, the main focus of activity centred on the Castello Sforzesco, a product of the 15th-century dynastic struggles, reinforced by the Spanish in the following century; the Piazza Mercanti, the centre of medieval economic activity; and the great Piazza del Duomo, laid out before the cathedral in 1489. Castle, cathedral, and a newer commercial area centred on the Piazza Cordusio, representatives of the motivating forces in Milanese life, dominate the modern city centre.

Several times since the late 19th century city planners have laid down the basis of a more organic plan, bypassing the traditional radial street plan, so that new districts might have wide streets and avenues intersecting at right angles. The centres of the newer suburban areas—Bollate, Novate Milanese, Cusano Milanino, Cinisello Balsamo, Sesto San Giovanni, and even Monza (nine miles [15 kilometres] away to the northeast)—are linked to the core of the ancient city by major arteries. Entire industrial districts have developed, particularly in the north and northeast and in the south and southwest. Unfortunately, while the periphery has been amply developed, the central nucleus has not benefited from a similar transformation, and the narrowness of the streets and squares creates problems for modern traffic. Since the end of World War II, practically all industrial growth has been concentrated in peripheral areas of the city. Industrial progress has reached such a level that a third of Milan's population is in some way connected with industrial construction. Heavy industries are concentrated outside the city boundaries, around Sesto San Giovanni. Since 1950 the city centre has fared badly under the influence of industrialization, with many old streets and buildings replaced haphazardly by massive blocks and skyscrapers containing apartments and offices. The Pirelli Building (1955–59), near the Stazione Centrale ("Central Station"), and the Olivetti Building in Via Clerici are among the few modern structures of architectural note.

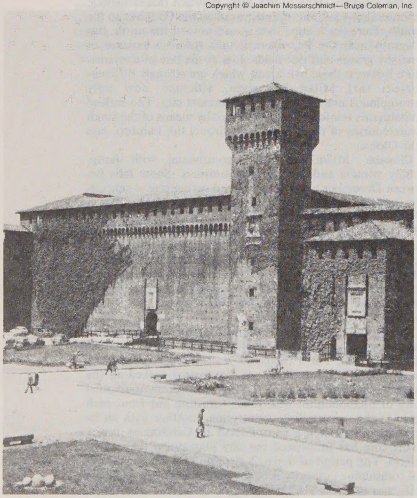
The basic plan

THE PEOPLE

Milan's population has shown a rapid increase since World War II. This increase has been due mainly to the flood of immigrants from the impoverished Italian south seeking improved conditions in the factories of the industrial north. Population pressure has resulted in the growth of slums and such shantytowns as Brianza, as well as in an expansion of the city itself. Milan has pressed outward into the surrounding countryside with renewed vigour, particularly to the northeast, toward Crescenzago, and to the south, toward Rogoredo and Vigentino. Milan's enormous urban expansion has contributed to its economic growth.

Immigration

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The Piazza d'Armi inside the walls of the Castello Sforzesco, Milan, and (right of centre) the Torre di Bona di Savoia. The castle is now an art museum.

THE ECONOMY

Industry. Milan, the most important economic centre of Italy, owes this fact to its geographical position. It is located at the centre of the traffic routes of the Val Padana and lies on the borderline between the advanced agriculture of the fertile irrigated plains to the south and the limited agriculture of the north. In addition, it is backed by an impressive industrial development. Milan's rich and extremely populous surroundings, differing from those of other large Italian manufacturing centres, increase the city's economic importance and potential for expansion. An extensive network of road and rail communications spreads toward the outlying areas and particularly toward the north, giving the city an economic advantage that other Italian cities do not possess.

Industrial products

The mechanical industries predominate; the production of automobiles, airplanes, motorcycles, major electric appliances, railroad materials, and other metalworking accounts for almost half of the work force. Textile manufactures (cotton, hemp, silk, and artificial fibres) are situated in the province of Milan, while in the city itself manufactures of ready-made clothing and designer fashions predominate. Milan's fashion industry has achieved great commercial importance, and the city contains the salons of some of the world's best known designers. Chemical production is also considerable. Besides large quantities of medicinal products, dyes, soaps, and acids are also manufactured. Also noteworthy to the city economy are graphic arts and publishing, as well as food, wood, paper, and rubber products. Milan's position as the electronic media centre of Italy has been augmented by the rapid growth of high-technology industries, including data processing and telecommunications.

Commerce. Commercial activity in the city has also been stimulated by industrial development. The largest wholesale markets of Italy are in Milan. Of greatest importance are the export trades, which include artificial fibres, cotton and wool goods, chemical products, and machinery. This enormous economic complex has benefited from the efficiency of the city's banks and of its stock market, which is the largest in Italy. Milan is the principal centre of exchange in Italy; every April the city hosts the International Sample Trade Fair (in Italy called Fiera Campionaria de Milano), which ranks as one of the major trade exhibitions in Europe.

Transportation. In addition to being a centre of production and exchange, Milan is also a national focus of transportation. The state-run railroads are integrated within the city landscape by means of a carefully designed and executed plan. The vast Piazza della Repubblica, for example, which contains the Pirelli Building and other tall buildings, is located on land formerly occupied by a railway station. Trade goods are sent and received at the Stazione Lambrate-Ortica. Two other stations serve for the transportation of passengers, five more for various kinds of merchandise. The largest railway loading site is the Stazione Centrale. Transalpine tunnels and other mainline connections link Milan with all parts of Europe, and there are many nonstop trains to and from major cities. The road network converging upon Milan is also important, carrying, as it does, an unceasing flow of foreign and domestic tourists. Besides being the focus of a number of major highways, Milan is also the starting point for the famous scenic route known as the Autostrada del Sole, which traverses the spine of the lengthy Italian peninsula. The metropolitan transportation service operates an extensive system of bus, tramway, and subway routes throughout the metropolitan area.



The Duomo, Milan.
Colour Library International

ADMINISTRATION AND SOCIAL CONDITIONS

Government. The city, technically the commune of Milan, capital of the province (*provincia*) of the same name and of the Lombardy Region (*regione*), is under the jurisdiction of the Republic of Italy. The government of the Italian state is composed of a central administration and of a peripheral or local administrative system, the latter having limited jurisdiction over a particular region. The most important division of the peripheral system is the prefecture (*prefettura*), at the head of which is the prefect, the highest authority of the executive power in the province of Milan. It supervises the activities of public administration. In its own area, the province performs the important functions of regulating health, sanitation, public works, welfare, education, agriculture, and commerce. The province of Milan, as all other Italian provinces, has a vice prefect, a counselor of prefecture, and an administrative and provincial assembly whose members, as well as its president, are selected by the prefect. The commune of Milan is administered by a council, chosen from a large assembly, and a mayor (*sindaco*). In the administrative elections of the communal council all electors registered in the province take part. The assembly and the mayor are elected by the communal council. The mayor is the head of the communal administration and represents the central government of the Republic of Italy. Mayoral responsibilities include performing marriage ceremonies, registering births and deaths, and maintaining safety and order on behalf of each citizen.

Regional innovations

The region and regional council, instituted in the early 1970s, are constituted as autonomous entities and have various prerogatives. Among these are the right to promulgate laws on matters related to the city so long as they do not infringe upon the national interest or the interest of other Italian regions. The regional authorities are the regional council, the assembly, and the president of the assembly. In the commune of Milan, the conciliation judge presides. The city is also divided into 20 zones, each of which has a council that can address matters of local concern.

Services. The central post office functions 24 hours per day. The city maintains a large, well-staffed streets and sanitation department, which endeavours to maintain both the cleanliness of the city and the health of its citizens. This task is made difficult, however, by overcrowding and poor housing conditions in some sectors. Health-care facilities are nonetheless generally good, and the city has a large network of publicly and privately run hospitals and clinics, as well as research facilities.

CULTURAL LIFE

The Duomo

The most striking of the monuments to be seen in contemporary Milan is the Duomo, a triumph of Gothic architecture; it is the third largest church of contemporary Europe, holding more than 20,000 people. Begun in 1386, it took five centuries to complete and rises over the area occupied at one time by the churches of Sta. Tecla and Sta. Maria Maggiore. The most imposing parts of the Duomo are its lateral aspects, its two top crosses, and the apse. In the latter, a powerful impression is made by the three immense Gothic windows of finely carved marble. The casing, of pink-tinged Italian marble, is to be found on all sides of the structure. At the lower level, it lends character to the small trilobate arches, capitals, and flowers; it also appears on the buttresses and, above them, runs along the crowning row of gigantic statues; above these, it covers the decorated water gutters and, finally, enhances the lacelike ornamental crest. The exterior of the cathedral is covered with a remarkable profusion of turrets, pinnacles, and more than 3,000 statues. Within are 52 pillars, each over 80 feet tall and more than 10 feet in diameter and bearing, instead of capitals, a crown of statues within their niches.

The most notable of the city's many palaces is the Palazzo di Brera, construction of which dates from 1651. Its architect, Francesco Maria Ricchino, infused the whole Milanese Baroque with his severe style. The Pinacoteca di Brera, one of the largest art galleries in Italy, contains a fine collection of north Italian painting. The building also contains the Biblioteca Nazionale Braidense, and its beautiful courtyard is dominated by Antonio Canova's statue of Napoleon. On the Corso Garibaldi stands S. Simpliciano, which according to tradition was founded in the 4th century by St. Ambrose. Its apse contains the 15th-century fresco "Coronation of the Virgin" by Ambrogio Bergognone. Other notable churches in the central area include S. Satiro, S. Eustorgio, S. Lorenzo Maggiore, and S. Babila. In Via Monte Napoleone, there are several handsome palaces, including the Bagatti-Valsecchi palaces. Leonardo da Vinci's fresco the "Last Supper," one of the most famous paintings of the Renaissance, is located in the former refectory of the Dominican monastery of Sta. Maria delle Grazie. Beyond the Piazza Cavour (which

contains a monument to the great Italian statesman for whom it is named as well as the imposing and ultra-modern Centro Svizzero ["Swiss Centre"]) lie the public gardens, in which the Museo Civico di Storia Naturale (Museum of Natural History) stands. One of its most interesting exhibits is the Turati ornithological collection. The former Villa Reale, now the Galleria d'Arte Moderna e Padiglione d'Arte Contemporanea, is also nearby.

Libraries and universities

The Biblioteca Ambrosiana (founded 1609) and the Biblioteca Comunale are also of significance. Other excellent libraries are found in the universities, the philological clubs of the Instituto Lombardo Accademia di Scienze e Lettere, as well as in the Donati Foundation. The Archivio di Stato also contain an imposing collection. Milan is the seat of three universities: the Università Cattolica del Sacro Cuore (1920), one of the best Roman Catholic schools in Italy; the state-run Università degli Studi (1923); and the Università Commerciale Luigi Bocconi (1902). Other institutions of higher education include the Instituto di Ingegneria Nucleare, Centro di Studi Nucleari Enrico Fermi and the Conservatorio di Musica Giuseppi Verdi.

Milan's Teatro alla Scala (popularly called La Scala), constructed 1776–78 by the leading Neoclassical architect Giuseppe Piermarini, is one of the great theatres of the world. (Piermarini, incidentally, designed the Corso di Porta Romana, the first paved street of modern Europe.) The city also contains several other theatres, including the Lirica, the Odeon, and the Stabile, which is the home of one of Italy's major theatrical companies. There are also numerous motion-picture houses.

Sections of a network of communication and transportation canals, the Navigli, constructed in the 16th century, remain, especially in the southern part of the city. In the summer a tour boat makes trips on the canals between Porta Ticinese and the Po, passing by country estates that were built from the 16th to the 19th century for Milanese nobles.

Milan is the leading sports centre of Italy. Many of the facilities are located in San Siro, on the northwestern edge of the city. The Palazzo dello Sport is a splendid example of recreational architecture. The Ippodromo del Gallopo, a large horse-racing arena, is one of the best in Europe. The Mirabello course is also excellent. In addition, San Siro has a fine association football (soccer) stadium, a civic arena, and numerous other fields for various sports, among which the modern Vigorelli, for cycling races, is well known. The Lago Idroscalo, an artificial lake next to Linate airport, is also a popular recreation area. The Grand Prix automobile-racing circuit at nearby Monza has an international reputation.

History

THE EARLY PERIOD

Foundation and early growth. The earliest settlement on the site of Milan was founded by the Gauls about the year 600 BC, and in ensuing centuries it became the capital of a Celtic tribe known as the Insubres. At the time of the Roman conquest, 222 BC, Mediolanum, as it was then called, was already one of the most powerful cities of the region on the Roman side of the Alps known as Cisalpine Gaul. Under the emperor Augustus, it became a part of the 11th region of Italy, acquiring increasing prestige and economic power until it became the second city of the Western Roman Empire behind Rome itself. In the 3rd century AD, following the partition of the empire instituted by the emperor Diocletian, it was assigned as residence and main administrative centre for one of the two emperors. The emperor Constantine the Great declared it the seat of the Vicar of Italy. In the year 452, Attila the Hun devastated the city, and in 539 the Goths destroyed it. The city, however, did not entirely perish as a result of these barbarian incursions, and by the second half of the 10th century city life was surging with renewed vigour. Under the Carolingians (the region was incorporated into the dominions of Charlemagne in 774), life in Milan showed increased vitality, particularly through the efforts of Archbishop Ansperto da Biassono, who rebuilt and strengthened the fallen walls of the city in the late 9th century. Under Ariberto da Antimiano (1018–45), the political power of the archbishopric reached its apogee. This assumption of temporal power by the archbishops, dating from about 1000, can be considered as the origin of the subsequent greatness of Milan.

Early settlement

Establishment of the commune

In 1045, however, as a result of tensions engendered by the authority of the archbishops and because of the increasing growth and stability of the city as a whole, Milan constituted itself as a commune (*comune*), with permanent and autonomous governmental structures. In the resultant struggle for primacy among the cities of Lombardy, Milan became involved in a series of long battles against its less prosperous neighbours—Pavia, Cremona, Como, and Lodi. In 1111 the Milanese razed Lodi, and, after a bitter struggle lasting from 1118 to 1127, Como was destroyed. This was the pretext for the intervention of Frederick I Barbarossa, who decided to bring Milan under the direct authority of the central imperial power of his Holy Roman Empire. The city held out until 1162, when it yielded after a nine-month siege. Its fortifications were then razed, and the destruction of the city was such that the Milanese were forced to seek refuge in the surrounding countryside. The war blazed on until 1183, the year of the Peace of Constance, although Milan, rebuilt in 1167 under the auspices of the newly founded Lombard League, succeeded in playing a major role in the defeat of the German forces of Barbarossa at the Battle of Legnano in 1176. Its privileges rewon, the city attained a splendid economic florescence over the next 100 years.

Feudal conflicts. In the early years of the 12th century, however, the new industrial classes, in particular the guilds of the woolens and armaments workers, increased constantly in power and influence. The feudal nature of the relationship between the archbishop and his allies meant that the archbishop had to make enormous concessions to the emergent social and political forces among the citizenry in order to reinforce his own party, diminishing thereby the financial privileges of the church. Following the worsening of the relationship with Frederick II of Swabia, the Milanese proclaimed Pagano della Torre, a member of a family emerging as leaders of the less feudal of the city's power groupings, as their protector. The city forces were nevertheless defeated by the Emperor in the Battle of Cortenuova (1237). In the shadow of the subsequent struggle between the Torriani family and another powerful Milanese family, the Visconti, the Signorial era was born. The Torrianis, leaders of the new popular forces, took the name of Guelfs; the Viscontis, followed by the aristocracy, headed the Ghibelline faction.

Dynastic struggles

In 1277 Ottone Visconti, archbishop of Milan, utterly defeated the enemy in the Battle of Desio. His nephew Matteo succeeded him, and, starting in 1311, Matteo and his heirs reigned as supreme lords of the city and of the surrounding state, replacing the political forms of the commune. Under this lordship, or *signoria,* the industrial and mercantile economy underwent rapid development, giving birth to further powerful coalitions of economic interests. But in 1450, Milan found itself besieged again. Francesco Sforza (1401–66), a ruthless and ambitious general, occupied the city and founded a new dynasty, basing his claim on his marriage to an illegitimate daughter of one of the Viscontis. A period of prosperity then began for Milan, based on the power of the Sforzas and the introduction of the silk industry. It was the golden period of the Italian Renaissance, typified by the splendour of the Sforza court.

The dynasty of the Sforzas, however, had but a short-lived enjoyment of power. In 1499 the Duchy of Milan fell into the hands of Louis XII, king of France, who was also a distant descendant of the Viscontis. In 1500 Ludovico Sforza (also called Il Moro) conquered the state but was defeated at Novara in the same year. The French continued to rule until 1513, at which point they were overthrown by Massimiliano Sforza, son of Il Moro, who had Swiss assistance. Francis I, successor to Louis XII, reconquered Milan in his renowned victory of Marignano (now Melegnano) in 1515. In accordance with the conditions of a peace treaty signed in 1529, Milan was once more returned to the Sforzas.

EVOLUTION OF THE MODERN CITY

In 1535 the incumbent duke died unexpectedly, and Milan and the entire Milanese state fell under the domination of the Habsburg emperor Charles V, who in 1540 invested his son—the future Philip II of Spain—with the duchy. Under Spanish rule—which was to last until 1706—the political and artistic elite of Milan rapidly succumbed. The dramatic period of dynastic struggle, which was also a period of economic growth, was to be replaced by a long period of economic stagnation and political decline associated with unimaginative foreign rule. In 1630 the city was struck by the great plague. This catastrophe was to be vividly portrayed by the local author Alessandro Manzoni (1785–1873) in his *I promessi sposi* (*The Betrothed*), a historical novel that is one of the finest artistic achievements of Italian and indeed European literature. The end of the desolation and squalor of the period of Spanish domination began with the outbreak, in 1701, of the War of the Spanish Succession. In September 1706 the city passed from Spanish to Austrian rule. Although the first half of the 18th century was marked by neglect and oppression, after the Treaty of Aix-la-Chapelle (1748), the new rulers, in collaboration with the wealthy commercial classes of Milan, fostered a half-century of enlightened, if despotic, growth. It is during this period that such figures as Cesare Beccaria, the outstanding criminologist and economist, and Pietro Verri, the gifted administrator and man of letters, were active. These and other members of a Milanese group known as the Società dei Pugni embraced the theoreticians of the French Revolution, in spite of Austrian censorship. Neoclassical architecture also flourished. When the republican army of France, with Napoleon Bonaparte at its head, entered Milan in 1796, it was greeted enthusiastically, particularly by the middle classes. In 1797 the constitution of a Cisalpine Republic was promulgated. In 1805 Milan became the capital of the Kingdom of Italy, under Napoleon, who was crowned in the city. A true awakening then occurred in the consciousness of the Milanese people, as their city prospered from its domination of most of the Italian peninsula.

The city under Napoleon

These hopes were dashed, however, by the invasion and reestablishment of Austrian authority that followed the collapse of the Napoleonic Empire in 1814. This alien control was to remain for nearly 50 years. Influenced by the new currents of Italian unity and nationalism known as the Risorgimento and smarting under the oppressive Austrian rule, the citizenry finally rose up in the "Cinque Giornate," the five days of March 18–22, 1848. In what has become one of the most celebrated episodes of the city's history, Milan was liberated from the Austrians for several months until the rebellion was finally suppressed. Although by Aug. 6, 1848, the brutal occupation forces of the aging Austrian commander Joseph Radetzky had taken firm control of Milan, resistance forces of the city continued their opposition to the invaders. Young men from Piedmont and Sardinia entered the city's army. It remained for the second War of Italian Independence to finally liberate Milan from foreign control, and a few days after the Battle of Magenta (June 4, 1859), the people of Milan witnessed the triumphant entry of Victor Emmanuel II, the Italian king of Piedmont and Sardinia. The city—by now in the throes of an industrial revolution emphasizing metal products—was incorporated into the new Italian state, maintaining itself in a position of prime importance in the national economy. (A.L./J.Fo.)

Restoration and revolution

At the turn of the 20th century, Milan was the centre of Italy's socialist mass trade union movement. It was also home to revolutionary socialist, anarchist, and nationalist movements. World War I gave a huge boost to Milan's heavy industry, but after the war, the city entered a period of instability. Fascism was born in Milan in 1919, and Benito Mussolini based his newspaper there. Fascism's national ascendancy was mirrored in Milan in 1922 when black-shirted squads occupied City Hall and effectively ended local democracy. Although Fascism never won over the Milanese working classes, it enjoyed strong support among the city's administrative, commercial, and business classes. Moreover, Fascism left its mark on Milan in a series of public projects, including the massive Law Courts, the imposing Central Station, and several broad boulevards.

During World War II, the city suffered grave damage from intensive Allied bombing. In 1943 the Germans occupied Milan, and partisans led sabotage campaigns that made the city the "capital of the Resistance." Partisans liberated the city before the Allies arrived in April 1945. Mussolini's dead body was famously displayed in Piazzale Loreto in Milan in the same month. The advent of the Cold War dashed the hopes of the city's left for radical change. A long economic boom during the 1950s and '60s brought prosperity for some but forced Milan's city government to address massive social problems such as the arrival of thousands of impoverished migrants from southern Italy and uncontrolled urban expansion. In 1968 Milan was at the centre of Italy's leftist student movement. In 1969 a bomb in a Milan bank killed 16 people. Although the authorities arrested thousands of leftists, the bombing had in fact been the work of neo-fascists trying to push the state to repress the left. Later, investigators discovered links between the bombers, the Italian secret services, and NATO agents. Ongoing terrorism and economic depression dominated the 1970s.

A second economic boom arrived in the 1980s, when the city's dominant Socialist Party embraced the new, postindustrial economy centred on finance, fashion, and design. However, the party's gloss and glitter concealed massive corruption. Beginning in 1992, Milanese judges, including Antonio Di Pietro, ordered the arrest of politicians and businessmen on charges of bribery. Milan became known as Tangentopoli ("Bribesville"). Within two years, the so-called "Clean Hands" investigations in Milan had destroyed Italy's patronage-based party structure, in which Milanese politicians had played a prominent and corrupt role. Milan's "moral capital" image was in tatters.

Out of the ruins of Tangentopoli came Silvio Berlusconi, who had become wealthy through building speculation in Milan and had purchased the AC Milan football team in 1986. The key to his success, however, was the creation of several hugely successful television and advertising companies. His Milanese base helped him form a new party in 1993—Forza Italia (Go Italy)—that retained a prominent role in Italian politics into the 21st century. Power, it seemed, was shifting away from Rome for the first time since World War I.

By the end of the 20th century, Milan had transformed from an industrial to a postindustrial powerhouse, thanks to a capable commercial and financial elite and a skilled workforce in fashion, design, and the media. The cheap labour of the more than 100,000 foreign immigrants who settled in and around Milan during the late 20th century also contributed to the city's prosperity. However, the city's glittering wealth masked persistent and largely unaddressed social and ecological problems. Milan entered the new millennium with one of the strongest urban economies in the world but without a clear vision of its future as a city. (J.Fo./Ed.)

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John Stuart Mill

John Stuart Mill was a British philosopher and economist, prominent as a publicist in the reforming age of the 19th century. He remains of lasting interest as a logician and an ethical theorist.

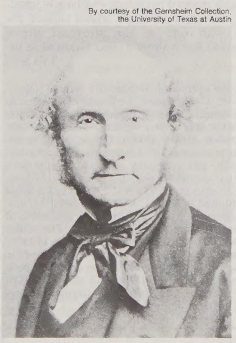
Early life and career. The eldest son of the British historian, economist, and philosopher James Mill, he was born on May 20, 1806, in his father's house in Pentonville, London. He was educated exclusively by his father, who was a strict disciplinarian. By his eighth year he had read in the original Greek Aesop's *Fables,* Xenophon's *Anabasis,* and the whole of the historian Herodotus. He was acquainted with the satirist Lucian, the historian of philosophy Diogenes Laërtius, the Athenian writer and educational theorist Isocrates, and six dialogues of Plato. He had also read a great deal of history in English. At the age of eight he started Latin, the geometry of Euclid, and algebra and began to teach the younger children of the family. His main reading was still history, but he went through all the Latin and Greek authors commonly read in the schools and universities and, by the age of 10 could read Plato and the Athenian statesman Demosthenes with ease. About the age of 12, he began a thorough study of Scholastic logic, at the same time reading Aristotle's logical treatises in the original. In the following year he was introduced to political economy and studied the work of the Scottish political economist and philosopher Adam Smith and that of the English economist David Ricardo.

While the training the younger Mill received has aroused amazement and criticism, its most important aspect was the close association it fostered with the strenuous character and vigorous intellect of his father. From his earliest days he spent much time in his father's study and habitually accompanied him on his walks. He thus inevitably acquired many of his father's speculative opinions and his father's way of defending them. But he did not receive the impress passively and mechanically. The duty of collecting and weighing evidence for himself was at every turn impressed upon the boy. His childhood was not unhappy, but it was a strain on his constitution and he suffered from the lack of natural, unforced development.

Effects of his education

From May 1820 until July 1821, Mill was in France with the family of Sir Samuel Bentham, brother of Jeremy Bentham, the English Utilitarian philosopher, economist, and theoretical jurist. Copious extracts from a diary kept at this time show how methodically he read and wrote, studied chemistry and botany, tackled advanced mathematical problems, and made notes on the scenery and the people and customs of the country. He also gained a thorough acquaintance with the French language. On his return in 1821 he added to his work the study of psychology and of Roman law, which he read with John Austin, his father having half decided on the bar as the best profession open to him. This intention, however, was abandoned, and in 1823, when he had just completed his 17th year, he entered the examiner's office of the India House. After a short probation he was promoted in 1828 to assistant examiner. For 20 years, from 1836 (when his father died) to 1856, Mill had charge of the British East India Company's relations with the Indian states, and in 1856 he became chief of the examiner's office.

By courtesy of the Gernsheim Collection, the University of Texas at Austin



Mill.

In 1822 Mill had read P.-E.-L. Dumont's exposition of Bentham's doctrines in the *Traités de Législation,* which made a lasting impression upon him. The impression was confirmed by the study of the English psychologists and also of two 18th-century French philosophers—Étienne Bonnot de Condillac, who was also a psychologist, and Claude-Adrien Helvétius, who was noted for his emphasis on physical sensations. Soon after, in 1822–23, Mill established among a few friends the Utilitarian Society, taking the word, as he tells us, from *Annals of the Parish,* a novel of Scottish country life by John Galt.

Two newspapers welcomed his contributions—*The Traveller,* edited by a friend of Bentham's, and *The Morning Chronicle,* edited by his father's friend John Black. One of his first efforts was a solid argument for freedom of discussion in a series of letters to the *Chronicle* on the prosecution of Richard Carlile, a 19th-century English radical and freethinker. Mill seized every chance for exposing departures from sound principle in Parliament and courts of justice. Another outlet was opened up for him (April 1824) with the founding of the *Westminster Review,* which was the organ of the philosophical radicals. In 1825 he began work on an edition of Bentham's *Rationale of Judicial Evidence* (5 vol., 1827). He took part eagerly in discussions with the many men of distinction who came to his father's house and engaged in set discussions at a reading society formed at the home of English historian George Grote in 1825 and in debates at the London Debating Society, formed in the same year.

Public life and writing. The *Autobiography* tells how in 1826 Mill's enthusiasm was checked by a misgiving as to the value of the ends that he had set before him. At the London Debating Society, where he first measured his strength in public conflict, he found himself looked upon with curiosity as a precocious phenomenon, a "made man," an intellectual machine set to grind certain tunes. The elder Mill, like Plato, would have put poets under ban as enemies of truth; he subordinated private to public affections; and Landor's maxims of "few acquaintances, fewer friends, no familiarities" had his cordial approval. The younger Mill now felt himself forced to abandon these doctrines. Too much in awe of his father to make him a confidant, he wrestled with his doubts in gloomy solitude. He emerged from the struggle with a more catholic view of human happiness, a delight in poetry for its own sake, a more placable attitude in controversy, a hatred of sectarianism, and an ambition no less noble and disinterested but moderated to practical possibilities. Gradually, the debates in the Debating Society attracted men with whom contact was invigorating and inspiring. Mill ceased to attend the society in 1829, but he carried away from it the conviction that a true system of political philosophy was

Beginning of his mature thought

> something much more complex and many-sided than he had previously had any idea of, and that its office was to supply, not a set of model institutions but principles from which the institutions suitable to any given circumstances might be deduced.

Mill's letters in *The Examiner* in the autumn of 1830, after a visit to Paris, where he made the acquaintance of the younger liberals, may be taken as marking his return to hopeful activity; and a series of articles on "The Spirit of the Age" appeared in the same paper in 1831. During the years 1832 and 1833 he contributed many essays to *Tait's Magazine, The Jurist,* and *The Monthly Repository.* In 1835 Sir William Molesworth founded *The London Review,* with Mill as editor. It was amalgamated with *The Westminster* (as *The London and Westminster Review*) in 1836, and Mill continued as editor (latterly as proprietor, also) until 1840. In and after 1840 he published several important articles in *The Edinburgh Review.* Some of the essays written for these journals were reprinted in the first two volumes (1859) of Mill's *Dissertations and Discussions* and give evidence of the increasing width of his interests. Among the more important are "Thoughts on Poetry and Its Varieties" (1833), "Writings of Alfred de Vigny" (1838), "Bentham" (1838), "Coleridge" (1840), "M. De Tocqueville on Democracy in America" (1840), "Michelet's History of France" (1844), and "Guizot's Essays and Lectures on History" (1845). The twin essays on Bentham and Coleridge show Mill's powers at their splendid best and indicate very clearly the new spirit that he tried to breathe into English radicalism.

Works on logic and political economy

During these years Mill also wrote his great systematic works on logic and on political economy. His reawakened enthusiasm for humanity had taken shape as an aspiration to supply an unimpeachable method of proof for conclusions in moral and social science; the French positivist philosopher Auguste Comte had some influence here, but the main inspiration undoubtedly came from the English scientist and mathematician Sir Isaac Newton, whose physics had already been accepted as a model of scientific exposition by such earlier British philosophers as John Locke, David Hume, Jeremy Bentham, and James Mill. But he was determined that the new logic should not simply oppose the old logic. In his *Westminster* review (of 1828) of Richard Whately's *Elements of Logic,* he was already defending the syllogism against the Scottish philosophers who had talked of superseding it by a supposed system of inductive logic. He required his inductive logic to "supplement and not supersede." For several years he searched in vain for the means of concatenation. Finally, in 1837, on reading William Whewell's *Philosophy of the Inductive Sciences* and rereading John F.W. Herschel's *Preliminary Discourse on the Study of Natural Philosophy,* Mill at last saw his way clear both to formulating the methods of scientific investigation and to joining the new logic onto the old as a supplement. *A System of Logic,* in two volumes, was published in 1843 (3rd–8th editions, introducing many changes, 1851–72). Book VI is his valiant attempt to formulate a logic of the human sciences—including history, psychology, and sociology—based on causal explanation conceived in Humean terms, a formulation that has lately come in for radical criticism.

Mill distinguished three stages in his development as a political economist. In 1844 he published the *Essays on Some Unsettled Questions of Political Economy,* which he had written several years earlier, and four out of five of these essays are solutions of perplexing technical problems—the distribution of the gains of international commerce, the influence of consumption on production, the definition of productive and unproductive labour, and the precise relations between profits and wages. Here for the most part Mill appears as the disciple of David Ricardo, striving after more precise statements and reaching forward to further consequences. In his second stage, originality and independence become more conspicuous as he struggles toward the standpoint from which he wrote his *Principles of Political Economy.* This was published in 1848 (2 vol.; 2nd and 3rd eds., with significant differences, 1849, 1852), and, at about the same time, Mill was advocating the creation of peasant proprietorships as a remedy for the distresses and disorder in Ireland. Thereafter, he made a more thorough study of Socialist writers. He was convinced that the social question was as important as the political question. He declined to accept property, devised originally to secure peace in a primitive society, as necessarily sacred in its existing developments in a quite different stage of society. He separated questions of production and distribution and could not rest satisfied with the distribution that condemned the labouring classes to a cramped and wretched existence, in many cases to starvation. He did not come to a Socialist solution, but he had the great merit of having considered afresh the foundations of society. This he called his third stage as a political economist, and he says that he was helped toward it by Mrs. Taylor (Harriet Hardy), who became his wife in 1851.

Activities during his married life

It is generally supposed that Mill writes with a lover's extravagance about Harriet's powers. He expressly says, indeed, that he owed none of his technical doctrine to her, that she influenced only his ideals of life for the individual and for society, and that the only work directly inspired by her is the essay on the "Enfranchisement of Women" (*Dissertations,* vol. 2). Nevertheless, Mill's relations with her have always been something of a puzzle.

During the seven years of his marriage Mill became increasingly absorbed in the work of the British East India Company and in consequence published less than at any other period of his life. In 1856 he became head of the examiner's office in the India House, and for two years, till the dissolution of the company in 1858, his official work kept him fully occupied. It fell to him as head of the office to write the defense of the company's government of India when the transfer of its powers was proposed. Mill opposed the transfer, and the documents in which he defended the company's administration are models of trenchant and dignified pleading. On the dissolution of the company, Mill was offered a seat in the new council but declined it and retired with a pension of £1,500. His retirement from official life was followed almost immediately by his wife's death at Avignon, France. He spent most of the rest of his life at a villa at Saint-Véran, near Avignon, returning to his house at Blackheath only for a short period in each year.

The later years. Mill sought relief by publishing a series of books on ethics and politics that he had meditated upon and partly written in collaboration with his wife. The essay *On Liberty* appeared in 1859 with a touching dedication to her and the *Thoughts on Parliamentary Reform* in the same year. In his *Considerations on Representative Government* (1861) he systematized opinions already put forward in many casual articles and essays. It has been remarked how Mill combined enthusiasm for democratic government with pessimism as to what democracy was likely to do; practically every discussion in these books exemplifies this. His *Utilitarianism* (in *Fraser's Magazine,* 1861; separate publication, 1863) was a closely reasoned attempt to answer objections to his ethical theory and to remove misconceptions about it. He was especially anxious to make it clear that he included in "utility" the pleasures of the imagination and the gratification of the higher emotions; and to make a place in his system for settled rules of conduct.

Mill also began to write again on the wider philosophical questions that had occupied him in the *Logic.* In 1865 he published both his *Examination of Sir William Hamilton's Philosophy* and his *Auguste Comte and Positivism,* but in both writings his motives were largely political. It was because he regarded the writings and sayings of Sir William Hamilton as the great fortress of intuitional philosophy in Great Britain that Mill undertook to counter his pretensions. In dealing with Comte, Mill distinguished sharply between Comte's earlier philosophical doctrine of Positivism and his later religion of humanity. The doctrine he commended (as he had frequently done previously) because he regarded it as a natural development of the outlook of George Berkeley and Hume; the religion he attacked because he saw in it merely another attempt to foist a priestly hierarchy upon suffering humanity. It is noticeable that Mill's language in these books is much closer to the language of Bentham and James Mill than it had been since his boyhood, and it was as an act of piety that in 1869 he republished his father's *Analysis of the Phenomena of the Human Mind* with additional illustrations and explanatory notes.

Mill in Parliament

While engaged in these years mainly with theoretical studies, Mill did not remit his interest in current politics. He supported the North in the U.S. Civil War, using all his strength to explain that the real issue at stake in the struggle was the abolition of slavery. In 1865 he stood as parliamentary candidate for Westminster, on conditions strictly in accordance with his principles. He would not canvass or pay agents to canvass for him, nor would he engage to attend to the local business of the constituency. He was with difficulty persuaded even to address a meeting of the electors but was elected. He took an active part in the debates preceding the passage of the 1867 Reform Bill, and helped to extort from the government several useful modifications of the bill, for the prevention of corrupt practices. The reform of land tenure in Ireland (see his *England and Ireland,* 1868, and his *Chapters and Speeches on the Irish Land Question,* 1870), the representation of women (see below), the reduction of the national debt, the reform of London government, and the abrogation of the Declaration of Paris (1856)—concerning the carriage of property at sea during the Crimean War—were among the topics on which he spoke. He took occasion more than once to enforce what he had often advocated, England's duty to intervene in foreign politics in support of freedom. As a speaker Mill was somewhat hesitating, but he showed great readiness in extemporaneous debate. Elected rector of St. Andrews University, he published his "Inaugural Address" in 1867.

Mill's subscription to the election expenses of the free-thinker and radical politician Charles Bradlaugh and his attack on the conduct of Gov. E.J. Eyre in Jamaica were perhaps the main causes of his defeat in the general parliamentary election of 1868. But his studied advocacy of unfamiliar projects of reform had made him unpopular with "moderate Liberals." He retired with a sense of relief to Avignon. His villa was filled with books and newspapers; the country round it furnished him with a variety of walks; he read, wrote, discussed, walked, botanized. He was extremely fond of music and was himself a fair pianist. His stepdaughter, Helen Taylor (died January 1907), was his constant companion after his wife's death. Mill was an enthusiastic botanist all his life and a frequent contributor of notes and short papers to the *Phytologist.* During his last journey to Avignon he was looking forward to seeing the spring flowers and completing a flora of the locality.

Mill did not relax his laborious habits or his ardent outlook on human affairs. The essays in the fourth volume of his *Dissertations* (1875; vol. 3 had appeared in 1867)—on endowments, on land, on labour, and on metaphysical and psychological questions—were written for the *Fortnightly Review* at intervals after his short parliamentary career. In 1867 he had been one of the founders, with Mrs. P.A. Taylor, Emily Davies, and others, of the first women's suffrage society, which developed into the National Union of Women's Suffrage Societies, and in 1869 he published *The Subjection of Women* (written 1861), the classical theoretical statement of the case for woman suffrage. His last public activity was concerned with the starting of the Land Tenure Reform Association, for which he wrote in *The Examiner* and made a public speech a few months before his death; the interception by the state of the unearned increment on land and the promotion of cooperative agriculture were the most striking features in his program, which he regarded as a timely compromise in view of the impending struggle between capital and labour in Europe. His *Autobiography* and *Three Essays on Religion* (1874) were published posthumously.

Mill died at Avignon on May 8, 1873. A bronze statue of him stands on the Thames embankment in London, and G.F. Watts's copy of his original portrait of Mill hangs in the National Gallery there.

Influence and significance. Mill was a man of extreme simplicity in his mode of life. The influence that his works exercised upon contemporary English thought can scarcely be overestimated, nor can there be any doubt about the value of the liberal and inquiring spirit with which he handled the great questions of his time. Beyond that, however, there has been considerable difference of opinion about the enduring merits of his philosophy. At first sight he is the most lucid of philosophers. Many people have spoken of the marvelous intelligibility of his writing. Usually, however, it is not long before doubts begin to creep in. Although the lucidity remains, its span is seen to be somewhat limited, and one sometimes has the uneasy feeling that he is being equally lucid on both sides of a question.

Oddly enough, however, this judgment has not led to any neglect of Mill. Little attention is now paid to Hamilton or to Whewell, but Mill's name continually crops up in philosophical discussions. This is partly due to the fact that Mill offers a body of doctrine and a set of technical terms on many subjects (notably on induction) that have proved extremely useful in the classroom. But a more important reason is that he has come to be regarded as a sort of personification of certain tendencies in philosophy that it is regarded as continually necessary to expound or expose because they make such a powerful appeal to serious minds. Thus he is or says he is a Utilitarian; yet nothing, it is pointed out, could tell more strongly against Utilitarianism than certain passages in his writings. Then again, he is said to be an Empiricist (although he says himself that he is not), and his theories of the syllogism and of mathematics are constantly used to demonstrate the fatal consequences of this way of thinking.

It is misleading to speak without qualification of Mill's Utilitarianism. Nor is it sufficient to add that Mill modified the Utilitarianism that he inherited from Bentham and from his father in one way and another in order to meet the criticisms that it encountered in Victorian times. He does, it is true, sometimes give that impression (as in his essay *Utilitarianism*); but elsewhere (as in his essay *On Liberty*) he scarcely attempts to conceal the fact that his premises are completely independent of Bentham's. Thus, contrary to the common belief, it appears to be very hazardous to characterize offhand the precise position of Mill on any major philosophical topic. He sometimes behaved with a reckless disregard of consequences more suitable to a Romantic than to a Utilitarian. He is thoroughly romantic, again, and thoroughly representative of his age in the eagerness with which he seeks out and endeavours to assimilate every last exotic line of thought which shows any signs of vitality. He himself claimed to be superior to most of his contemporaries in "ability and willingness to learn from everybody," and indeed, for all his father's careful schooling, there was never anybody less buttoned up against alien influences than Mill. In his writings there can be discerned traces of every wind of doctrine of the early 19th century.

MAJOR WORKS

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(R.P.An./Ed.)

Milton

John Milton ranks second only to Shakespeare among English poets; his writings and his influence are a very important part of the history of English literature, culture, and libertarian thought. He is best known for *Paradise Lost,* which is generally regarded as the greatest epic poem in the English language. Milton's prose works, however, are also important as a valuable interpretation of the Puritan revolution, and they have their place in modern histories of political and religious thought.



Milton, engraving by W. Faithorne, 1670. In the National Portrait Gallery, London.
By courtesy of the National Portrait Gallery, London

Milton was born in London on Dec. 9, 1608. His grandfather, an Oxfordshire yeoman, had been a staunch Roman Catholic who had disinherited his son, the poet's father, for turning Protestant. John Milton, Sr., went to London, where he made his way to prominence and a comfortable fortune as a scrivener, or notary, and through the collateral business of private banking or moneylending. Milton was to pay repeated tributes to his father's generous concern with his education. Of his mother (d. 1637) Milton said only that she was well esteemed and known for her charities. He had an older sister, Anne, and a younger brother, Christopher, who became a lawyer.

Education and early poems. Milton was educated at St. Paul's School, London. The conventional date given for his admission is 1620, but it may have been as early as 1615. In addition to his regular schoolwork in Latin, Greek, and, later, Hebrew, the boy had instruction at home, perhaps partly in modern languages, from private tutors. Milton was a voracious student; he traced the initial cause of his later blindness to his having, from his 12th year, rarely quit his books before midnight. Along with a couple of Latin exercises that have survived, his earliest attempts at verse, made when he was 15, were rhymed paraphrases of Psalms 114 and 136. Milton's closest friend, at school and later, was Charles Diodati, the son of a prominent physician of Italian origin, who went from St. Paul's to Oxford.

Years at Cambridge

On April 9, 1625, Milton entered Christ's College, Cambridge; he received his Bachelor of Arts degree in March 1629 and his Master of Arts in July 1632. His experience at Cambridge can be partly gathered from his abundant Latin verse and his seven Latin prolusions (public speeches that were expected to display the speaker's learning and rhetorical and argumentative powers). Apparently in March 1626 he clashed in some way with his tutor and was suspended temporarily. On his return to the university he was assigned to another tutor and graduated at the normal time.

Milton's nickname at the university, "the Lady," was apparently bestowed because of his handsome and delicate features and a purity of mind and behaviour that disdained the diversions of his coarser fellows. During his seven years at Cambridge he seems to have moved from some unpopularity to general respect and, among dons and cultivated students, to high esteem. He did not love the scholastic logic that dominated the curriculum; then, as well as later, he denounced it as barren. In his last prolusion (*c.* 1631/32) he proclaimed the fervent creed and dream of a young Renaissance humanist who was at once a Christian and a Platonist. By Milton's own account, his early enthusiasm for the sensual poetry of Ovid and other Roman writers gave way to an appreciation of the idealism of Dante, Petrarch, and Edmund Spenser. He then moved on to Platonic philosophy and finally came to hold the mysticism of the biblical Book of Revelation in the highest esteem.

Meanwhile, Milton had been learning his craft and sometimes revealing his inner self in writing Latin verse. (Latin was then the standard language of the university world.) The young poet's sensuous instincts were revealed in these poems and were further displayed, along with his mastery of Italian, in six Italian pieces (1630?), with which his first English sonnet, "O Nightingale," may be linked.

Earliest extant English poems

Early in 1628 Milton wrote the first of his extant English poems (apart from the two psalms), "On the Death of a Fair Infant," an elegy, in the Elizabethan vein, on his baby niece, Anne Phillips. In part of an academic prolusion in English couplets ("At a Vacation Exercise," July 1628) he declared his devotion to his native language, a style free from eccentricity, and exalted themes concerning nature and humanity. And in the Latin "Elegy VI," addressed to Diodati in the Christmas season of 1629–30, he praised the light verse kindled by wine and love but turned from that to celebrate the ascetic purity of the heroic poet. The elegy ended with a reference to a poem he had just written, his first great poem in English, "On the Morning of Christ's Nativity." Such a poem, composed shortly after his 21st birthday, may be taken as a kind of announcement of his poetical coming of age and future direction, both in its religious theme and in its mastery of conception and form and image and rhythm. Probably in 1631 Milton wrote the companion poems "L'Allegro" and "Il Penseroso." Though less ambitious in theme than the "Nativity," they have their own complexity, concealed beneath a unique grace and charm. Milton had lately (1630) also written the lines "On Shakespeare," which were printed in the Shakespearean Second Folio, 1632.

Milton's scholarly and literary gifts had from childhood marked him out in the minds of his family and teachers for the ministry; in his later prose he said he had refused to "subscribe slave" in a church governed by prelacy, but the date of his negative decision is not known. As his academic career approached its end, the problem of an occupation came up, and the poem "Ad Patrem"—though some scholars link it with *Comus* (1634)—may well have been written in 1631–32. In "Ad Patrem" ("To Father"), with a mixture of filial gratitude, firmness, and confidence in poetry and himself, Milton assumes or urges that he should not be pushed into some basely lucrative profession by a father who has fostered his literary pursuits and is himself a devotee of the muses.

Horton period (1632–38). On taking his Master of Arts degree in July 1632, Milton retired to his father's house—until 1635 at Hammersmith, then at the country estate at Horton, near Windsor—and proceeded to give himself the liberal education Cambridge had not provided. It was in these years that he laid the foundation or set the direction of his liberal thinking. He sought to digest the mass of history, literature, and philosophy, to gain the "insight

Self-education

into all seemly and generous arts and affairs" needed by the citizen-poet who would be a leader and teacher.

Two short religious poems written at this time, "On Time" and "At a Solemn Musick" (1632–33?), are early renderings of the beatific vision that always kindled Milton's imagination. Both contrast the grossness of temporal life, the jarring discord of sin, with the eternity and harmony of heaven and good. The same contrast is sounded in the masque known as *Comus.* During 1630–34, perhaps in 1632, Milton had, at the invitation probably of the musician Henry Lawes, written *Arcades,* a miniature masque of Jonsonian courtliness. This presumably led to a request from Lawes for another masque. *Comus* was presented on Sept. 29, 1634, before John Egerton, earl of Bridgewater, at Ludlow Castle in Shropshire, in honour of his becoming lord president of Wales. The acted version of *Comus,* though somewhat shorter than the text familiar to readers, in length and elevated seriousness went far beyond the limits of the usual court masque, which emphasized lavish costumes, spectacle, music, and dancing. *Comus* is a masque against "masquing," contrasting a private heroism in chastity and virtue with the courtly round of revelry and pleasure. It was Milton's first dramatizing of his great theme, the conflict of good and evil.

The allegorical story in *Comus* centres on a virtuous Lady who becomes separated from her two brothers while traveling in the woods. The Lady encounters the evil sorcerer Comus, son of Bacchus and Circe, who imprisons her by magic in his palace. In debate the Lady rejects Comus' hedonistic philosophy and defends temperance and chastity. The chastity the Lady represents is not mere abstinence; it is a positive love of the good that is both Christian and Platonic. Comus, who is portrayed with a dramatic irony that anticipates the treatment of Satan in *Paradise Lost,* puts forth specious naturalistic arguments which the Lady answers first on the rational level; then, with a conscious change of tone, she rises to an impassioned religious affirmation of chastity, and the masque's epilogue celebrates the love of virtue.

Composition of "Lycidas"

If *Comus* is, in a way, a song of innocence, "Lycidas" (written in November 1637) is a song of experience—Milton's first attempt to justify the ways of God to himself and to men. His former fellow collegian, Edward King, was drowned in a shipwreck in the Irish Sea in August 1637, and Milton was asked to contribute to a volume of elegies; "Lycidas," signed "J.M.," appeared at the end of an undistinguished collection of pieces in Latin, Greek, and English (1638). The classical pastoral elegy had, from its Greek beginnings, proved its value as a dramatic vehicle for almost anything that a poet wished to say. Milton, working as usual within a venerable tradition, as usual recreated it. He had no reason to feel deep personal sorrow, but the drowning of a virtuous and promising young man, on the threshold of service as a clergyman, brought home the whole enigma of life and death, of the rightness of things in a world where such events could happen. What if his own talents—which during his years of study he had been nurturing—should be cut off? At the poem's end, divine justice and providence and the conditions of earthly life are vindicated not by reason but by the beatific vision of Lycidas' soul received into heaven. It is impossible to summarize the complexities and depths of the poem, its reverberating solidity of reference, its rich variety of pace and tone, the artistic control that dominates turbulent emotions and ends with the high serenity of victory won. "Lycidas" may be the greatest short poem in the English language.

Italian tour (1638–39). In May 1638, a year after his mother's death, Milton set off—with one servant—on a visit to Italy. He sojourned chiefly in Florence, Rome, and Naples. Milton and some of his early Latin poems were cordially welcomed among men of letters and patrons and their academies. This experience warmed his heart and nourished his self-confidence. (It should be remembered that at home he had very little literary acquaintance and, outside a small circle, no poetic reputation.) In Naples he was the guest of Giambattista Manso, marchese di Villa, who had been the patron of Torquato Tasso, and in Florence he made a call—later recorded in *Areopagitica*—on the aged astronomer Galileo Galilei, who was under house arrest because his views on the universe conflicted with the doctrine of the Roman Catholic church. Milton felt obliged to forgo a visit to Sicily and Greece because of news of mounting political tension in England, although he lingered some time longer in Italy. In August 1638 Milton's friend Diodati died. Milton had been informed of his loss while in Italy; on his way home he stopped to see Diodati's uncle, Giovanni Diodati, who was professor of theology at the University of Geneva.

Middle period (1641–60). Milton returned to England in July 1639, settled in a house in London, and prepared to take in pupils. He composed an elaborate pastoral elegy on Diodati, "Epitaphium Damonis" (*c.* 1640), which has commonly been ranked as his finest Latin poem, though as an elegy it is inferior to "Lycidas." Milton had returned to England with plans for an Arthurian epic; like other ambitious poets of the Renaissance, he hoped to write the great modern heroic poem. But he was also deeply anxious about the Puritan cause. In his denunciation of hireling clergy in "Lycidas," Milton had virtually declared his Puritan allegiance, and the years 1641–60 he gave almost wholly to pamphleteering in the cause of religious and civil liberty. There is an important personal passage in his fourth tract, *The Reason of Church-Government Urg'd Against Prelaty* (1642), that shows it was a heavy sacrifice to put aside his craving for poetic immortality and leave his cherished studies to "embark in a troubled sea of noises and hoarse disputes." And, as his work went on, he was sustained by the conviction that in his many and varied defenses of liberty he was, in another way, fulfilling his epic and patriotic aspirations. His first five pamphlets (1641–42) were contributions to the attack made on prelacy in the Anglican church by a group of Presbyterian divines (called, from their initials, the "Smectymnuus" group). The attack was directed chiefly against the church's episcopal hierarchy, *The Book of Common Prayer,* and ritual, as being a compromise with Rome. The group urged a return to the democratic simplicity and purity of the apostolic church. Milton's first tract was *Of Reformation Touching Church Discipline in England* (1641). This begins by assailing the Anglican service and ends with a vision of the new and grand Reformation. In a personal passage in his fourth pamphlet, *The Reason of Church-Government,* Milton explains his religious conception of poetry and the deferment of his great epic because of what he feels to be his public duty.

Allegiance to Puritanism

Notoriety came in 1643, with Milton's pamphlet *Doctrine and Discipline of Divorce* (enlarged edition 1644), which was followed by three more tracts in 1644 and 1645 on the same theme. His preoccupation with the subject of divorce was presumably hastened by his own marital disaster. In June(?) 1642, several months before the outbreak of the Civil Wars, Milton had married Mary Powell, the daughter of a royalist squire of Oxfordshire who owed money to his father. Success could hardly be predicted for the marriage of a scholar and poet of 33 to an uneducated girl half his age from a large, easygoing household. The young wife, visiting her family a little later, declined—doubtless with their backing—to return to her new husband's household. The shock must have been especially severe for a man who—as one may infer from the anguished cries that recur in the *Doctrine*—had approached marriage with high hopes and earnest prayers, and there was no release from such a tragic mistake. In the tracts Milton argued that the sole cause admitted for divorce—adultery—might be less valid than incompatibility and that the forced yoke of a loveless marriage was a crime against human dignity. For this he was attacked as a libertine by royalists and Presbyterians alike. In 1645 friends brought about a reunion between Milton and his wife, and in 1646, when the Powells had been ruined by the war, he took into his house, for nearly a year, the whole noisy family of 10. Three daughters, Anne, Mary, and Deborah, were born in 1646, 1648, and 1652. A son died in infancy. Mrs. Milton died a few days after Deborah's birth.

First marriage

In 1644 Milton published what are for modern readers his best-known pamphlets, *Of Education* and *Areopagit-*

ica. Of Education is one of the last in a long line of European expositions of Renaissance humanism. His aim was to mold boys into enlightened, cultivated, responsible citizens and leaders on the basis of the study of the ancient classics, in due subordination to the Bible and Christian teaching. But he also gave notable emphasis to science. *Areopagitica* is on the freedom of the press and was specifically written to protest an order issued by Parliament the previous year requiring government approval and licensing of all published books. Milton argues that to mandate licensing is to follow the example of the detested papacy. He defends the free circulation of ideas as essential to moral and intellectual development and reasserts above all his belief in the power of truth to triumph over falsehood through free inquiry and discussion. *Areopagitica* is now regarded as a classic plea on behalf of civil liberties and democratic values, but the tract seems to have had very little effect in its own time.

During the next four years Milton may have worked chiefly on his *The History of Britain* (1670). On Feb. 13, 1649, two weeks after the execution of Charles I, Milton's first political tract, *The Tenure of Kings and Magistrates,* appeared. In it he expounds the doctrine that power resides always in the people, who delegate it to a sovereign but may, if it is abused, resume it and depose or even execute the tyrant. A month later he was invited to become secretary for foreign languages to Cromwell's Council of State. Hitherto a detached observer, Milton, in spite of his private studies, was doubtless eager to have a hand in the workings of government. He was not on the policy-making level, but he had the easy command of Latin needed for foreign correspondence. Also, as a publicist of demonstrated sympathy with the revolution, he was expected to continue his defense of the cause against the multiplying attacks on the regicides.

Secretary for foreign languages to the Council of State

Milton's first effort in this line was *Eikonoklastes* (October 1649), one of a number of answers to *Eikon Basilike,* a book edited from the late king's papers by his chaplain, John Gauden. During 1651 Milton was censor and supervisory editor of the chief Commonwealth newspaper, *Mercurius Politicus,* edited by Marchamont Needham. In this year appeared his Latin *Defence of the People of England.* Charles II, in exile, had engaged Claudius Salmasius (Claude de Saumaise), the most eminent of classical scholars, to arraign the regicides (*Defensio Regia pro Carolo I,* 1649). Milton was less effective in legal argument than in discrediting Salmasius by personal abuse; like some other crusaders, he tended to see opponents as monstrous enemies of a sacred cause who must be destroyed by any means.

If he was, then and later, uplifted by the vanquishing of a renowned antagonist, he was inevitably and profoundly depressed by the loss of his eyesight; it had been failing for years, and blindness became complete in the winter of 1651–52. Milton was only 43, and the great poem was still unwritten. Blindness reduced his strictly secretarial duties, though he continued through 1659 as a translator of state letters.

Onset of blindness

The Second Defence of the People of England—also in Latin, since it was also addressed to Europe at large—was much more worthy of its subject and its author. In it he celebrated the achievements of the Commonwealth leaders (though he was bold enough to warn Cromwell against one-man rule). In 1659 two more tracts on church and state were published. In *A Treatise of Civil Power in Ecclesiastical Causes* Milton argued for religious freedom (except for Roman Catholics, since Catholicism had shown itself a danger to national security). In *Considerations Touching the Likeliest Means to Remove Hirelings out of the Church* he reasserted the ideal of a clergy of apostolic simplicity of life.

His last political pamphlet, *The Readie and Easie Way to Establish a Free Commonwealth,* was published in March 1660 and again, enlarged, in April. It was an act no less courageous than futile, since machinery was patently moving to bring back Charles II and install him as king (he made his triumphal entry on May 29). Milton's pamphlet is a cry of incredulity and despair from the last champion of "the good Old Cause." The glories of the Commonwealth, to which he himself had given 20 years and his eyesight, were being swept away by a nation of slaves "now choosing them a captain back for Egypt." The Restoration was the last and heaviest of Milton's many disillusionments.

The Restoration government executed the Commonwealth leader Sir Henry Vane the Younger and exhumed and hanged at Tyburn the bodies of Cromwell, Henry Ireton, and John Bradshaw. Milton himself, as a noted defender of the regicides, was in real danger. In the summer of 1660 a warrant was out for his arrest; he was kept in hiding by friends. In August the Act of Oblivion, granting pardon to most Commonwealth supporters, was passed. Milton was safe within its terms but was nevertheless taken into custody (and released on December 15). According to various early stories, his life was spared through the intercession either of the poet Andrew Marvell, who in 1657 had become a fellow secretary and was now a member of Parliament, or of the royalist playwright Sir William Davenant, whose life Milton had earlier been the means of saving. It may have been decided that the blind writer was now harmless and that token proceedings against him would be enough.

The large bulk of Milton's prose—which fills four times as many volumes as his poetry—is read only by scholars, but much of it is important for several reasons. In an age of great prose, Milton's, at its best, has an individual if often undisciplined greatness, and *Areopagitica* at least is a classic document. Moreover, as the record of Milton's growth (a leftward growth, in religion and politics) and of his dreams and disillusionments, his prose works are the essential introduction to *Paradise Lost, Paradise Regained,* and *Samson Agonistes,* providing a bridge between the radiant idealism of his youth and the much-tried faith and fortitude of his later years. In particular, his *A Treatise on Christian Doctrine* held a central place in his thoughts and labours. He seems to have finished it by about 1658–60 (it was first printed and translated by Charles Sumner in 1825). Its importance is that it expounds, with differences, the theological frame of *Paradise Lost.* Viewed in perspective, most of Milton's essential beliefs are those of traditional Christianity, but he does depart from orthodoxy on a few points, notably his denial of predestination. Brought up, like most Anglicans of his time, as a Calvinist, he regarded himself as one at least until 1644, but his final belief was in the Arminian doctrine—the salvation not of a predestined few but of all believers, who constitute the true elect. Milton above all insisted on humanity's rational freedom and responsible power of choice.

Estimate of the prose works

Sonnets and other poems (1642–58). Milton's early poems, in English, Latin, Greek, and Italian, were published at the beginning of 1646 (dated 1645). During the 20 years given to public affairs he was mostly cut off from poetry but did write 17 occasional sonnets, versified a number of psalms, and began the composition of *Paradise Lost.* Some of the sonnets are deeply personal: two on his blindness (1652–55) and one on the death in 1658, some months after childbirth, of his second wife, Katherine Woodcock, whom he had married in 1656.

The major sonnets have much poetical as well as autobiographical interest, and as a group they illustrate (with "Lycidas") both in texture and rhythm the beginnings of the grand style (*i.e.,* a literary style marked by a sustained and lofty dignity and sublimity) that was to have full scope in *Paradise Lost.* One is less conscious of sonnet structure and of rhymes than of a single massive unit that approaches a paragraph of Milton's blank verse.

Paradise Lost. By 1650 Milton had given up the idea of composing a British epic. Instead he chose what was considered the most momentous event, next to the life and death of Christ, in the world's history—the fall of mankind from grace. It is not known when *Paradise Lost* was actually begun. Guesses have centred on 1655–58. Clearly, the lines on the poet's having fallen on evil days, in the prelude to Book 7, were composed after the Restoration, and the whole may have been done pretty much in the order in which it stands. It was finished by 1665. The first edition of 1667 was in 10 books; this was reissued in 1668 and 1669, and in some of these issues

Composition of *Paradise Lost*

Milton added the prefatory note on his use of blank verse and "The Argument." In the second edition (1674), Books 7 and 10 were each split into two, making a total of 12 books. The arguments, which summarize the contents of each book and were formerly grouped together, were placed at the head of the respective books.

Paradise Lost is an epic poem written in blank verse—*i.e.,* unrhymed iambic pentameter verse. It tells the story of Satan's rebellion against God and his expulsion from heaven and the subsequent temptation and expulsion of Adam and Eve from the Garden of Eden. By Milton's time the Fall of Man had already received innumerable literary treatments, narrative and dramatic, so that the simple tale in Genesis and the more shadowy role of Satan in heaven, earth, and hell had acquired a good deal of interpretative and concrete embellishment. So the main motives and events of *Paradise Lost* had abundant literary precedent, though they were handled with powerful originality; Milton, like a Greek dramatist, was reworking a story familiar in outline to his audience. His story, moreover, gave him the advantage of immemorial belief and association in the minds of his earlier readers. This advantage no longer operates in the same way—although, for modern readers, the fable still possesses at least the immemorial and universal import of archetypal myth.

The story of the Fall of Man had little of the solidity and variety of character and action of the classical epics, however, and so Milton the classicist naturally borrowed much in the way of form and style and epic convention. While he was said to have known the Homeric poems by heart, his great classical model was Virgil's *Aeneid,* with which *Paradise Lost* has some inner as well as surface affinities.

Some Virgilian features of *Paradise Lost* are easily observable. Milton centres the magnificent first two books of his poem on the figure of Satan and his legions as they lie in hell. Virgil has a roll call of the Italian chiefs who gather to oppose Aeneas; Milton's roll call of the leaders of the fallen angels, in making them individuals, also becomes a survey of the spread of heathen idolatry over the Eastern world. The realistic power of the debate of the fallen angels in hell dwarfs all other epic councils. Epic accounts of Hades are combined, in Milton's pictures of hell, with Christian lore, but the lurid and dismal scenes and the physical and mental diversions of the fallen angels symbolize their spiritual death and futile striving. The wars of gods and Titans and giants in classical literature supply details for the war in heaven in *Paradise Lost,* which is a large metaphor for the anarchy of sin. And Odysseus' and Aeneas' retellings of past events become the archangel Raphael's account of Satan's revolt and war and the Son's creation of the world.

Much has been written about Milton's powerful characterization of Satan, who is one of the supreme figures in world literature. Satan has, on a superhuman scale, the strength, the courage, and the capacity for leadership that belong to the ancient epic hero, but these qualities are all perverted in being devoted to evil and self-aggrandizement. In his first grand speech to his lieutenant Beelzebub, Satan's defiance of God manifests his egoistic pride, his false conception of freedom, and his alienation from all good; and his other public harangues reinforce and amplify our sense of power that is religiously and morally corrupt and blind. Against the background of hell, Satan maintains the false magnificence of his "heroic" stature, but outside of hell he loses even that. In his soliloquy addressed to the Sun, he reveals, like Dr. Faustus or Macbeth, his despairing consciousness of his own evil and damnation, a consciousness that gives him potentially tragic dimensions. Thus Satan and his fellows are enveloped in dramatic irony because—though the corruption of man is achieved—they fight and scheme in ignorance of the unshakable power of God and goodness.

Dramatic irony in *Paradise Lost*

Adam and Eve are enveloped in a parallel kind of irony. The picture of the Garden of Eden is a symbolic rendering of Milton's vision of perfection, but it is presented when the reader accompanies Satan into the garden, so that idyllic innocence and happiness are seen only under the shadow of evil. Though the pair have had warnings, Eve is beguiled by an appeal to her vanity and ambition, by the hubristic dream of attaining godlike knowledge and power; and Adam allows his love for Eve to oversway his love for God. Both, far from attaining godlike knowledge, succumb to animal lust; yet, when grace and penitence begin to work in them, they have a strength beyond the reach of Satan. On the other hand, though there is promised redemption for the faithful, and though the poem is, logically, a divine comedy with a happy ending, Milton's panorama of human history gives little ground for hope on earth. Irony, profoundly compassionate irony, pervades the moving last lines which describe Adam and Eve as they depart from Eden—not now the majestic lords of creation but two frail human beings beginning life anew in the world of sin and sorrow and death, though "with Providence their guide" and the hope of achieving a "paradise within."

The more one reads *Paradise Lost* the more one recognizes Milton's powers of imagination and organization. Everywhere, on the largest or the smallest scale, in abstract idea or concrete act, theme and material are closely knit through parallel and contrast. The central conflict and contrast between good and evil are reflected and intensified in the contrasts between heaven and hell, light and darkness, order and chaos, love and hate, humility and pride, reason and passion. In the council in hell, Satan alone volunteers for the perilous journey to earth to bring about the Fall of Man; in the council in heaven, the Son alone volunteers to suffer on earth for man's salvation. Satan unlooses the destructive anarchy of war; the Son creates the world. Eve and Adam reenact the sin and fall of Satan. The boundless scene of *Paradise Lost* is indeed only a backdrop or magnified reflection of the drama that goes on in the hearts of the human protagonists, and, when they fall, the ideal world of eternal spring and eternal life becomes the world we live in.

To speak of the setting in more literal terms, Milton's imagination fills space so immense that the created universe—the Ptolemaic one—hangs from heaven like one of the smallest stars close to the Moon. Milton showed his awareness of the Copernican universe, but the Ptolemaic one had the advantages of traditional familiarity and of keeping earth and man at the focal centre. In his handling of vast space Milton's imagination and language work with a suggestive vagueness that is very different from the minute particularity of Dante's world. He is excited by the starry dance of the cosmic order and, likewise, by the fecundity of Eden, and his account of creation is alive with the sense of movement and growth. The poem is rich in its appeal to both the eye and the ear.

Milton's preface stresses the novelty and rightness of blank verse for a heroic poem, and his manipulation of rhythm and sound is of course one of his supreme achievements. The continuous flow of his long sentences and paragraphs is naturally unlike the dramatic blank verse of Shakespearean dialogue, and it builds up a continuous onward pressure. While the iambic pentameter line remains the norm, there may be extra syllables, and there is endless variety in the number, weight, and position of stresses. At the same time there is a secondary and still more fluid system of rhythmic units, which flow from the caesura in one line to the caesura in the next, resulting in an infinity of permutations and combinations. Milton's blank verse is never monotonous, and the pattern of sound is so wedded to the pattern of sense that each is essential to the other.

Milton's frequently Latinate syntax and diction have sometimes been censured, especially by modern poets and critics for whom colloquial speech and rhythm are the only acceptable medium. But Milton's means of achieving the elevation required by a lofty theme is intermixed with pure simplicity. His use of Latinate syntax or structure and his freedom in the placing of phrases and clauses greatly enlarge and enrich his range of emphasis and his use of economy, contrast, suspension, all the devices of forceful utterance—devices often really colloquial. Many other functional elements of the grand style can be noted: periphrasis, epic similes, geographic, historical, and mythological allusions, and so on.

Last major works. In *Paradise Lost* (Book 9) Milton had spoken of "patience and heroic martyrdom" as themes

Paradise Regained and *Samson Agonistes*

unsung, though nobler than martial prowess, and this "better fortitude" was celebrated in the epic poem *Paradise Regained* and the tragedy *Samson Agonistes* (published in the same volume in 1671). *Paradise Regained* is a natural sequel to *Paradise Lost:* Christ, the second Adam, wins back for man what the first Adam had lost. But Milton did not, as might have been expected, deal with the Crucifixion; instead, he showed Christ in the wilderness overcoming Satan the tempter, thereby proving his fitness for his ultimate trial and, in his human role, showing what humankind might achieve through strong integrity and humble obedience to the divine will. Although the poem has been found cold by the mass of readers and critics, it nevertheless has all the fire of Milton's religious and moral passion and his reverence for true heroism.

For some readers, the drama of *Samson Agonistes* is the most powerful and completely satisfying of Milton's major works. It is by far the greatest English drama on the Greek model and is known as a closet tragedy—*i.e.,* one more suited for reading than performance. The play deals with the final phase of Samson's life and recounts the story as told in the Book of Judges of the Old Testament. The action, up to the reported catastrophe, is wholly psychological; it is the process by which Samson, "eyeless in Gaza at the mill with slaves," moves from preoccupation with his misery and disgrace to selfless humility and renewed spiritual strength, so that he can once more feel himself God's chosen champion. He is granted a return of his old strength and pulls down the pillars that support the temple of the Philistine god Dagon (also spelled Dagan), crushing himself along with his captors. The drama must owe a great deal of its power to Milton's sense of kinship with his hero; he has been eyeless in London among a nation of slaves. But nowhere does the classical impersonality and restraint of Milton's art show so strongly; there is nothing in the drama that does not belong to the story of Samson. And Milton's classical style appears in a new phase, in a rugged, sinewy, colloquial texture, and in irregular rhythms of new expressiveness.

Altogether, if *Samson* was his last epic poem, it was a grand testament. Like Samson, Milton was able to conquer despair or to sublimate it in his last three great poems. These expressed not his earlier revolutionary faith in men and movements but a purified faith in God and the regenerative strength of the individual soul.

Last years (1658–74). The poet's final 16 years of life, during which these three works were finished or composed, were peaceful, although there were concrete troubles: a frugal domestic economy necessitated by greatly diminished resources; blindness and what was sometimes a more severe affliction, the pains of gout; and a degree of friction with his daughters, due probably to faults on both sides. Apart from the publication of books, the chief events of these years were Milton's marriage (1663) to a third wife, the young and amiable Elizabeth Minshull, who survived him, and the removal, during the plague of 1665, to a house (now a Milton museum) at Chalfont St. Giles, Buckinghamshire.

Last works

The publications of Milton's late years were *Paradise Lost* (1667), for which he received £10; textbooks of simplified Latin grammar (1669) and logic (1672); *The History of Britain* (1670); *Paradise Regained* and *Samson Agonistes* (1671); the second, enlarged edition of the *Poems* of 1645 (1673); the second, revised edition of *Paradise Lost* (1674); and *Epistolae Familiares* with the *Prolusiones Oratoriae* (1674). *A Brief History of Moscovia* appeared in 1682. A Latin dictionary on which Milton had long worked was completed by others and published in 1693. Edward Phillips translated *Letters of State* (1694). Milton's great epic poems were, of course, composed in his head, especially at night, as famous allusions in *Paradise Lost* indicate; when he was ready "to be milked," he would dictate, often with one leg flung over the arm of his chair. The taking of dictation, the correcting of copy, and reading aloud in various languages were services performed by paid assistants, his two nephews, his younger daughters, and friends and disciples.

In religion Milton had moved from the low-church Anglicanism of his parents to Presbyterianism to Independency to independence. In the latter part of his life, according to his early biographer John Toland, "he was not a professed member of any particular sect among Christians, he frequented none of their assemblies, nor made use of their peculiar rites in his family." But, as Samuel Johnson observed, "his studies and meditations were an habitual prayer." Milton died on Nov. 8, 1674, "of the gout stuck in," just before his 66th birthday. His burial in the churchyard of St. Giles, Crippiegate, was attended by "all his learned and great friends in London, not without a friendly concourse of the vulgar."

Reputation. Milton's reputation grew steadily after 1667 and was well established before Joseph Addison's papers on *Paradise Lost* appeared in *The Spectator* (1712); these were instrumental in extending the poet's fame to the Continent. His influence on 18th-century verse was immense. In the 19th century two main streams of critical opinion are evident. On the one hand, the revolutionary Romantic poets William Blake and Percy Bysshe Shelley launched the "Satanist" misinterpretation of *Paradise Lost* and made its author, like themselves, a rebel; their attitude is summed up in Blake's saying that Milton was of the devil's party without knowing it (in other words, that he had projected himself into Satan, who was the poem's real hero). On the other hand, other critics—also concentrating on the epic—threw overboard Milton's beliefs and ideas as long-dead fundamentalism and attended to the poem's purely literary qualities.

The poet's influence waned during the Victorian age, and in the 20th century the new poetry and criticism launched by Ezra Pound and T.S. Eliot were strongly anti-Milton and pro-John Donne. But during the 1940s and '50s a shift in critical attitudes took place, and dozens of books and hundreds of articles were given to the ideas and beliefs of the thinker, the publicist, and the poet and brought a new refinement of perception and analysis to the aesthetic study of Milton's poetry. By the second half of the 20th century his works had regained their place in the canon of Western literature.

MAJOR WORKS

Poems. *A Maske Presented at Ludlow Castle, 1634* [*Comus*], in an enlarged text, and "Lycidas" (1638) were both reprinted in *Poems* (1645), which included nearly all the other early pieces, "L'Allegro," "Il Penseroso," etc. The second edition (1673) reprinted the 1645 *Poems,* adding two early pieces and later sonnets; four sonnets were excluded for political reasons, since they were addressed to Sir Thomas Fairfax, Cromwell, Sir Henry Vane, and Skinner (the one beginning "Cyriack, this three years' day"). *Paradise Lost,* in 10 books, appeared in 1667 (revised in 12 books, 1674); *Paradise Regained* and *Samson Agonistes* were printed together in 1671.

Prose. *Of Reformation Touching Church Discipline in England* (1641); *The Reason of Church-Government Urg'd Against Prelaty* (1642); *An Apology Against a Pamphlet Call'd A Modest Confutation of the Animadversions upon a Remonstrant Against Smectymnuus* (1642); *The Doctrine and Discipline of Divorce* (1643, enlarged 1644); *Of Education* (1644); *Areopagitica* (1644); *The Tenure of Kings and Magistrates* (1649); *Eikonoklastes* (1649); *A Treatise of Civil Power in Ecclesiastical Causes* (1659); *Considerations Touching the Likeliest Means to Remove Hirelings out of the Church* (1659); *The Readie and Easie Way to Establish a Free Commonwealth* (1660); *The History of Britain* (1670); *Of True Religion, Haeresie, Schism, Toleration, and What Best Means May Be Us'd Against the Growth of Popery* (1673); *A Brief History of Moscovia* (1682).

Works in Latin, Greek, and Italian. *Poems:* The volume entitled *Poems* (1645) contained three Greek pieces and five Italian sonnets and a canzone. Most of the notable Latin poems are mentioned above; one other, "Elegy V" ("On the Coming of Spring"), was a fervently "pagan" celebration of awakening life and sexuality.

Prose: The seven Latin speeches delivered at Cambridge and Latin letters to friends (published 1674); *Pro Populo Anglicano Defensio* (1651); *Pro Populo Anglicano Defensio Secunda* (1654); *Pro Se Defensio* (1655); *De Doctrina Christiana* (published 1825).

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8 vol. (1953–82), includes translations of the Latin works and elaborate commentaries. J. MAX PATRICK (ed.), *The Prose of John Milton* (1967), contains annotated selections. Annotated editions of the complete poems are HELEN DARBISHIRE (ed.), *The Poetical Works of John Milton*, 2 vol. (1952–55, reissued as *Poetical Works*, 1966), with mainly textual notes; DOUGLAS BUSH (ed.), *Complete Poetical Works* (1965); JOHN CAREY and ALASTAIR FOWLER (eds.), *The Poems of John Milton* (1968); and JOHN T. SHAWCROSS (compiler), *The Complete Poetry of John Milton*, rev. ed. (1971).

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On the poems: MERRITT Y. HUGHES (ed.), *A Variorum Commentary on the Poems of John Milton* (1970–), is a multivolume work with introductions, notes, and interpretive criticism. Studies of major poems, early and late, include MARJORIE HOPE NICOLSON, *John Milton: A Reader's Guide to His Poetry* (1963, reissued 1983); JOHN REESING, *Milton's Poetic Art* (1968); BALACHANDRA RAJAN, *The Lofty Rhyme* (1970); and DON CAMERON ALLEN, *The Harmonious Vision*, enlarged ed. (1970). Studies of *Comus* are ALAN RUDRUM, *A Critical Commentary on Milton's Comus and Shorter Poems* (1967); ANGUS FLETCHER, *The Transcendental Masque* (1971); and JOHN S. DIEKHOFF (ed.), *A Maske at Ludlow: Essays on Milton's Comus* (1968). Useful anthologies of essays on three of the early poems are ELAINE B. SAFER and THOMAS L. ERSKINE (eds.), *L'Allegro and Il Penseroso* (1970); and C.A. PATRIDES (ed.), *Milton's Lycidas: The Tradition and the Poem*, new and rev. ed. (1983). The sonnets have been collected in JOHN S. SMART (ed.), *The Sonnets of Milton* (1921, reprinted 1966); and in E.A.J. HONIGMANN (ed.), *Milton's Sonnets* (1966), both of which also provide commentaries.

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Mimicry

Mimicry is a biologic phenomenon characterized by the superficial resemblance of two or more organisms that are not closely related taxonomically. This resemblance confers an advantage—such as protection from predation—upon one or both organisms through some form of "information flow" that passes between the organisms and the animate agent of selection. The agent of selection (which may be, for example, a predator, a symbiont, or the host of a parasite, depending on the type of mimicry encountered) interacts directly with the similar organisms and is deceived by their similarity. This type of natural selection distinguishes mimicry from other types of convergent resemblance that result from the action of other forces of natural selection (*e.g.*, temperature, food habits) on unrelated organisms.

In the most studied mimetic relationships the advantage is one-sided, one species (the mimic) gaining advantage from a resemblance to the other (the model). Since the discovery of mimicry in butterflies in the mid-19th century, a great many plants and animals have been found to be mimetic. In many cases the organisms involved belong to the same class, order, or even family, but numerous instances are known of plants mimicking animals and vice versa. Although the best-known examples of mimicry involve similarity of appearance, investigations have disclosed fascinating cases in which the resemblance involves sound, smell, behaviour, and even biochemistry.

A key element in virtually every mimetic situation is deception by the mimic, perpetrated upon a third party, which mistakes the mimic for the model. This third party may be the collective potential predators upon the mimic, potential prey of a predacious mimic, or even one sex of the mimic's own species. In some cases, such as host mimicry by parasites, the organism deceived is the model.

Because of the variety of situations in which mimicry occurs, a formal definition must rest upon the effect of certain key communicative signals upon the appropriate receiver and the resultant evolutionary effect upon the emitters of the signals. Mimicry may be defined as a situation in which virtually identical signals, emitted by two different organisms, have in common at least one receiver that reacts in the same manner to both signals because it is advantageous to react in that manner to one of them (that of the model), although it may be disadvantageous to react thus to the counterfeit signal.

The distinction between camouflage and mimicry is not always clear when only the model and the mimic are at hand. When the receiver is known and its reactions understood, however, the distinction is quite clear: in mimicry the signals have a special significance for the receiver and for the sender, which has evolved the signals in order to be perceived by the receiver; in camouflage the sender seeks to avoid detection by the receiver through imitation of what is neutral background to the receiver. For information on camouflage, see COLORATION, BIOLOGICAL.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, section 312.

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BASIC TYPES OF MIMICRY

Batesian mimicry. In 1862 the English naturalist Henry W. Bates published an explanation for unexpected similarities in appearance between certain Brazilian forest butterflies of two distinct families. Members of one family, the Heliconiidae, are unpalatable to birds and are conspicuously coloured; members of the other family, the Pieridae, are edible to predators. Bates concluded that the conspicuous coloration of the inedible species must serve as a warning for predators that had learned of their inedibility through experience. The deceptively similar colour patterns of the edible species would provide protection from the same predators. This form of mimicry, in which a defenseless organism bears a close resemblance to a noxious and conspicuous one, is called Batesian, in honour of its discoverer.

Müllerian mimicry. Bates observed, but could not explain, a resemblance among several unrelated butterflies, all of which were known to be inedible. There seemed to be no reason for these species, each of which had an ample defense with which to back up the warning coloration, to be similar. In 1878 Fritz Müller, a German zoologist, suggested that an explanation for this so-called Bates's paradox might lie in the advantage to one inedible species in having a predator learn from another. Once the predator has learned to avoid the particular colour pattern with which it had its initial contact, it would then avoid all other similarly patterned species, edible and inedible. The initial learning experience of the predator often results in death or damage to the inedible individual that provided the lesson; there is thus some cost to the species that teaches the predator of its inedibility. Evidence indicates that there is little or no inherited recognition by certain predators; each individual learns of noxious or inedible species by sampling them. Other inedible species resembling the first, however, do not have to sacrifice individuals to teach this same predator, and the number of individuals sacrificed in educating the entire predator population is spread over all of the species sharing the same warning pattern. The tendency of inedible or noxious species to resemble each other is called Müllerian mimicry.

Edible and inedible butterflies

Aggressive mimicry. In some situations it is of advantage to a predator to resemble its prey, or a parasite its host. Aggressive mimicry, for which the phrase "a wolf in sheep's clothing" is an apt description, does not involve warning mechanisms. The mimic adopts certain of the recognition marks of its model in order to secure advantage over the model itself or over a third species that interacts with the model. The model may be mimicked during only a single stage of the life cycle, as in the case

of parasitic cuckoos, the eggs of which resemble those of their hosts (see below *The occurrence of mimicry among plants and animals*), or the model may be a prey of the mimic's victim, as in the case of angler fishes, which possess rodlike spines tipped with a fleshy "bait" to lure other fishes within reach.

Automimicry. The phenomenon of automimicry involves the advantage gained by some members of a species from its resemblance to others of the same species. Males of many bees and wasps, although defenseless, are protected from predators by their resemblance to females that are equipped with stingers. Some butterflies are able to gain protection against predators through the ability to absorb, tolerate, and retain in the immature (larval) stage, poisons from the plants on which they feed. Individuals or even subpopulations of such butterflies may fail to acquire such protection, as a result of feeding on nonpoisonous plants, but they are avoided by predators that have sampled protected individuals of the same species.

Other forms. Many forms of mimicry do not fit neatly into any of the above categories. The roles of mimic, model, and receiver may be juxtaposed and multiplied to provide intricate and remarkable relationships, the unraveling of which may take years of study. One such case involves the South American coral snakes (*Micrurus*), long recognized as dangerously poisonous—which possess a brilliant red, black, and yellow ringed pattern—and several genera of nonpoisonous and mildly poisonous "false coral snakes" with nearly identical colour patterns.

Coral snake mimicry

WARNING SYSTEMS

The chemical basis for repulsion. Many plants are characterized by the production of large amounts of metabolic end products, often called secondary metabolites—complex chemicals that include alkaloids, terpenes, phenylpropanes, resins, lignins, saponins, flavonols, and anthocyanins—stored in the plant tissues. Many such substances are also found in animals that feed upon such plants. Some animals produce substances similar to the secondary metabolites of plants; they store these substances in glandular pockets (as in toads, salamanders, and some insects) or in musk glands (as in beavers and muskrats). Arthropods, particularly insects, are notable for the production of excretory substances that serve as means of defense. Millipedes of the family Glomeridae, for example, secrete a bitter substance (a quinazoline) that repels birds; similar substances, differing only slightly in molecular structure, are found in palms. The fact that a certain chemical substance is restricted to a specific function, such as sex attraction, does not necessarily mean that it was evolved solely for that purpose. It seems rather that natural selection follows the easiest course and makes use of substances already present, and sometimes widely distributed. If so, the appearance of such substances in other organisms is not too surprising.

Protective secretions

Among the chemical compounds that protect certain plants from insects or other animals that might feed on them are the cardenolides, or cardiac glycosides. These substances have a highly specific toxic effect on the vertebrate heart and also activate the nerve centre in the brain that causes vomiting. Because the amount necessary to cause vomiting is about half the amount necessary to cause death through heart failure, an animal that samples a plant containing cardenolides is not killed but survives with the knowledge that the plant is inedible. Certain milkweeds (*Asclepias*) that contain cardenolides are the primary food of the larvae of danaine butterflies, including the familiar monarch and queen butterflies (*Danaus plexippus* and *D. gilippus*). The larvae consume the poison without ill effects and retain it through the pupal stage to adulthood. As adult butterflies, they enjoy protection from vertebrate predators.

There is, of course, no such thing as complete protection. Just as danaine larvae are able to eat the protected milkweeds, some predators are able to prey upon the protected butterflies. Birds of the Old World bee eater family (Meropidae) and a few other birds are able to eat bees because the horny beak protects them from being stung while the insect is being killed and because they have evolved behavioral mechanisms for removing the stinger (usually by wiping the insect on a perch) before swallowing the prey. Rabbits are able to eat the extremely poisonous mushrooms of the genus *Amanita* without ill effects. The larvae of the Florida feather moth (*Trichoptilus parvulus*) consume the insect-trapping glands on the leaves of the sundew (*Drosera*).

The evolution of warning systems. *The selective advantage of warning.* When an organism possesses a mechanism that provides protection from predators, there is a further advantage in preventing the potential predator from even sampling the protected organism. By the act of learning of the danger, the predator may well kill or maim the individual if, for instance, the protected species must be tasted for its inedibility to become known. Many protected insects are provided with tougher skins than their unprotected relatives, but the sampling by a vertebrate predator is almost sure to do some damage. Many noxious organisms have evolved warning (aposematic) mechanisms that serve to identify them clearly to a predator who has had prior experience with the same or similar species.

Types of warning systems

Warning systems often rely primarily on bright colours, but these may be supplemented by olfactory, acoustic, or behavioral means. The New World skunks, for example, have a prominent black and white pattern that renders them clearly recognizable to potential nocturnal predators. When threatened, skunks perform a highly stylized display dance, thus ensuring that the predator will see and recognize the warning coloration.

Acoustic warning signals are often favoured over visual ones because they allow the animal the option of remaining hidden. The rattlesnakes (*Crotalus* and relatives), which need protective coloration to avoid alerting their prey, are able to provide acoustic warning to large animals that threaten them. Many moths of the families Arctiidae and Ctenuchidae are foul-tasting but would be vulnerable to nocturnal predation by bats were it not for the emission of a series of high-pitched clicks, audible to bats, made when the moths hear the bats' own ultrasonic navigational pulses. That the moth clicks actually do serve as warnings is borne out by the fact that captive bats ignore thrown mealworms (which they normally eat) when the mealworms are accompanied by recorded moth clicks. Several species of edible moths also produce clicks and may be regarded as Batesian mimics of the unpalatable species.

The role of the receiver. In some cases, the animal who serves as the receiver of the warning signal reacts by means of an innate system that exists independently of experience. Generally, however, a predator must learn the significance of the warning signal through experience. If the predator is a slow learner, or if the warning signal is not sufficiently distinct to avoid confusion with beneficial sensory impressions that the predator receives, several experiences may be necessary. Natural selection, therefore, will favour warning systems that are devoid of ambiguity. Experimentation has shown that certain birds and mammals, at least, are capable of acquiring and retaining knowledge of some aposematic mechanisms from a single experience.

Combination of warning systems with concealing coloration. It is of obvious advantage for an aposematic organism to be able to control the display of the warning system, partly to minimize the amount of sampling, with its concomitant liability of injury, by naive receivers. Acoustic and chemical warning systems allow this. Many protected animals are coloured to match their backgrounds but provided with flash areas of warning coloration. Examples of these organisms are the tiger moths (certain of the Arctiidae), in which the hind wings are yellow or orange but are kept under the streaked brown forewings until the moth is molested..

THE OCCURRENCE OF MIMICRY AMONG PLANTS AND ANIMALS

Batesian mimicry. The stinging Hymenoptera (particularly the bees, wasps, and hornets), well protected from most predators and usually equipped with conspicuous warning coloration, are mimicked by insects of many other orders. Ladybird beetles (Coccinellidae) and leaf bee-

tles (Chrysomelidae) are inedible and are provided with prominent colours and usually with contrasting spots. A whole group of Philippine roaches of the genus *Prosoplecta* mimics these beetles, having undergone profound modification to achieve the similarity. To simulate the short, rounded form of the ladybirds, the large hind wings of the roaches are rolled and folded in a manner unparalleled in other insects.

The order Lepidoptera abounds with Batesian mimics, the best known of which is a swallowtail butterfly, *Papilio dardanus,* a widespread African species. In many populations of this species the females are polymorphic; *i.e.,* a number of different types (morphs) of coloration are found, with each morph a mimic of a species of inedible butterfly of another genus (either *Danaus* or *Amauris*). In all populations, the males are nonmimetic, retaining the same yellow and black pattern throughout. The presence of polymorphism, coupled with the ability of the lepidopterist to breed and rear this species in the laboratory, makes this an apt species for the study of colour inheritance. Investigators have found that mimicry in *P. dardanus* depends upon the action of certain primary genes, the expression of which is switched on or off by modifier genes. The modifier genes reduce the number of possible morphs to the restricted number of mimetic forms. The effects of modifier genes are not carried to the offspring when members of different geographic races are crossed. This finding suggests that each set of modifier genes is adapted to the gene complex in which it normally occurs and in which it probably evolved.

Müllerian mimicry. Müllerian mimicry often occurs in groups of unrelated species, all noxious or inedible and all possessing the same conspicuous warning coloration.

Mimicry rings

Such groups, called mimicry rings, often have associated Batesian mimics. It is not always easy to evaluate the palatability of members of such rings, and thus to distinguish Müllerian from Batesian mimics. Parallel Müllerian mimicry rings are known from South Africa, Borneo, and the tropical Americas; each contains such unrelated insects as malacodermoid and longicorn beetles, butterflies, true bugs, and spider wasps. In South America inedible butterflies of many distinct nymphalid subfamilies (Danainae, Ithomiinae, Acraeinae, and Heliconiinae) share the same warning coloration. Certain species show a highly perplexing divergence from the usual mimicry principles, however. It is axiomatic that maximum protection is gained by Müllerian mimics when all individuals employ the same signal, a principle known as signal standardization. Two species of *Heliconius* (*H. melpomene* and *H. erato*) are polymorphic, however, with each morph in one species duplicated by one in the other and with the morphs of each pair having virtually contiguous geographic ranges. Ecological and genetic evidence indicates that the racial divergence within these species was produced by differences in the abundance (or degree of protection) of different mimicry rings in different refuges, as have lasted for several thousand years, with the species coming to mimic whichever abundant, protected species was within reach by a single mutation.

Aggressive mimicry. Examples of aggressive mimicry are abundant and varied; each demonstrates its own particular variation of basic mimicry principles. The examples cited below illustrate a few of the remarkable extremes in the evolution of mimicry.

Mimicry in the fluke

Parasitic worms. The flukes (Trematoda) are a class of parasitic worms belonging to the phylum Platyhelminthes. One species, *Leucochloridium macrostomum,* resides principally in the intestine of songbirds. The eggs of the parasite pass to the outside in the feces of the birds and are readily ingested by a terrestrial snail, *Succinea,* an inhabitant of waterlogged meadows and riverbanks. The parasite eggs hatch into the first larval form within the snail. The next stage, called the sporocyst, is strikingly green in colour and bears yellow-brown rings. The sporocyst develops in the snail tissues and carries several sacs of "spores," one of which is placed into each of the snail's tentacles, or eyestalks. The sac then begins to pulsate violently, at about 40 to 70 beats per minute. The tentacle of the snail becomes greatly enlarged and eventually is transformed into a transparent covering over the pulsating sporocyst. *Succinea* usually avoids light, but specimens with this parasite do not. When the snail appears with its conspicuous, pulsing eyestalks, birds mistake the eyestalks for insect larvae, bite them off, and eat them. Within the bird, the sporocyst then hatches into the final larval stage, which grows into an adult worm. In the meantime the snail's eyestalk regenerates, and the cycle is repeated when another sac passes into the new eyestalks. Because the sporocysts of other trematodes are neither brightly coloured nor mobile, it can be concluded that the colour and pulsation of *Leucochloridium* are adaptations for arousing the interest of the insectivorous birds. Under normal circumstances the host birds do not eat snails, so the sporocyst must imitate the bird's proper food in order to be eaten and to complete its life cycle in the bird host. The process represents an unusual case of aggressive mimicry, for the parasite manipulates its hosts and causes the bird to infect itself with the parasite.

Another trematode, *Cercaria mirabilis,* is notable for its unusually large larvae form, called a cercaria. The size of this cercaria and its hopping mode of locomotion cause it to resemble a small, swimming crustacean or mosquito larva, with the result that fish mistake it for food and swallow it. Research on parasites of this kind is much easier when it is recognized that the larval stages often mimic the food of their respective hosts. Examination of the parasite often provides a suggestion as to the probable host.

Insect-luring plants. Newly hatched flesh flies (*Sarcophaga*), blowflies (*Calliphora*), and greenbottle flies (*Lucilia*) are attracted to glistening droplets or imitations of droplets. The grass of parnassus (*Parnassia palustris*) has flowers with five nectar petals, which bear glistening buttons but no nectar. They attract flies, nevertheless, and reward them with nectar in two depressions on the upper surfaces of the petals. The insectivorous sundew (*Drosera*), on the other hand, presents a deceptive lure, consisting of glistening secretory droplets on the glandular leaves, which trap insects that are then dissolved with digestive juices.

Pitcher plants

The pitcher plants (*Nepenthes, Darlingtonia, Sarracenia, Cephalotus*) have juglike leaves, which may bear flowerlike markings near their openings. Some have a flap or hood that enhances the resemblance to a flower and prevents filling with rainwater. One form, *Nepenthes,* secretes nectar at the lip of the pitcher. A foraging insect landing on this apparent flower slips on the edge and falls in. A band of gland cells below the slippery region secretes an enzyme that digests protein. The lower part of the pitcher contains a watery mixture of digestive fluids.

The cleaner mimic. One of the few cases of mimicry reported among vertebrates is that of a so-called cleaner fish. This example involves a particularly close model imitation involving shape, coloration, and behaviour. The

The wrasse model

model, a wrasse (*Labroides dimidiatus*) of the Indo-Pacific Ocean, is known as a cleaner fish because it removes and eats externally attached parasites and, occasionally, damaged skin fragments from other marine fish. It occupies specific sites, or territories, on coral reefs, where, within a six-hour period, the individual cleaner may be visited by up to 300 other fish seeking its services. The other fish are attracted by the conspicuous black and white coloration of the cleaner and by its dancelike swimming pattern, in which the tail fin is spread and the posterior part of the fish oscillates up and down. The fish undergoing cleaning acts as though it were in a trance, while the cleaner fish cleans its body, including the inside of the mouth and gills. Even large predatory fish allow themselves to be cleaned, and the much smaller cleaner almost invariably emerges uninjured from their throats. It is quite apparent that the cleaners are protected from these predators although neither inedible nor capable of self-defense.

At the cleaning stations of the cleaner fish, there is often found quite another fish, the sabre-toothed blenny (*Aspidontus taeniatus*). It is similar to the cleaner fish in size, coloration, and swimming behaviour, and it even exhibits the same dance as the cleaner. Fish that have had experience with the cleaner position themselves unsuspectingly in front of this mimic, which approaches carefully and bites off a semicircular piece of fin from the victim and

Müllerian and other forms of mimicry



The odour of the pelican flower *Aristolochia grandiflora* attracts small flies that act as pollinating agents when they become trapped temporarily at the bottom of the flower.



The labellum (lip) of the flower of the orchid *Ophrys apifera* imitates a female bee; males attempting to copulate with the flower act as pollinators.



Mimicry in coral snakes and similar forms. (Left) venomous Eastern coral snake *Micrurus fulvius*; (centre) harmless king snake *Lampropeltis polyzona*; (right) moderately venomous rear-fanged false coral snake *Erythrolamprus aesculapii*.

Müllerian mimicry in unpalatable New World tropical butterflies.

Melinaea othra (family Ithomiidae)



Mechanitis lysimnia (family Ithomiidae)



Lycorea halia (family Danaidae)



Heliconius narcaea (family Heliconiidae)



Painting by C. Olsen



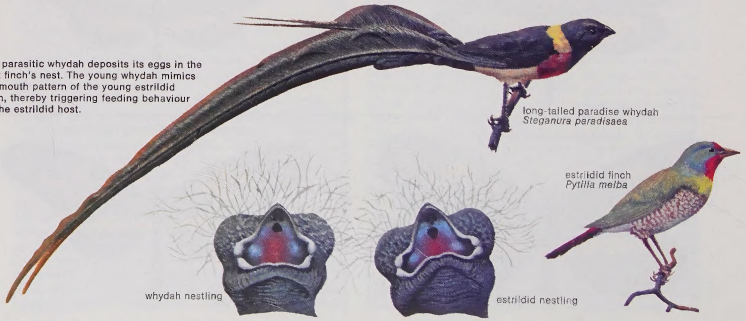
The zone-tailed hawk is able to surprise its prey because of its resemblance in appearance and flight pattern to the carrion-feeding turkey vulture.

Aggressive mimicry in birds

Superficial resemblances of cuckoos to the sparrowhawk and shikra frighten other birds from their nests, allowing the cuckoos to deposit their eggs in them.



The parasitic whydah deposits its eggs in the host finch's nest. The young whydah mimics the mouth pattern of the young estrildid finch, thereby triggering feeding behaviour by the estrildid host.



Painting by C. Olsen based on (*Steganura paradisaea*, *Pytilia melba*, nestlings) W. Wickler, *Mimicry in Plants and Animals* (© 1968), used with permission of McGraw-Hill Book Company.

eats it. After having been repeatedly bitten in this way, fish become distrustful even toward genuine cleaners. Observations in the wild indicate that younger fish are the principal victims of the mimic, whereas older fish avoid it whenever possible. It is unlikely that the ability to discriminate between the mimic and the model develops automatically with age and is independent of experience; this is borne out by the finding that adult fish kept in an aquarium and not previously exposed to the mimic confuse cleaner and mimic just as younger fish do. If such adult fish are kept with the mimics for a certain length of time, however, they eventually avoid these and the genuine cleaners. The obvious conclusion from these experiments is that other fish cannot distinguish between the model and the mimic without having had experience with both. Evidently victims of the mimic seek out and learn characteristics that enable them to distinguish between reliable and unreliable cleaners—that is, between the model and mimic, respectively. The most successful individuals among the mimics, therefore, are those that most confuse their victims. As a result, the further development of the mimic is steered in the direction determined by the characteristics of the cleaner; for example, the model occurs as a number of local races within its area of distribution, each of which shows its own peculiarities in coloration, such as a small or large black vertical stripe at the base of the pectoral fins or an orange-red spot on the flanks. In every case, the local population of the mimic shows the same special coloration as does the model in that particular area (see Figure 1).

From W. Wickler, *Mimicry in Plants and Animals* (© 1968); used by permission of McGraw-Hill Book Co., Inc.

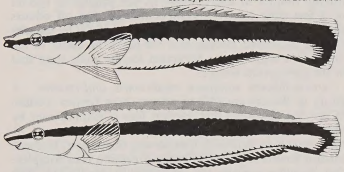


Figure 1: Differences and similarities between (top) the cleaner wrasse (*Labroides dimidiatus*) and (bottom) its mimic, the sabre-toothed blenny (*Aspidontus taeniatus*).

One of the interesting and highly unusual aspects of the cleaner–mimic relationship is that the individual characters of the mimicry pattern, especially the behavioral ones, have been traced to their origins. Certain characteristics, such as body size and shape and swimming pattern, amount to chance similarities. The mimic's drive to approach other fish, for example, is a specialization of a more general pattern, observable in non-mimicking relatives of the blenny, involving searching for food on suitable surfaces. The basic colour pattern of light and dark horizontal stripes is characteristic of fish that swim in open water, but the actual coloration of the mimicking blenny, owing to the forces of natural selection, bears a close resemblance to the cleaner wrasse. Interestingly enough, the blenny alters its coloration with its motivational state and adopts the appearance of the cleaner only under the specific conditions of self-confidence and intent to attack. As a group, blennies tend to wriggle while swimming, in order to counteract a strong tendency to sink at the tail. The sabre-toothed blenny, however, when confronted with danger holds the body stiffly without wriggling, allowing the hindquarters to sink somewhat, and advances solely by the use of the pectoral fins, in the manner common to wrasses. Superimposed on this motion is a nodding of the blenny's head, which is typical of approach-retreat conflict behaviour in blennies but which results in a simulation of the swaying dance of the cleaner. The combination of coloration and behavioral signals has a particular significance for the experienced visitor to the cleaner's station and causes it to adopt the posture that invites cleaning. In so doing, the visitor gives the mimic an opportunity to take a bite from a fin.

Behaviour mimicry

Fireflies. A form of aggressive mimicry that relies entirely on behaviour occurs in certain North American fireflies (Lampyridae). Males of these familiar nightflying beetles emit light bursts in flight according to highly specific patterns. The females, usually stationary, respond to the flash patterns of males of their own species with specific patterns of their own. The flying male responds to the appropriate female signal by approaching, landing, and courting. Most adult fireflies are short-lived and do not feed at all, but females of the genus *Photuris* have been found to feed on other beetles, including males of the genus *Photinus.* Upon perceiving a flashing male *Photinus,* the female *Photuris* responds with a flash that mimics the slower response time of the female *Photinus* (Figure 2). As the male *Photinus* approaches, the female *Photuris* even reduces the intensity of her flashes, to resemble more closely the weaker signals of the smaller female *Photinus.* The hapless male, after landing, is seized and eaten by the *Photuris.* In response to males of her own species, of course, the female *Photuris* gives a flash response quite different from that of *Photinus.*

Host mimicry by parasites. Another form of mimicry, sometimes considered an extension of aggressive mimicry, is mimicry of a host by its parasite. Most of the best-known examples occur among birds and represent some of the few known instances of mimicry in that class of animals.

Cuckoos. The European cuckoo (*Cuculus canorus*) is a brood parasite; *i.e.,* it lays its eggs in the nests of other birds, which act as foster parents for the young cuckoos. The most frequent foster parents are various species of small songbirds. Although the eggs of the various host species span a great range of colours and spotting, there is a striking correspondence in appearance between the eggs of the cuckoo and those of the host. Most small birds react unfavourably if they perceive a foreign egg in the nest and either abandon the nest, build another nest right over the first, or eject the strange egg. Each female cuckoo consistently lays eggs of one colour pattern and must therefore parasitize a particular host species. One survey has shown that of 1,642 cuckoo eggs laid in the nests of the correct (matching) hosts, only 8 percent were lost, whereas of 298 in the nests of the wrong hosts, 24 percent were lost. It is logical to conclude, therefore, that a cuckoo that lays its egg randomly, leaving the survival of the eggs to chance, would produce fewer offspring than one that selects hosts whose eggs match her own. Although the control of egg coloration is probably genetically determined, the choice of correct hosts is believed to be the result of a learning

Egg matching by cuckoos

By courtesy of James E. Lloyd

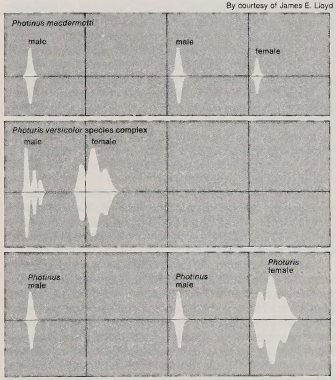


Figure 2: Comparative pulse rates of two genera of fireflies, *Photinus* and *Photuris,* showing (bottom) the deceptive response of *Photuris* female to *Photinus* male.

process that takes place when the female cuckoo is a nestling and learns to recognize her own foster parents.

Parasitic weaverbirds. Brood parasitism is also found in African whydahs, or widow birds, of the subfamily Viduinae of the weaverbird family, Ploceidae. Each species of whydah parasitizes a single species of estrildid finch (Estrildidae). In this case, egg colour does not seem to be a factor in acceptance of the parasite's egg, because both groups have pure white eggs. It has been argued that the whydah, many relatives of which have spotted eggs, have evolved white eggs in order to match those of their estrildid hosts.

More significant than the mimicry of egg colour, however, is the highly specific pattern of spots and protuberances at the corners of the mouth (gape) and on the palate, tongue, and lower mandible of the nestling. This pattern, which varies from one species of finch to another, serves as a releaser for feeding behaviour on the part of the parents, which ignore any nestling that does not display the proper pattern for the particular species. In every species of parasitic weaverbird studied, the nestling has been found to match perfectly the mouth pattern of the estrildid host. In addition to mimicking the mouth patterns of their hosts, whydah nestlings also duplicate the specific begging calls and peculiar head movements of their hosts. The coloration of the juvenile plumage of the young whydah is identical to that of the host species, ensuring that the whydah will be fed after fledging. The digestive system of the young whydah is closely adapted to the particular type of food utilized by its host species, unlike that of the young cuckoo, which seems to be able to accept a variety of foods, from insects to mouse meat.

Mimicry of mouth patterns

With each species of parasitic weaverbird closely committed to a single species of estrildid finch, it is obviously important that whydah species not hybridize, for the hybrid offspring would certainly not match either possible host in all of the important features. It is surprising to find seven forms of the paradise whydah (*Steganura*) so similar in appearance that they were once considered races of one species. Each of the seven, however, has its own estrildid host species, indicating that seven species of paradise whydah are represented.

As is frequently the case with closely similar bird species, hybridization is effectively prevented through the use of species-specific vocalizations by the males. An unusual feature of this situation is that each whydah species uses the same vocal pattern as its estrildine host. The young parasitic weaverbirds learn the songs of their host species during the critical learning period common to songbirds generally. As adults, the male whydahs use these estrildid vocalizations and gain response only from females that have been reared by the same foster species. This example is the only known one of a species-isolating mechanism consisting of vocalizations learned from another species. Vocal imitations by some bird species that have not been shown to give rise to mimicry systems are nevertheless frequently called mimicry.

Mimicry to effect pollination and dispersal. In some instances, plants have been found to rely on mimicry to attract insects as aids in pollination or in the dissemination of seeds or spores.

Orchids. Many flowering plants lure insects through the use of bright colours that indicate the presence of nectar. Some orchids mimic other flowering plants without offering any nectar, relying on those that do provide nectar to reward the nectar seekers.

Flowers that resemble female insects

A group of orchids, often known by such descriptive names as fly orchid, bee orchid, and spider orchid, carries the deception further, actually mimicking the insects themselves. The best-known orchids of this type are members of the genus *Ophrys*. The labellum (lip) of the *Ophrys* flower is a specialized median petal that acts as a dummy female of a species of bee or wasp (depending on the species of *Ophrys*), the resemblance being so close that males visit the flower in an attempt to copulate with the dummy female. In the course of precopulatory and copulatory movements, the visiting insect acquires the pollen sacs (pollinia) of the orchid and subsequently transmits them to other blossoms. A similar situation occurs in an Australian orchid, *Cryptostylis leptochila,* which bears a sufficient resemblance to the female of the ichneumon wasp *Lissopimpla semipunctata* to induce copulation by the male wasp.

An important feature in the mimicry of female insects by orchids is flower size. Flowers that are too small do not provide adequate stimulus for the copulatory attempts necessary to plant the pollinia on the insect. Conversely, if the flower is too large for the insect, the insect's head does not reach the stigma of the flower (the female receptor site for pollen), and the pollinia are not deposited on the insect.

The colour of the orchid's labellum is also important in attracting and properly orienting the male insect. The males are more attracted to dark than to light colours and to a contrasting dark spot on a light background. A velvety surface is a more effective attractant than a shiny one. The centre of the labellum of *Ophrys insectifera* bears a dark red spot, almost black, whereas the lateral lobes of the labellum are a somewhat lighter purple-red. Female wasps of the genus *Gorytes,* males of which are highly attentive to this orchid, are black dorsally with dark purple wings. Where the folded wings overlap over the female's body, there is a glistening area closely resembling the shiny central spot on the flower. The overall effect is further enhanced by movements of the flower in the wind.

Flowers that emit pheromones

Odour plays a particularly strong role in attracting male insects to the mimicking orchids. Some female Hymenoptera secrete odoriferous substances (pheromones) that initiate search behaviour in the males and guide them to the stationary females. Such attractant chemicals are usually limited in effectiveness to the producing species or a few close relatives. *Ophrys* flowers give off odours similar to, if not identical with, those produced by females of their associated insects. In a few cases the odour of the flower is a more potent attractant for the male than that of the appropriate female.

Carrion flowers, stinkhorn mushrooms, and mosses. A group of flowers are able to attract dung beetles (certain of the Scarabaeidae) and carrion flies (Calliphoridae) by mimicking the odours of dung or rotting flesh used by these insects as guides to sites for egg deposition. In some carrion flowers (*e.g., Stapelia*) the deception is so complete that blowflies actually lay their eggs in the flowers. The cuckoopint (*Arum maculatum*), which has a metabolic level unequaled among plants, spreads its odour over a wide area by an elevation of temperature that increases the vaporization rate of the volatile odour substance. An elaborate mechanism in the cuckoopint ensures that a pollen-laden visitor remains long enough to deposit the pollen. The sheath of the floral structure, upon which the insect lands, is made slippery by oil droplets with the result that the insect slides down into a cup equipped with a ring of spines to prevent escape. In trying to climb out, the insect deposits pollen on the tiny female flowers, from which the insect receives nectar. During the night, the male flowers mature and cover the resting insect with pollen. Then the spines shrink, and the insect is released (Figure 3). The production of the attractant odour occurs at midday, when many carrion-seeking insects are active, on the day before the male flowers mature; the timing of the cuckoopint's odour production is controlled by a substance produced by the male flowers six to 18 hours before maturity.

The trap of the cuckoopint

A similar situation is found in stinkhorn mushrooms of the genus *Phallus,* found in woodlands and meadows of the Northern Hemisphere. The cap of the young stinkhorn is covered with a thick, greenish-black, shiny layer of gelatinous spore slime (gleba), which is eaten by blowflies and other insects attracted by the carrion-like odour. The spores pass through the digestive tracts of the insects and are voided with the feces, thus ensuring dispersal.

Some mosses (*e.g.,* some members of the genus *Splanchnum*) have flowerlike structures that are designed to attract flies to aid in spore dispersal. Insects are attracted by the mimic of a nectar-bearing true flower and by a carrion-like odour.

Defensive egg dummies. Several species of passionflower (*Passiflora*) and cruciferous plants (*Streptanthus*)

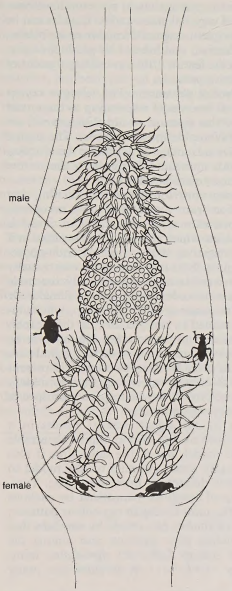


Figure 3: Flowers of the cuckoopint (*Arum maculatum*). The odour emitted by the flowers attracts insects that deposit pollen.

From W. Wickler, *Mimicry in Plants and Animals* (© 1968); used by permission of McGraw-Hill Book Co., Inc.

decrease their attractiveness to ovipositing female butterflies (thus reducing predation from butterfly larvae) by producing pigmented callosities that mimic the eggs of those insects. Prior to ovipositing, females visually assess the egg load on individual host plants, avoiding parts that are already "occupied." Removal of the egg mimics significantly increases the probability of an oviposition relative to similar, intact plants.

Mimicry within species. The three essential participants in mimicry—model, mimic, and receiver—need not always be members of different species. In mimicry of the host by a parasite, for instance, the host species provides both model and receiver. In another type of mimicry the mimic and receiver are members of the same species. An example of this type of mimicry is found in the small South American characoid fish *Corynopoma riisei,* in which the gill cover of the male is elongated into a thin, whitish stalk that terminates in a small, blackish plate. During courtship, the male raises the stalk and waves it jerkily in view of the female, who mistakes the tip of the stalk for an edible object, such as a tiny crustacean. As the female nears the male to grasp this supposed prey, mating takes place.

Egg mimicry in cichlid fishes

Another remarkable form of mimicry within the same species occurs in the African mouth-breeding cichlid fish of the genus *Haplochromis.* The female takes the eggs into her mouth immediately after they are laid, even before the male can fertilize them. The male, however, carries conspicuous yellow or orange spots near the base of the anal fin, which closely resemble the eggs of the particular species. Although the female is inhibited from eating while carrying eggs, she is strongly motivated to pick up loose eggs in her mouth. The male displays the fin spots to the female while releasing sperm; the female, as she attempts to pick up the false eggs, takes in sperm that fertilize the eggs in her mouth. In this case the model (real eggs), mimic (false eggs), and receiver (adult female) are all of the same species.

THE EVOLUTION OF MIMICRY

The effectiveness of warning systems. There is considerable experimental evidence to illustrate how effectively predators learn to avoid certain adverse stimuli. Chickens conditioned by electric shock to avoid drinking dark green water drank progressively more from paler solutions in proportion to the intensity of the colour. This experiment suggests that even an incomplete warning system provides a modicum of protection. The degree of protection provided is also affected by the strength of the punishment; after strong shocks the chickens drank only from very light coloured solutions. In the presence of severe punishment, an improved warning system made little additional effect once a threshold level was reached.

In other experiments, starlings (*Sturnus vulgaris*) were fed normal mealworms, two segments of which had been painted orange. To provide aposematic "models," the experimenter made other mealworms distasteful and painted the same segments green. "Mimics" were marked with green but not rendered unpalatable. There is no known instance in nature in which animals employ green for warning; there was therefore no possibility that the birds had already learned to avoid the experimental colour pattern. Before long the green-marked worms were completely avoided, regardless of palatability, even when the ratio of edible to distasteful was 60:40. This indicates that the number of mimics can exceed that of the model, when the resemblance is close, without loss of protection. When the ratio was increased to 90:10, 17 percent of the mimics were avoided, probably sufficient to a selective advantage in nature. Although a test bird would occasionally peck at a model, then reject it, the same action was sometimes shown to a mimic that it had picked up, suggesting that a premature response had been subsequently corrected.

The reconstruction of evolutionary pathways. Analysis and understanding of a given mimicry system require a rather comprehensive knowledge of morphology, behaviour, ecology, and mutual relationships of animals usually in different classes—for example, wasps (Hymenoptera), flies (Diptera), insect-eating amphibians, reptiles, birds, and small mammals. Tracing the evolution of such a complicated system requires a detailed acquaintance with a large group of forms related to each of the animals involved. Such data, in fact, are seldom available.

Reconstructing the evolution of a case of mimicry within the same species, however, is relatively simple, requiring detailed knowledge of but one rather narrow taxonomic unit. Such a reconstruction is valuable, because mimicry is an indispensable tool in the study of the evolution of animal communication, and usually starts from conspicuously elaborated signals, which postulate a signal receiver interested in them. The receiver practically always has undergone a special molding toward optimal receiving of the signal. The mutual adaptations of the sender and the receiver must be examined separately.

Mimicry and animal communication

This examination is easily made, so far as the evolution of a reaction or of a receiving mechanism is concerned, in all predators trying to find their prey and in all prey animals attempting to escape an approaching predator. The suppression of signals may be studied in predators trying to sneak up on a prey unnoticed. The elaboration of a signal, which must, of course, be important to the receiver, can only be studied after consideration of compensatory adaptations in the receiver and in situations where the sender has a one-sided interest in the signal. The deceiving signal can be derived only from one of two types: a signal developed by the receiver and another signal sender in their common interest or a signal emitted by another signal sender and made use of by the receiver only in its own interest. Both cases, by the definition given above, are called mimicry. An additional advantage is that the model is known to be the final stage toward which the mimic will evolve (so far as the signal characters are concerned),

thus indicating a trend in evolution that is still operating and that probably over time will further elaborate the mimetic signals.

If the female *Haplochromis* fish were to discriminate between real eggs and the egg dummies of the male and were to stop reacting toward the latter, her eggs would remain unfertilized. In such cases of deceptive signals developed within the same species, natural selection operates against better signal discrimination on the part of the signal receiver.

The importance of the signal receiver. Fundamental characteristics of mimicry are determined mainly by behavioral properties of the signal receiver. A precise knowledge of the identity of the receiver and a thorough study of its behaviour are therefore indispensable for the understanding of mimicry. Moreover, mimicry gradually merges into other sender–receiver systems. Palatability is a matter of degree; whole ranges of distastefulness therefore exist, even in the mimics, model and mimic in the case of Müllerian mimicry being equally unpalatable and sharing the same warning coloration. Müllerian mimicry could be considered not to be true mimicry, after all, because no one is deceived, and it is impossible to designate one as model and the other as mimic.

Although all individuals of a given wasp species look alike and are all equally protected, this phenomenon is not usually called Müllerian mimicry, simply because the signals were not independently evolved, a property known as convergence. Because, however, the male wasps have no protective properties but retain their group-specific warning coloration, this is Batesian mimicry, although model and mimic are of the same species and their signals homologous (evolved from the same source). Convergence (or independent evolution) of the signal characters, therefore, is essential only for the so-called Müllerian mimicry, and thus Müllerian mimicry is distinguished from other cases of signal standardization. The typical (Batesian) mimicry merges into Müllerian mimicry if the difference between the consequences for the receiver of reacting similarly to model and mimic diminishes; and by homology of the signal characters it further merges into general signal standardization.

Mimicry and mimesis

An insect may be protectively coloured to resemble, for example, a wasp or a twig. In the first case the coloration is called mimicry, in the second, mimesis, or protective coloration. The difference lies within the signal receiver. If the mimetic signal does not release any reaction in the receiver, the mimic is said to exhibit mimesis. This distinction is illustrated by the experiments of the Dutch biologist L. de Ruiter with stick caterpillars, which, by virtue of their close resemblance to twigs, are protected against insect-eating birds. As soon as the number of "twigs" becomes too large, however, the bird develops an interest in them, attacks some real twigs, and also finds some caterpillars. If one positive experience with the caterpillar has the same weight as a negative one with the twig (the signal remaining unchanged), the relative abundance of caterpillars and twigs determines whether all twigs are mistakenly exterminated or whether the feeding reaction toward twiglike objects disappears, thus protecting the caterpillars.

This study again illustrates the importance of the bird's ability to decide correctly which is the model and further shows how easily an object (the twig) may quite involuntarily become a "mimic." Another example illustrating the importance of a correct model is found in the common farming relationship between ants and aphids. The protuberances, called the siphones and cauda, on the abdomens of aphids resemble respectively the bases of the antennae and labium of the ant's head. The aphid's abdomen is thus mistaken by the ant for the head of a fellow ant, thereby eliciting the food-begging response, which is identical with milking. Saturated ants in turn even try to feed the abdomens of the aphids. Aphid species with reduced abdominal siphones use their hind legs as antennae dummies, the movements elicited being originally defensive movements. This situation is exactly the way in which mimicry arises. Mimetic characters need not have evolved under the selection pressure of mimicking; in fact, their earliest evolutionary stages could not even have been brought about in this way. All cases studied thus far can be traced back to an incipient stage of deceptive resemblance, initiated as a preadaptive, nondirected by-product of pre-existing species-specific features, thus providing a point of attack for new selective pressure.

The effects of selective pressure. The selective consequences for the signal receiver of responding to the model are always positive (the reaction would disappear if, on balance, it were unfavourable to the receiver). The mimic always has a selective advantage in releasing the reaction from the receiver. An unfavourable signal by the mimic would also disappear by natural selection.

The selective consequences of signaling by the model

The selective consequence for the model eliciting and obtaining the reaction from the receiver may be of several types. Consequences may be absent, if the model is an inanimate object on which natural selection does not act. They may be negative, if the model is non-aposematic (non-warning), such as the tiny crustacean, usually eaten by the signal receiver and mimicked by the male *Corynopoma* characin in order to attract the female. Or they may instead be positive, as in the wasp, which remains alive if it is avoided by the predator; in the cleaner, which feeds on parasites harmful to other fish; or in those hymenopteran females whose male-attracting signals are mimicked by certain orchids. Mutual interest is present between model and receiver in cases of aggressive mimicry where both parties belong to the same particular species and also in typical Batesian mimicry.

Constant learning by the signal receiver results in a strong selective pressure on the mimic against detectable differences from the model, but at the same time it also exerts a complementary strong pressure on the model to develop just such new differences from the mimic. Typically, it is the group of songbirds parasitized by cuckoos that has developed the most divergent egg-colour patterns; the group of estrildine finches parasitized by whydahs that has developed particular gape patterns; and among the cleaner wrasses the species *Labroides dimidiatus* mimicked by the blenny *Aspidontus* that develops into many different local races.

There is a boomerang effect, characteristic of the parasite–host relationship, that the more successfully a bird rears young cuckoos, the more certain it is that it will lose its own young, because they are killed off by the young cuckoo. Parasites that are too successful, therefore, harm themselves, for each female cuckoo needs several nests of the same host species for her eggs. In an area that contains particularly successful cuckoos, the number of reed warbler nests has been found to decrease from year to year, while the percentage of nests parasitized by cuckoos increases from year to year. This ratio means that a cuckoo that is too well adapted reduces the availability of its own hosts, while one insufficiently adapted kills off its own offspring. Presumably, selection in both directions produces a continual oscillation in the densities of hosts and cuckoos.

A similar dilemma is inflicted on human beings, who act as predators against weeds in crop fields and by winnowing select the wanted seeds from the usually smaller weed seeds. The flax dodder (*Cuscuta epilinum*), for example, which grows as a creeper around flax and linseed plants and damages them, originally had small seeds that could be easily separated from the larger flax seeds. By a mutation that produced twin seeds, the dodder has evolved the capability of being separated out and planted with the desirable flax seeds. This mutant of the flax dodder is now cultivated and spread by growers, despite being against their interests. In this case, the parasite mimics the protected plant, receiving the same protection.

The effects of geographic distribution and population density. It has been postulated that the model and the mimic should always occur in the same area—*i.e.*, be sympatric. They need not always be sympatric, however, but must always have a signal receiver in common: a model might be in Africa, for instance, and its mimic might be in Europe (or vice versa), functionally connected by a migratory bird.

Another postulate, that mimics must naturally be less

Relative populations of model and mimic

numerous than their models, means, correctly stated, that the receiver has to meet the mimic less often than the model; this postulate is based on the assumption that one experience with the model has the same aftereffect, the same weight, as has one with the mimic. This assumption, however, has been proved not always to be so; in fact, the negative experience seems usually to be the stronger one. This negative experience may result from an encounter with the model (such as a wasp) or with the mimic (for example, the sabre-toothed blenny). There might be more wasp mimics than wasps, but in cases such as that of the cleaner wrasse mimic, the mimic probably has to be less numerous than the model. The protective power of the model, of course, is reduced with an increasing number of mimics, because the predator may eat larger numbers of them before his first encounter with the model.

The importance of mimicry to evolutionary theory. The mimicry hypothesis emerged in the middle of the Darwinian controversy and provided an ideal test case for the views of Charles Darwin and his contemporary Alfred Russel Wallace on the operation of natural selection in the evolutionary change of living organisms. It is now quite evident that the basic theory of natural selection is correct and that the theory is strengthened by many detailed studies of the process by which a mimetic resemblance is brought about and selected for. In addition, investigating suitable cases of mimicry provides important insight into the evolution of signals and the "semantization" process by which signals get their meaning.

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(W.J.H.W.)

The Philosophy of Mind

One attribute that sharply distinguishes man from the rest of nature is his highly developed capacity for thought, feeling, and deliberate action. Here and there in other animals, rudiments, approximations, and limited elements of this capacity may occasionally be found; but the full-blown development that is called a mind is unmatched elsewhere in nature.

The task assumed by the discipline known as the philosophy of mind is to examine and analyze those concepts that involve the mind (including the very concept of the mind itself) in an attempt to discover the nature of each of these concepts, the relations between them, how they are to be classified, and how they are to be related to certain other concepts—especially to the concepts of matter and energy, the human body, and, in particular, the central nervous system.

It should be clear that the range of topics in the philosophy of mind goes far beyond what is intended in everyday discourse by "mind." When, for example, the layman speaks of someone as having "a good mind" or as pursuing "the pleasures of the mind," he is thinking of those particular activities that have to do with abstract reasoning, intellectual pursuits, and the exercise of intelligence. The "mind," as the term is used more technically in this article and in the philosophy of mind in general today, encompasses a variety of elements including sensation and sense perception, feeling and emotion, dreams, traits of character and personality, the unconscious, and the volitional aspects of human life, as well as the more narrowly intellectual phenomena, such as thought, memory, and belief.

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PHILOSOPHY OF MIND AS A DISCIPLINE

In distinguishing the field of philosophy of mind from other sorts of investigation, one immediately obvious feature is its subject matter, the nature of mind and its various manifestations. This serves to distinguish it from empirical sciences such as astronomy and physics, which study matter in motion; from formal disciplines such as geometry and algebra, which study mathematical relationships; and from other fields of philosophy such as the philosophy of art and the philosophy of law. But subject matter alone does not serve to distinguish the philosophy of mind, since the mind is the subject of investigation of other disciplines as well—especially of psychology and of certain phases of biology, physiology, sociology, and anthropology. In comparison with these fields, it is by its method that the philosophy of mind is to be distinguished; for it proceeds not by the methods of empirical investigation—detailed sense observation, the formulation of predictions, the construction of experiments, inductive confirmation, the inventing and testing of contingent generalizations, theories, and laws—but by the method of philosophical reflection. That method consists of the examination of meanings, the analysis and clarification of concepts, the search for necessary truths, the use of deductive inference, reductio ad absurdum, and arguments with infinitely repeating terms and other forms of a priori reasoning, and the attempt to arrive at and evaluate the fundamental principles that underlie and justify the basic forms of human thought and endeavour.

Relation to other fields

Although the philosophy of mind is a distinct field of investigation, it has many important relations with other fields. First, its methods, being those of philosophy in general, are to be tested by the fruits that they have yielded in other areas: if a method has been successful in other areas, it is reasonable to try it here; if unsuccessful in other areas, it is suspect here. Second, the conclusions achieved in such fields as epistemology, metaphysics, logic, ethics, and the philosophy of religion are quite relevant to the philosophy of mind; and its conclusions, in turn, have important implications for those fields. Moreover, this reciprocity applies as well to its relations to such empirical disciplines as neurology, psychology, sociology, and history. Thus, the philosopher of mind must keep informed of developments in all related fields of investigation.

THE SEARCH FOR A CRITERION OF THE MENTAL

The bewildering variety of phenomena that fall under the heading of the mind or the mental was suggested earlier in a list. The question arises, however, whether there is some attribute that all of these mental phenomena have in common, something that characterizes them or that can serve as a criterion of the mental. More specifically, are there certain features that are either necessary or sufficient for mental phenomena?

Purposeful behaviour. Whenever a man watches a hungry animal using stealth and cunning in searching out, attacking, and killing its prey, he cannot but believe that the animal has a purpose and uses intelligence in achieving his goal. Whether it be a team of scientists designing a way of launching a man to the Moon, an ape figuring out how to screw two pieces of pipe together to get a banana that is out of reach, or—at a much lower level—a lobster trying to get out of a pot of boiling water, there seems to be a mind at work. Somewhere, as the phenomenon is traced farther down the ladder in the scheme of things toward inanimate matter, a line must eventually be drawn; but there is no agreement about where it should be drawn. It would be widely agreed that an ovum that has just been fertilized does not have a mind and that a normal adult does—but it is impossible to say exactly where in human development the change occurs. On the other hand, it would be just as erroneous to conclude that because there is no sharp dividing line there is no change as it would be to conclude that red and orange are the same colour because no sharp line divides them in the spectrum. In both instances there exists a transitional range within which the designation of a dividing line would be purely arbitrary; but at either end beyond that range a clear and definite difference is evident.

The question may then be raised as to how adequate purposeful activity is as a criterion of the mental. A major issue arises from the fact that a mechanical device can

be built that exhibits the kind of activity ordinarily called purposeful—a surface-to-air missile, for example, so designed that it will hunt for a jet aircraft by searching for, and zeroing in on, the heat exhaust, thereby finding and destroying the aircraft. Such devices, known as "servomechanisms" (of which a thermostat is a simple example), achieve an end state by systematically diminishing any deviation from that predetermined end state. There are, in addition, the modern computers, capable of receiving, storing, and retrieving information, of making inferences, and of communicating information. Near the height of modern sophistication in machine technology are those machines, combining servomechanisms and computers, designed to roam the surfaces of other planets, gathering, processing, and sending back data and thus providing what would seem to be paradigms of purposeful behaviour and raising the question whether such systems are examples of minds at work. There are three possibilities worth considering: (1) one might continue to hold that purposeful behaviour is the criterion of the mental but argue that these devices do not really meet the criterion of exhibiting purposeful behaviour; (2) one might hold that the more complex of these devices do indeed have what can be called minds—simple and rudimentary, to be sure, but still minds—"artificial intelligences" that in a very literal sense have beliefs, think thoughts, solve problems, and achieve goals; or (3) one might give up the criterion of purposeful behaviour, or at least give it up as a *sufficient* condition of the mental.

Teleological mechanisms versus mental activity

Someone defending possibility (1) would attempt to find some feature of purposeful behaviour that could not be found in any mechanical device. He might hold, for instance, that the alleged purposes of mechanical devices are built in by their designers and that it is not up to the devices to choose their purposes. Against this line of argument, however, others might assert that for a large number of organisms the basic purposes are also built in through the genetic mechanisms of heredity: basic biological drives for food, reproduction, and safety govern most of their purposeful behaviour. People who accept this point of view argue that, in most cases, the organism is not really free to choose its purposes. On this argument, even human beings seem to display such built-in purposes; and it would be specious, at least in this instance, to deny them minds on this account.

Conceding that organisms have some built-in controls, the defender of the first possibility might then argue that the higher organisms have a flexibility that allows for the development of purposive methods that are novel. Machines, he would allege, solve problems only by the methods designed into them, whereas creatures with minds can invent new methods. Against this line of argument others might argue that machines have been developed to use trial and error, analyze the outcomes of trends, and come up with new approaches that are more successful than earlier ones, and that, in an important sense, such machines might be called creative, since they "learn from experience" and use "ingenuity." Many observers assume that this trend in machine technology will continue and that machines will be developed with much, if not all, of the flexibility of many of the creatures that would unhesitatingly be acknowledged to have minds.

Machines, man, and inventiveness

The basic issue, then, is whether a philosopher would want to say that a machine has a mind if it exhibits the flexibility in purposeful activity of, say, a normal seven-year-old child, who undoubtedly has a mind. In accepting possibility (2), the philosopher would maintain that such a machine does indeed have a mind and exhibits a wide range of the phenomena called mental. Many contemporary philosophers, however, would reject that thesis, considering it a needless flaunting of common sense and an affront to ordinary language to speak of a heat-seeking missile, for example, or even a lunar robot, as having a mind. Because something essential still appears to be omitted, further attempts are made below to determine the essence of the mind.

Intentionality. Another characteristic of the mental is sometimes thought to be found in certain ways in which an individual may be said to have something as his object. Thus, thinking, believing, desiring, and other such attitudes are thought to resemble one another in that they may be said to take an object, or to be directed upon an object, in a way quite unlike anything to be found in what is purely physical. "Intentionality" is the term for this way of being directed upon an object. The concept had been emphasized by some of the Scholastics and was introduced to modern philosophy in 1874 by a German philosopher and psychologist, Franz Brentano, and clarified and defended by a U.S. philosopher, Roderick M. Chisholm, in the 20th century.

The nature of intentionality. The idea of intentionality can be explicated in the following way: if one imagines three objects arranged as in Figure 1 and then supposes that the wind blows them so that they are arranged as in Figure 2, there results, from the physical point of view, simply a new arrangement. From a psychological point of view, however, something radically new also has been introduced: one object now appears to be pointing to another—aimed at or directed toward it. It would seem that such pointing cannot be accounted for if the observer confines himself to the purely physical facts of the new configuration and that his mind has to be brought in to account for the feature of pointing to. Thus, intentionality is prima facie a reasonable candidate for the criterion of the mental.

Added characteristic of aim or direction

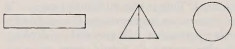


Figure 1: Three arbitrary physical objects in meaningless configuration (see text).

Intentionality is exhibited in a variety of phenomena. Thus, if a person experiences an emotion toward an object—*e.g.*, loves, fears, pities, envies, or reveres it—he has an intentional attitude toward it. Other examples of intentional attitudes toward an object are: looking for or expecting, believing in, doubting or conjecturing about, daydreaming, reminiscing, imagining, favouring, or disapproving—a list that seems to go on endlessly. Because it clearly comprises so many of the things that one thinks of as typically mental, intentionality, being of broader scope than purposefulness, would seem to be a more appropriate choice than purposeful behaviour for the criterion of the mental.

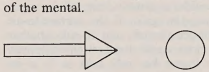


Figure 2: Physical objects with intentionality.

One of the characteristics of intentionality is what the Scholastics called "inexistence": a man may be intentionally related to an object that does not exist or to an event that does not occur. Thus, what a man looks for may not exist, and an event that he believes to occur may not occur at all. In contrast with such a nonintentional phenomenon as bumping into something, in which the object bumped into must be real, looking for something (an intentional act) does not necessarily imply that the object looked for exists. Similarly, in contrast with an explosion's resulting in the fact that many were hurt, a witness's believing that many were hurt (again an intentional act) does not imply the fact that many were hurt. Thus, existence and truth are irrelevant to intentionality.

Though this possible relationship to nonexistent objects as opposed to existent ones is a necessary feature of intentionality, it is not sufficient to define it, for there are phenomena that are equally concerned with nonexistent essences that are nonetheless nonintentional. "That lady resembles a mermaid," to use an example of Chisholm's, may be a true sentence even if mermaids, though having an essence, do not exist. Similarly, "That metal will ignite at temperatures above 1,000,000°" may be true whether or not such temperatures exist. Thus, intentionality requires further characterization if its scope is to be narrowed to exclude such examples as these.

Another characteristic of the intentional state is that not every description of its object will be appropriate. Assuming that his pen is the millionth pen produced this year, for example, a man may be in the intentional state of searching for it as his pen but not in a state of searching for the millionth pen produced this year; similarly, he may believe this is his pen and yet not believe that this is the millionth pen produced this year. This second feature of intentionality, often called "referential opacity," is such that a true sentence asserting an intentional state will become false when some alternative description of the object of that state is substituted for it (it is false that he is searching for the millionth pen).

There is no general agreement on the best way of conceiving of intentional phenomena. Brentano, at one point, thought of intentionality as being a relation between a subject and an entity, in which the entity is something that might or might not exist; but difficulties arise in characterizing the ontological status of such an entity—*i.e.,* its kind of reality. More popular today are certain linguistic approaches: intentionality may be viewed, for example, as it was by Rudolf Carnap, a philosopher of science, and others, as a relation between a subject and a piece of language or, as others have explained, as a relation between a subject and a linguistic practice or linguistic role. Under this view, the intentionality consists not in the relation of a subject to an *essence* (that of a millionth pen) but in its relation to a *sentence* ("This is the millionth pen . . . ") that has that alleged essence as its meaning. It remains to be seen whether such approaches will succeed in dealing with all intentional phenomena. It would seem to pose particular difficulty in those cases in which the intentional state is overtly directed toward some existent entity, with language playing a minor or null role, as in situations in which one feels anger, pity, or love toward someone; or when an animal is stalking its prey (which involves an intentional state). In such instances, an analysis in terms of linguistic attitudes would seem wide of the mark.

The scope of application of intentionality. The question of whether or not intentionality can apply to nonliving physical systems has become a controversial issue. If it can apply, then either intentionality would have to be given up as an exclusive criterion of the mental or else one would have to say that such systems exhibit some mental characteristics.

Application of intentionality to nonliving systems

It will be useful to consider a system designed for some purpose, taking the example again of the surface-to-air missile that searches for jet aircraft, and to ask whether it has intentionality. It does satisfy the first characteristic mentioned above: that it can be truly said to be a jet searcher regardless of whether there are or have been any jet aircraft (one could similarly design a unicorn searcher built to detect unicorns by their special horn). The question next arises whether some descriptions of the object are inappropriate. On the supposition that all and only jet aircraft have a component made of compound *X,* one can ask whether it would be true of the missile that it searches for things with a component made of compound *X.* It would seem that—unless this compound chances to be what the search system was sensitized to—the foregoing statement is a false, and thus an inappropriate, description of the device; and if so, it is plausible to regard the missile as a physical system with intentionality as that notion has been here characterized. An intentional physical system, however, would have to be of considerable complexity. One would not want to say that the left-hand complex in Figure 2 was pointed to the right-hand figure unless he had in mind that, if the right-hand figure were to shift its location, the left-hand complex would shift appropriately. If it did keep shifting appropriately, however, it would seem proper to say that it points to the right-hand figure. The question remains, however, whether *all* intentional phenomena are capable of appearing as instances in nonliving physical systems—whether such a physical system could have, for example, an emotion toward something, daydream about something, or be amused by something. Here it is very difficult to cite a plausible case; it would appear that one would have to strain such concepts considerably to apply them to nonliving systems.

The thesis that intentional phenomena are the essence of the mental thus seems problematic. Its suggestion that the jet-searching missile has a mind or partakes of the mental, as appeared in the discussion of the criterion of purposeful behaviour, would, to many scholars, appear to be quite implausible. Nor does it seem that the trouble lies in the limited number of intentional phenomena found in the missile. Even the lunar-exploration machines, with all of their flexibility and multiplicity of functions, would not be said by most analysts to have minds.

It might be possible to save intentionality as the criterion of the mental by insisting on the presence of such highly sophisticated intentional phenomena as emotions, daydreams, or amusement, but then one would have to deny minds to those human beings who lack a sense of humour, never daydream, or are cold-bloodedly unemotional, which does not seem correct either. Some progress can be made here if the question is asked whether intentionality is a necessary condition of all mental phenomena—whether there are any phenomena that are mental but nonintentional. Examples of a mental phenomenon that can most plausibly be said to be nonintentional are sensations, such as feeling pain, which lack both of the aforementioned characteristics of intentionality—inexistence and referential opacity. A man cannot feel a pain that, unbeknownst to him, does not exist; if he feels pain, there must be something he feels. Moreover, if a man feels pain, and the pain is identified with the effect of a tumour, then he does feel the effect of the tumour.

Sensations, which thus lack both of the characteristics of intentional phenomena, are not just an odd counterexample; not only do sensations comprise a large and central group of mental phenomena, but they also call attention to an important aspect of many other mental phenomena, viz., subjective experience. The arrow in Figure 2 may point to the circle, but it does not have the subjective experience of pointing, it does not feel itself pointing; and the jet-searching missile does not experience how it feels to be searching for jets. But when a person is in an intentional state, directed toward an object, he—at least sometimes—experiences, feels, or is aware of that directedness.

Clearly, this usage of "intentionality" differs somewhat from that found in medieval philosophy; and there are other features of the concept, not covered here, that are stressed by Phenomenologists and Existentialists.

Subjective experience. It is often maintained that the essence of the mental consists of states of consciousness taken as subjective experiences. When a person wakes up or regains consciousness after a general anesthetic, a host of experiences of colour and light, sounds, feelings, thoughts, and memories flood in on him. As far as his objective, observable behaviour is concerned, he may be lying unmoved and unmoving; but as far as his state of consciousness is concerned, he may be undergoing a series of subjective experiences. To take an example, when a person sees a scarlet patch, he experiences the homogeneous, spread-out, distinctive scarletness present before him. A blind or colour-blind person who has never experienced scarlet would not have the awareness of scarlet that the normally-sighted person has. He might have some vague idea, as did the hero of the story told by John Locke, a 17th-century British Empiricist:

Consciousness, "raw feels," discrimination

> A studious blind man, who had mightily beat his head about visible objects, and made use of the explication of his books and friends, to understand those names of light and colours which often came in his way, bragged one day, that he now understood what scarlet signified. Upon which his friend demanding, what scarlet was? the blind man answered, It was like the sound of a trumpet.

This reply is not totally wide of the mark; but any sighted person will have a far more precise idea of scarlet than that. What he has and what the blind person lacks is something that philosophers have called the "raw feel" of scarlet, that peculiar and special way scarlet looks.

The subjective experience of scarlet is to be contrasted with the discrimination of scarlet things. One could imagine a blind person who was able to discriminate scarlet from other colours by the use of optical instruments (*e.g.,* spectroscopes with Braille printouts). But he would lack

the subjective experience of the colour; he would not know the look of scarlet. Defenders of this view would claim that there is a great variety of subjective experiences and that the experience of colours is only one of them. Sensations (*e.g.,* the experiences of pain, tickles, throbbings, pangs, nausea, and tiredness) provide another such example. Still other subjective experiences include: the experiencing of images (afterimages, memory images, and others); feelings of exultation, depression, pride, anger, fear, and love; and thoughts (imaginings, surmisings, doubtings, and recollectings). All of these are episodes, occurring at a particular time and place, in which the subject is in a state of awareness that has a particular content.

Adequacy as a criterion of the mental. The question now arises of how adequate subjective experience is as a criterion of the mental—whether, though it is obviously a sufficient condition for something to be mental, it is a sufficient condition for something to have a mind. The Scotsman David Hume, an 18th-century philosophical Skeptic and historian, once asked whether a creature that had but one state of consciousness could be said to have a mind and concluded that it could not. In his view, it takes, at the very least, a number of states of consciousness linked by memory before one would say that the creature has a mind; and it may be that there has to be a certain level of complexity in the nature and relation of the conscious states for there to be a mind.

The unconscious, dispositional, behavioral

It is doubtful, however, whether consciousness is a necessary condition for the mental. Before Sigmund Freud, it would have been widely agreed that the notion of unconscious mental phenomena was logically impossible—a contradiction in the very terms. That view had one important exception, however: Gottfried Wilhelm Leibniz, a 17th-century Rationalist and mathematician, held that there are *petites perceptions* of which the subject is unconscious. They are so slight, so similar to others, so familiar, or in such a crowd of other perceptions, that the subject is unaware of them at the time. One of the examples that Leibniz cited is the person who is unaware of the roar of the waterfall or the rumble of the mill if he has lived nearby for some time. Leibniz seemed to have had in mind what modern psychologists call "subliminal" perceptions, viz., those below the threshold of awareness but still capable of leaving some effects on the mind. But Leibniz confined unconscious states to perceptions; he would not have allowed unconscious beliefs, desires, emotions, or judgments.

It was Freud's great contribution to have discovered a range of phenomena of which the patient was unconscious but which were very much like typically mental phenomena, especially in their behavioral manifestations. In the light of such similarities, it was plausible to extend the concept of the mental to include these unconscious phenomena—especially since they were such that the patient could become conscious of them through hypnosis or psychotherapy. Freud postulated a mechanism that he called "repression" to explain why the patient is unconscious of them.

In addition to the subliminal and the unconscious, there are more familiar characteristically mental phenomena that do not consist of states of consciousness. When a man falls into a dreamless sleep, he does not lose all his beliefs or abandon all his goals, he does not cease wanting a better world or being artistic or imaginative or lazy, nor does he forget how to do arithmetic or speak French. A person is not jealous of someone only when thinking of him, nor does a businessman have confidence in the dollar only when concentrating on business. Obviously, these mentalistic characteristics can apply in a dispositional way to people who are not at that moment expressing or exhibiting the disposition.

Furthermore, as Gilbert Ryle has pointed out in great detail, a person may use his mind on many occasions without the feeling of subjective experiences. As he says,

> When we describe people as exercising qualities of mind, we are not referring to occult episodes of which their overt acts and utterances are effects; we are referring to those overt acts and utterances themselves. (This and the following quotations attributed to Ryle are from *The Concept of Mind* by Gilbert Ryle. Copyright © 1949 by Gilbert Ryle. Reprinted by permission of Barnes & Noble, Publishers, New York, Hutchinson Publishing Group Ltd., London.)

To be responsive to one's surroundings, to act intelligently, deliberately, with wit or good grace, to utilize arithmetic or logic, to be sympathetic or coldhearted, to drive alertly or absentmindedly—none of these requires the occurrence of subjective experiences or inner states of consciousness, the immediacy of feelings or sensations. In such activity, there may be nothing going on except performances of a particular kind, and there may be nothing more required except that under further circumstances other performances of a particular kind will be forthcoming. It is, thus, reasonable to conclude that subjective experience is not a necessary condition for the mental.

Ryle's charge of a category-mistake

Those who have put the private events of subjective experience at the centre of the mental have committed what Ryle calls a "category-mistake . . . represent[ing] the facts of mental life as if they belonged to one logical type or category, . . . when they actually belong to another." The mistake consists of taking talk about a person's mind as talk of events in a world parallel to the ordinary world but occult and mysterious. The truth, according to Ryle, is that

> to talk of a person's mind . . . is to talk of the person's abilities, liabilities and inclinations to do and undergo certain sorts of things, and of the doing and undergoing of these things in the ordinary world.

It would be rash, however, to draw the further conclusion that subjective experiences are in no way involved in whatever is mental. Returning to the case of Leibniz' *petites perceptions* that are not experienced, a person can be conscious of them in various ways, either before getting used to them or when they are alone or when their intensity or his own sensitivity is increased; and Freud's unconscious phenomena can become conscious phenomena under favourable conditions. The beliefs that an individual is not aware of in sleep are sometimes the objects of his consciousness, as are his moments of laziness and imaginativeness, his knowledge of arithmetic, and his goals. It is dubious that something that has no connection with states of consciousness could qualify as mental.

Core characteristics of subjectivity. Philosophers deeply disagree on how to characterize what is peculiar to subjective experiences. Some hold that the existence of subjective experience indicates that there are peculiar events that do not occur in the public space–time world that everyone shares and has equal access to but occur only in a private world that each person has exclusively to himself, which he cannot share with others, and to which no one else has access. Ryle has called this view, with what he admits to be "deliberate abusiveness," "the dogma of the Ghost in the Machine." He characterizes the dogma as follows:

The role of privacy

> Minds are not in space, nor are their operations subject to mechanical laws. The workings of one mind are not witnessable by other observers; its career is private. Only I can take direct cognisance of the states and processes of my own mind. A person therefore lives through two collateral histories, one consisting of what happens in and to his body, the other consisting of what happens in and to his mind. The first is public, the second private. The events in the first history are events in the physical world, those in the second are events in the mental world.

Are there private events? Even so adamant a critic of privacy as Ryle admits the existence of some private phenomena, chiefly dreams and daydreams, sensations, thoughts, and imaginings. He insists, however, that

> the sequence of your sensations and imaginings is not the sole field in which your wits and character are shown; perhaps only for lunatics is it more than a small corner of that field.

In Ryle's view, private events occupy a small and inessential place in the total range of mental phenomena; but they do occur.

The notion of privacy is really the conflation of two ideas: the metaphysical idea that mental events do not occur in space and the epistemological idea that mental events are objects of awareness solely to the person who is subject to them. Each of these may be considered in turn.

The Rationalist René Descartes, the earliest major philosopher of modern times, held that the essence of all

Non-spatiality of mental events

that is nonmental consists in being extended in space. Turning this around and broadening it, one could say that the essence of the mental consists in the lack of spatiality; *i.e.,* the lack of shape, size, and, above all, location. If the philosopher confined himself to events, he would say that necessarily a physical event occurs in some place or other, but, necessarily, a mental event does not. It would be conceded that the person who experiences the mental event does typically have a location, and this leads to the question of why the event is not located where the person is located.

A defender of the nonspatiality criterion would argue that such ascriptions of location to mental events are very different from ascriptions of location for physical events. For a physical event, it is always possible to ask whether it occurred at some point, in some part, or throughout the location. Thus, if the temperature of a body of water rises, one can ask precisely where the rise occurred—at certain points, in certain parts, or throughout the volume. But if a thought occurs, it is senseless to ask whether it occurred throughout the area or only in some part of it. Furthermore, if the water undergoing the rise in temperature is in a box, it is reasonable to say that a rise in temperature occurred in the box; but if the person having a thought is in a box, it is senseless to say that a thought occurred in the box. So the sort of ascription of location is quite different for mental events, and the criterion can still be used to mark off the mental from the physical.

The question remains whether the sort of nonspatiality that is allegedly appropriate to the mental is peculiar to it. If such a physical event as recovering from an illness or changing shape is considered, it would appear also that it does not make sense to ask whether the event occurred throughout the whole volume, in some part, or at some point. Thus, it would seem that even this modified notion of spatiality does not uniquely distinguish the mental.

Privileged status of subjectivity. Other philosophers would interpret subjective experiences not as private events but as a special way of knowing certain events, specifically by introspection. This is called the "privileged access" view. John Locke, contrasting this way of knowing with sensation, called it "reflection," defining it as "that notice which the mind takes of its own operations and the manner of them." It is a way of being aware of one's own present states without the intervention or use of the senses. The emphasis here is on the way of knowing rather than on the events known. Someone who holds the privacy view will have to hold that there is some special way of knowing these special events, but someone who holds the privileged access view is not necessarily committed to holding that the events so known are in any way special. A person could hold that one and the same event can be known both by sense perception and in some other way. Being knowable by introspection would then be the characteristic that defines events as mental. Such an account, however, would not rule out that they may also be knowable by sense perception or by inference.

Objections and rejoinders

Some contemporary philosophers deny that there is any such special way of knowing. Ryle offers three objections: first, it would require that there be simultaneously multiple attentions—in the mental event itself and in the attending to that event; though it is not denied that such divisions of attention are possible, he suggests that they are more unusual and difficult to achieve than the proponent of introspection would have the reader believe; second, because there is obviously some upper limit to the number of simultaneous attendings that a person is capable of, there will have to be some mental acts of which a person is unaware, and if it is admitted that some mental events occur without being known in this special way, it is fair to ask whether one must assume that any of them are known that way; finally, for many states of mind—*e.g.,* extreme panic or fury—the person is so involved that he is incapable of taking note of them, yet such states are not, in consequence, suspect—the person involved is as sure that they occur as he is of any so-called mental events. There is thus no need to postulate this special way of knowing to account for man's knowledge of any such events.

It is not clear how compelling Ryle's objections are. It is admitted that attention can be divided, though it may be contended that it is unusual and difficult to achieve this division. Others would reply that it is a lot more common and easier than might be thought, that it occurs whenever a man takes note of his mental states. And from the fact that he cannot take note at the same time of very many of his mental states, it hardly follows that he never does; each could still be introspectable even if it was not actually introspected on that occasion. As for Ryle's third objection, it might be that some states of mind cannot be introspected, but it does not follow that none can be introspected; they might still be private for all that. Ryle, for instance, while denying introspection, admits retrospection, a capacity to recall one's states just after they occur. It would seem, however, that there is no important difference between a concurrent "introspection" and a prompt "retrospection." One advantage of retrospection is that it would explain an individual's self-knowledge of those events that are difficult to explain in terms of introspection; *e.g.,* extreme panic or fury.

Whether a person introspects or retrospects (the truth appears to be that sometimes he does the one, sometimes the other), he would still seem to have a kind of knowledge about his own present and recently past mental states that he does not have of the mental states of others and that others do not have of his. It is not possible either to introspect or to retrospect the mental states of others; the knowledge that a man has of the present and immediately past mental states of others must be based upon perceptions or inferences from perceptions, whereas the knowledge that he has of his own present and immediately past mental states need not be, and usually is not, so based.

Introspection as defining the mental

It is possible that the notion of introspection can thus be used to define the mental. Such a definition would be of the form: a mental event is an inner event that can be introspected. The difficulty remains, however, of how "introspected" is to be defined. If it is defined merely as "known without inference or sense perception," then it would seem to apply equally to the knowledge of certain bodily events that no one would want to call mental. An individual can know without sense perception, for example, that his heart is beating rapidly or that his fingers are crossed. To rule such cases out, one can include among the senses the kinesthetic sense that utilizes nerve endings within the body—those, for instance, that register the conditions of one's own muscles. But then it might appear that one must say that sensations are not mental phenomena, since the awareness of them typically involves such nerve endings. Such an admission, however, would be fatal for the privileged access view because sensations are precisely the sort of thing to which a person is supposed to have privileged access. If, on the other hand, the philosopher makes it a matter of definition that introspection applies only to the mental, then he cannot define the mental in terms of introspection. Thus, philosophers are at the present time faced with serious and unsolved difficulties in using the notion of introspection to define the mental.

Finally, it is significant here, as it was in the discussion of subjective experience, that to much of man's mental life and to many of the exercises of his mind—*e.g.,* employments of intelligence—he has no special privileged access; there are, in addition, the unconscious phenomena that are not introspectable. So introspection cannot be a necessary condition of the mental.

A clue to a more satisfactory criterion of the mental can be found in the attack on introspection cited above. There the difficulty was noted that there does not seem to be a way of distinguishing how an individual knows his mental state from how he knows such inner physical states as the rapid beating of his heart. But it may be argued that there does seem to be a difference between these two ways of knowing: specifically, it is clear how a person could be shown that he was mistaken in believing that his heart was beating rapidly; but it is by no means clear what would show a person that he was mistaken in believing himself to be feeling a particular throbbing, pounding sensation. For mental events, the subject's own beliefs are peculiarly authoritative. This authority only holds, of course, for present mental events; it is clear that

Indubitability; incorrigibility; presumption

many things could show that a person's belief about a past mental event of his was mistaken. It is sometimes claimed that what distinguishes mental events is their so-called indubitability—the fact that a belief by the subject that the event is occurring cannot be false or in error. However, the view that first-person, present-tense reports of mental events are indubitable has come under serious attack; to make such a report is to classify, and it is argued that it is always possible to err in classification.

Instead of holding that such beliefs are indubitable, it is often more modestly maintained merely that such beliefs are "incorrigible," meaning that nothing will count as overthrowing (or correcting) such beliefs. A person who believes that he is experiencing a throbbing sensation may be mistaken; but there is nothing that will show an observer or him that he is mistaken, nothing that will entitle either of them to believe that he is mistaken. He may be experiencing a throbbing sensation even when no part of his body is actually throbbing, though the explanation for this curious fact might not be known.

It might be objected against the incorrigibility thesis that the same difficulty that arises for the alleged indubitability of first-person, present-tense beliefs about mental events also arises for their alleged incorrigibility. For if misclassification is possible, it would also seem possible to gather evidence that someone is misclassifying. If one could confuse a throbbing sensation with a different but somewhat similar sensation, it is reasonable to believe that this confusion could be known by others to have occurred. Perhaps the best that can be said for the incorrigibility thesis is that there is always a strong presumption that such beliefs are true, though this presumption can sometimes prove to be unwarranted. But then it is by no means clear that privileged authority is a unique criterion that distinguishes mental events, for such a presumption would also hold for many nonmental events as well (*e.g.*, the belief that one's heart is beating rapidly). Yet if the degree of presumptive force is taken into account, it is reasonable to say that it would be *comparatively* harder to overthrow beliefs about one's present mental events; and perhaps this is all that one needs to give the criterion force.

THE EXISTENCE AND STATUS OF THE MIND

The basic metaphysical issues in the philosophy of mind concern whether the mind exists and, if it does, what kind of existence it has and what its relation is to the rest of what exists. Materialists hold that only physical matter (and physical energy) exists. For those who hold, on the other hand, that the mind exists as an immaterial entity, there are dualistic theories for which both immaterial minds and material bodies exist, and immaterialistic theories for which only minds exist but not bodies. There are, finally, the so-called neutral monist theories for which the fundamental existents in nature are neither mental nor physical but some neutral stuff out of which both the mental and the material are formed.

The mind as material. The basic contention of Materialism is that nothing exists but matter and its purely material properties, so that the concepts that are necessary and sufficient for describing and explaining matter will be necessary and sufficient for describing everything that exists. This view can be found in the early Greek philosophers. Thales of Miletus, who lived some 2,500 years ago (6th century BC) and who is generally regarded as the first philosopher in the Western tradition, is supposed to have held that all things are composed of water in some form or other; later thinkers added air, fire, and earth to the list of fundamental elements. The philosopher Anaxagoras of Clazomenae, born about 500 BC, introduced a new factor, *Nous* (Mind), which arranged all other things in their proper order, started them in motion, and continues to control them. There is still controversy as to how his concept of Mind is to be understood, but since he spoke of Mind as being "the finest and purest of all things" and as occupying space, it is likely that he did not think of it, as some later thinkers did, as nonmaterial stuff but rather as a very special kind of material stuff.

History of Materialism

It was with the Atomists, Leucippus of Miletus and his disciple Democritus of Abdera, in the 5th and early 4th centuries BC, that Materialism was given its most developed statement. According to them, nature consists solely of an infinite number of indivisible particles, having shape, size, and impenetrability, and no further properties, and moving through an otherwise empty space. The shape, size, location, and movement of these particles make up literally all of the qualities, relations, and other features of the natural world. Such phenomena as sensations, images, sense perceptions, and thought—of particular interest to the philosophy of mind—are explicitly held to consist in the various qualities and relations of the particles.

Contemporary Materialists would, no doubt, wish to incorporate into their theory the latest findings of the physical sciences—the convertibility of matter and energy, the wave–particle duality, and the various subatomic particles and antiparticles with their peculiar properties, including the conservation of charge, direction of spin, and direction of time—but these would represent mere changes in detail. In broad outline, the theory would be the same.

Given the theory of Materialism in such broad outline, however, a serious question remains concerning the actual account to be given of such phenomena as sensations, images, perceptions, emotions, memories and expectations, desires, beliefs, thoughts, imaginings, and intentions. Among the possible views are those called eliminative Materialism, Behaviourism, and the central-state theory.

Eliminative Materialism. A philosopher might hold that there are no such things as sensations, images, perceptions, or emotions and that there never have been such. From this view, those who have believed in the existence of such things have simply been mistaken. A person might hold this view, called eliminative Materialism, on the grounds that all talk of such supposed phenomena is (1) meaningless verbiage, or (2) part of a set of theories that are outmoded, scientifically fruitless, and to be discarded, like theories about witches or the Homeric gods. On either account, it is implied that all such terms should be eliminated from the philosopher's vocabulary. There is a further doctrine, however, to the effect that all such talk is (3) meaningful but nondescriptive and without truth value. On this account, the proper function of such language is not to state facts but might be to prescribe or evaluate.

Among Materialistic views, the alternative to eliminative Materialism is some kind of reductive Materialism. According to this view, there are indeed such things as sensations, images, perceptions, and emotions, but they are only complicated forms of matter in motion. The philosopher may thus continue to use terms referring to such things (in contrast with eliminative Materialism), but he should keep in mind that no extra entities or features are being postulated over and above the physical entities with their physical features.

Two kinds of reductive Materialism

Behaviourism. If one asks reductive Materialists what sensations, images, and the like are, one will find that two alternatives have been proposed. The first is Behaviourism, the view that all such terms refer to the behaviour or movements of certain bodies, particularly of the higher animals. Thus, the Behaviourist would claim that to feel pain is to groan, writhe, blanch, moan, and so on, or at least to be disposed or tend toward such behaviour; to desire food is to engage in eating in the presence of food, in hunting in the absence of food, and so on, or at least to be disposed or tend toward such behaviour; and so also with all of the states and activities that one thinks of as mental.

Usually, Behaviourism is intended as a logical doctrine to the effect that the very meanings of the words referring to the mind, its mental states and activities, are to be analyzed in behavioral terms, that every mentalistic term is synonymous in meaning with some behavioral term. It is important to distinguish this view, logical Behaviourism, from the view of many psychologists that the most fruitful way to study psychological phenomena is to study human and animal behaviour. Such a view might be called methodological Behaviourism because it is actually the proposal that the science of psychology restrict itself to certain methods. It does not entail logical Behaviourism. Logical Behaviourism might also be distinguished from

the view that psychological and behavioral terms, though not synonymous in meaning, have, as a matter of fact, the same denotation or reference, a view that might be called de facto Behaviourism.

Central-state theory. The second type of reductive Materialism is the central-state theory. In this view, mental states and activities are identical with states and activities within the body (hence this theory is sometimes called the identity thesis). In particular, they are identical with states and activities of the central nervous system or brain. Thus, to feel pain is for the brain to be in a particular state; to desire food is for the brain to be in another state.

Distinctions parallel to those for Behaviourism can be made for the central-state theory. A psychologist might hold that the only useful way of studying psychological phenomena is to study the central nervous system; this view might then be called methodological central-statism. A philosopher might hold that the very terms referring to the mind, its mental states and activities, are synonymous with neurological terms (or, more plausibly, that they *should* be taken to be synonymous—they obviously are not synonymous as language now stands). This position, which could be called logical central-statism, would differ from the eliminative Materialism mentioned above in that it would retain mentalistic terms rather than eliminate them but would redefine them neurologically. If this came to pass, such terms might eventually disappear, a result that eliminative Materialism would strive to achieve more directly.

Plato's *psychē*

The mind as immaterial. Plato was the first important figure in the Western tradition explicitly to defend the doctrine that the mind is an entirely nonmaterial entity—without such defining material properties as size, shape, or impenetrability—separate and distinct from the human body and able to exist apart from it. Plato used the Greek word *psychē* (traditionally translated as "soul").

Plato held that the mind (*psychē*) was in charge of the body and directed its movements. In his dialogue the *Phaedrus,* Plato spoke of the mind as having both appetitive desires and the higher desires and as having, in addition, a rational capacity to control, direct, and adjudicate between the two. This rational capacity of mind is the most valuable aspect of man, the part most worthy to be nurtured and developed, and the aspect of man most likely to be immortal (much of the dialogue concerning the last hours of Socrates, the *Phaedo,* is about these topics).

Dualism. Plato was a dualist; he believed in the existence of both material entities and immaterial ones. The most explicit statement of dualism, however, is found in the writing of René Descartes, who argued that mind and matter are two separate and distinct sorts of substances, absolutely opposed in their natures, each capable of existing entirely independently of the other.

Descartes's substances

The dualist is faced with the question of how, if at all, mind and matter are related to each other. Most dualists would agree that in rocks, tables, and other material things, matter exists alone and unrelated to mind; and that at what is called death (since for Descartes the soul is immortal), immaterial minds exist unrelated to matter. In the case of a living human being, however, there are two substances: a mind and a body. Thus, the question arises of how the relation between them is to be conceived. Any dualistic theory would have to account for certain obvious facts about human beings. When people's bodies are affected in certain ways—when subjected, for example, to bright lights, loud noises, rises in temperature—people often experience colours, sounds, or sensations of warmth or of pain. Again, when people experience certain things, their bodies undergo certain changes—they shut their eyes, they put their hands to their ears, they perspire, or their faces become pale.

Interactionism; epiphenomenalism; parallelism

There are various ways that dualists have proposed to account for these facts. The most straightforward position is interactionism, the view (held by Descartes) that mind and body are capable of affecting each other causally, so that what happens in the body can produce effects in the mind and vice versa. Descartes decided that somewhere within the nerve tissues of the brain was the place where the interactions occurred and chose the pineal gland as the precise point because of its central location. (It is now known that the pineal gland cannot perform the functions that Descartes attributed to it, though its precise functions are still unknown.)

It is an implication of interactionism that there cannot be a complete explanation of brain functioning exclusively in terms of the laws of neurology because of the intervention at crucial moments of the influences of the mind. This limitation has struck many scholars as an important difficulty. One way around it is epiphenomenalism, the view that the body can affect the mind but that the mind cannot affect the body. Mental events are mere by-products of brain activity, like the exhaust from an engine or the shadows cast by moving figures. When the mind would appear to be affecting the body, as when the experience of pain seems to cause one to grimace, the epiphenomenalist hypothesizes that the very brain state that produces the experience of pain also produces the grimace.

Dualists of either the interactionist or epiphenomenalist persuasion are committed to the existence of causal relations between body and mind. Some philosophers, struck by how entirely different mind and matter are supposed to be on the dualist hypothesis, have held it to be impossible that they could affect each other. Psychophysical parallelism avoids this difficulty by postulating that mind and body are like two perfect clocks, each with its own mechanism but in constant and uniform correlation with the other. Unfortunately, the analogy does not hold very well, for the mind does not seem to have the kind of internal mechanism that would account for any precise sequence of its successive states, and without such a mechanism it would be implausible to expect a constant but noncausal correlation between those states and states of the body.

Immaterialism. Some philosophers have held the doctrine of immaterialism, so named by Bishop George Berkeley, one of the classic British Empiricists, in whose view everything that exists is mental, of "the stuff that dreams are made on," and there is no such thing as the material. There are two major alternatives here: that reality consists of one vast, all-encompassing mind, or that it consists of a plurality of minds. The former position is sometimes called absolute Idealism; the latter, which Berkeley himself held, is sometimes called subjective Idealism.

Berkeley's mentalism

The philosophy of Berkeley represents a highly developed and energetically defended statement of the position that reality consists wholly of minds, the divine Mind and the multiplicity of finite minds that includes all men. Whatever exists does so either because it is a mind or because it is dependent upon a mind; nothing material exists. Berkeley argued that the notion of the material should play no role in one's thinking, for its existence is unverifiable, its postulation unnecessary, and, at bottom, the very notion is self-contradictory. How does Berkeley view the status of tables and chairs, rocks, the Moon, and all of the other apparently material things that everyone accepts as existing? Berkeley agreed that they do indeed exist but only as collections of ideas that exist in the mind of God and that are often caused by God to exist in the minds of men as well.

There are well-known difficulties in Berkeley's view. His account of the nature of tables and other objects cannot be accepted as an account of the meanings of these terms because it is implausible to think that the concept of a divine Mind is somehow part of their meaning. Nor does it seem a plausible scientific theory about such objects because of its ad hoc character and its lack of predictive value. If the notion of God is dropped, however, the philosopher is left with the phenomenalistic theory that such objects are collections of appearances. But phenomenalism also has serious difficulties; in particular, it cannot in the end account for the difference between real objects and illusions because it cannot provide an account of the difference between circumstances in which perceptions are veridical and those in which they are not.

The other variety of immaterialism, called absolute Idealism, derives from certain doctrines of Immanuel Kant and of the classical German Idealists who followed him—Johann Fichte, Friedrich Schelling, and G.W.F. Hegel—concerning the fundamental dependence of reality on

mind or spirit in general. Among the several philosophers who have defended this view, there was, at the turn of the 20th century, F.H. Bradley, whose *Appearance and Reality* (1893; 2nd edition 1897) comprises its most systematic exposition and defense. Bradley denied that a plurality of minds exists and insisted that there is only one infinite Mind, Idea, or Experience that comprehends all of existence within it.

Neutral theories. Another important view has been that neither the mental nor the physical is really fundamental; each is an aspect of some underlying reality that is neither mental nor physical but neutral between them. There are many variants of such a view. Spinoza, a 17th-century Rationalist, held that the underlying substance, which encompassed all of reality and which he called God or Nature, had both thinking (the mental) and extension (the material) as attributes. A modern version of this position is that of Peter Strawson, a leading philosopher of the Oxford "ordinary language" school, who differs from Spinoza in holding that there is a multiplicity of substances, some of which are purely material and some of which are persons (thus he is not really a monist). Strawson conceives of persons as substances whose nature is to have both mental and physical attributes. Thus, one and the same substance can have both qualities, and the difference between the mental and the physical is conceived as a basic difference between the qualities.

Spinoza's substance and attributes

A different approach was suggested in some of Hume's writings and diversely stated by the Pragmatist William James and by various Positivists (Ernst Mach, Rudolf Carnap, and A.J. Ayer). They postulate a number of particular entities, experiences, that go to make up minds when they are related in certain ways, as by the laws of association and memory, and that go to make up bodies when the entities are related in other ways, as by the laws of perspective. Thus, a person's mind is conceived to be just the collection of his experiences, whereas a physical object is conceived to be just the collection of experiences that people can have of it. Here the difference between the mental and physical consists in the different kinds of relations obtaining between the neutral particulars, experiences.

Recently, it has been suggested by certain Linguistic philosophers that the difference between mind and body lies in two different kinds of language or conceptual systems: the physicalistic-conceptual language, on the one hand, with its spatiotemporal terms, and person-talk, on the other, with its reference to norms for assessing the rationality, moral responsibility, and ethical value of human actions.

Existentialist and Phenomenological philosophers have expressed similar conclusions, supported not so much by linguistic considerations as by general observations of man's condition as a being in the world, with a body, which he experiences and which, by its nature, affects his experience. Man can be viewed as a spatiotemporal aggregate, an object for observation, study, and manipulation, an instance of the laws of nature. But man can also be viewed as a self-moved mover, a being who alters himself and the world through the decisions he makes, who determines values and invests things with those values, who can make his life and his world according to the values that he determines, and who, in the end, can negate his values and even terminate his life by choice. Here the philosopher finds surprising similarities between some Analytic philosophers of the English-speaking world and the more speculative continental philosophers.

Existentialist and Phenomenological views

THE ANALYSIS OF MENTAL PHENOMENA

When the specific phenomena that go to make up the mental are considered, one finds that they all raise philosophical issues, only some of which can be sketched here. Mental phenomena are traditionally divided into three areas: the cognitive, which is concerned with knowledge; the affective, with feeling; and the volitional, with action. It is no longer believed that this division reflects the three so-called basic faculties that comprise the mind; nevertheless, as a very rough classification, it provides a convenient approach to the variety of mental phenomena.

The cognitive. Many philosophers since Plato have taken man's ability to know as the characteristic distinguishing him from all other animals. The very name of his species, *Homo sapiens,* means "man the knower."

If one asks what knowledge is, he has raised the central problem of a major field of philosophy, epistemology (see EPISTEMOLOGY). But there is also a very important psychological aspect to knowledge, and that is where the philosophy of mind becomes relevant. It is often claimed, for example, that knowing that something is so entails believing that it is so; and the nature of belief lies clearly within the province of the philosophy of mind. Since a person does not lose a belief when he is not consciously attending to it, the approach to belief most in favour today is to treat it as a disposition, which, like all such, comes to open expression only sporadically. Other psychological phenomena falling within the area of the cognitive are attention, sense perception, understanding, memory, inference, and doubt. The view that each of these requires a subjective experience has been effectively refuted in the writings of Ludwig Wittgenstein, one of the seminal thinkers of modern Linguistic Analysis. Remembering that the oven is still turned on may consist in nothing but getting up in the middle of a conversation, going over to the oven, and turning it off, all the while animatedly continuing the conversation. But exactly why this is called "remembering that the oven is still on" is not clear. Perhaps the best that can be said is that there are analogies between such instances of remembering and other, more self-conscious instances. It is the task of the philosophy of mind to examine, classify, and analyze the relations among such phenomena.

Psychological aspect and phenomena

The affective. Man has not only the capacity to know but also the capacity to respond emotionally to what he knows. A man may not only believe that some event will occur, but he may also dread it or welcome it. Concerning the things that a person knows, he may approve or disapprove, love or hate, pity or envy, enjoy or abhor. Here, although the subjective experience often plays an important role, it clearly is not the whole story. To enjoy doing something, as has been pointed out, is not to do the thing *and also* undergo a series of experiences of enjoyment; it may simply be to do the thing when circumstances permit and make efforts to avoid its cessation or interruption. But a disposition-to-behave approach will be less successful for other affective phenomena. For example, people have feelings about the past—regret, nostalgia, pride—feelings in which future behaviour plays a relatively minor role.

All of the affective phenomena so far considered have the property of intentionality, of being directed toward an object. It is clear, however, that this is not a sufficient condition for defining the affective, since it marks out too broad a scope—including, for example, believing, which, though intentional, falls not within the affective but within the cognitive. But neither does intentionality seem to be a necessary condition of the affective. Moods such as depression, anxiety, or joviality may not have any specific object, though it is sometimes replied that such emotions take as objects anything the person happens to think of. Sensations also do not seem to be intentional, even though they are usually classified as affects. One view is that sensations are really cognitions—the awareness of some bodily disturbance. The difficulty in trying to decide whether a sensation is an affect or a cognition further illustrates the inadequacy of the classification of mental phenomena into the cognitive, affective, and volitional.

The volitional. Intellect and emotion often come to expression in volition and action, important topics in the philosophy of mind—topics that comprise such concepts as motive, desire and purpose, deliberation, decision, intention, attempt, and action, both voluntary and involuntary.

There is a rough distinction to be made between the things that happen to a person and the things he does or makes to happen. If a person slips on the ice, it is something that happens to him; if he walks on the ice, it is something that he does. "Henry slid on the ice" is ambiguous: it may report something that happened to Henry or something that Henry did, depending upon the meaning. In this example, the observable event may be the same:

from a photograph of Henry sliding on the ice one may not be able to tell which it is. The problem of action is primarily to understand this distinction and its ramifications. Wittgenstein once put the question this way: "And the problem arises: what is left over if I subtract the fact that my arm goes up from the fact that I raise my arm?"

Wittgenstein's question on action

There are a number of different answers: (1) Actions are events produced by causes of certain sorts—volitions or acts of will according to some theories; beliefs and desires under other theories; and simply persons or agents in yet another theory. (2) Actions are events that are "caused" in a special sense; they have a teleological rather than an efficient or mechanical cause, or an immanent (or originating) cause rather than one that is merely a reaction to, or modification of, an action coming from some other source. (3) Actions are events that are properly characterized and assessed in terms of rules of conduct, or principles of rational and ethical behaviour, and for which the agent is held responsible, liable, accountable, to be praised or blamed, rewarded or punished.

Any theory of action is expected to throw light on the issue of free will, a matter of great importance for ethical theory. If the philosopher holds that free will is compatible with determinism, any of the views above will allow for free will. Even if he holds that an action is not free if it has causes that eventually lie outside the agent, his view will be compatible with the various views of action unless he holds the version of (1)—that an action is an event produced by volitions or beliefs and desires—and also holds the additional thesis (2)—that volitions or beliefs and desires themselves have causes that lie outside the agent. Only then will there be no freedom of the will.

SOME METAPHYSICAL AND EPISTEMOLOGICAL ISSUES

Personal identity through time. A person, as he goes through life, changes in many ways; but he remains the person that he was. He is that person who was born on a certain day, that person who graduated 23rd in a particular high school class, who married on a certain date in a certain place; he has a particular identity through time. It is difficult to state what exactly it is that makes a person one and the same self through time.

Bodily versus psychological criteria

An obvious starting point is the fact that throughout a person's natural life he has the same body and that this is what makes him one and the same person throughout a particular period of time. But there are difficulties in this view. First, since the body cells are constantly being replaced and in some instances whole organs are transplanted, it is not clear what makes a particular body identical with a body that existed, say, 20 years earlier. A second difficulty arises through the hypothetical possibility of brain transplants; if two brains were interchanged, in all likelihood there would be a systematic interchange of memory, beliefs, personality and character traits, skills, and habits of thought and action. Such a transplant would incline one to say that not merely a small portion of each body had been interchanged but two people as well; for one also takes as a criterion of personal identity similarities through time of memory, personality, skills, and habits. After all, a man is often willing to say that this is the same person who did something in the past, not on the basis of knowing that it is the same body but on a quite different basis—that the person recounts the past situation with great accuracy, exhibits similar personal reactions, and displays the same skills.

Because two different kinds of criteria, bodily and psychological, are used for determining personal identity, it is possible to imagine instances of conflict in which the criterion of bodily identity would indicate that it is a different person but the psychological criteria would indicate that it is the same person and vice versa. The Austro-Czech novelist Franz Kafka, known for his nightmarish works, in his short story *Die Verwandlung* (1915; *The Metamorphosis*) tells of a person who awoke one morning to find, to his horror, that he had the body of a large insect. Although his family accepted his conclusion that he was the same person even though he had an entirely different body, others would have disagreed. There is still, in fact, considerable disagreement among scholars on this whole issue—on how to state precisely the bodily criterion; on whether there is a psychological criterion as well and, if so, how it is to be formulated; on what is the basic criterion of personal identity; and on what to say about instances in which criteria conflict.

Personal immortality. Many people believe that when the human body ceases to be a living system, there is not total annihilation of the person but that in some respect the person continues to exist. The philosopher of mind can put aside the various watered-down versions of immortality in which the person continues to exist in the remote sense that people still remember him or his works or that his influence continues through history. The philosopher does look with interest, however, on the claim that there is an immortality in which a person, in his survival, meets the psychological criteria of personal identity, of inheritance of memory, beliefs, habits, and personality characteristics.

Problems of meaning and fact

It is clear that a person's view of immortality will be affected by opinions that he holds about the relation of mind to matter. Given the versions of Materialism that urge the elimination of mental terms or their definition in bodily terms or that take bodily identity to be the basic criterion of personal identity, the very notion of survival after death is completely unintelligible. Many philosophers, however, reason that, since the notion of survival is intelligible, such versions of Materialism cannot be accepted. Central-state or identity theorists would admit survival to be an intelligible notion but would view it, like lightning without electricity, as something that never happens; they would thus be in agreement with many dualists, in particular epiphenomenalists and psychophysical parallelists. Even an interactionist would be free to accept or reject survival, as would a neutral monist.

If a philosopher holds that survival is an intelligible notion, he is still left with the further question of whether it ever happens. In the past there have been various a priori arguments for survival after death. Arguments based upon the nature of the self, such as its indivisibility, can be found in Plato's *Phaedo*. Kant argued that man's moral principles require survival as a postulate. But among those today who hold that survival is intelligible, it is widely agreed that a priori arguments will not do. If there is survival, they say, it is a contingent fact and not a necessity; one must thus look to empirical data for guidance. A survey of the evidence shows that the case against survival, though strong, is by no means conclusive. One thing is clear: if there is survival, the survivors can theoretically give firsthand testimony to it, whereas if there is no survival, there will be no one to give such testimony.

Knowledge of other minds. An important problem in the theory of knowledge has been the status of the belief in other minds, the belief that one's own consciousness is not the only consciousness in existence. Though few, if any, sane persons have seriously accepted solipsism (the view that one's own is the only consciousness), the grounds for rejecting it are not at all clear.

Again, as with the problems of personal identity and personal survival, one's view of the relation of mind to matter is relevant. On various Materialistic views, the problem reduces itself to that of justifying the belief in an external world that contains other bodies of the appropriate sort and with the appropriate behaviour. But for dualists and immaterialists, who hold that mental phenomena are something irreducibly different from the physical, there is the further question of whether that something is unique to oneself or whether there are other instances of it in the world.

Direct, transcendental, analogical approaches

Some scholars claim that individuals sometimes have direct awareness of the conscious states of others, either in telepathic experiences, moments of empathy, or even in everyday social intercourse. There is, moreover, a transcendental argument, found in Kant and defended by Strawson, holding that, unless a person could be confident of the existence of other minds, he could not be confident of the existence of his own mind. A different line of reasoning, the so-called argument from analogy, is based upon the similarities between one's own body and its behaviour, on the one hand, and other human bodies and

their behaviour on the other. To pursue the argument, since a mind is known to be associated with one's own body, it is reasonable to conclude that another mind is associated with the body of another person. Finally, there is the view that the best way to explain the complex behaviour of other bodies, especially their ability to behave rationally and in particular to speak and communicate information, is to postulate other minds at work.

None of these arguments compels strong conviction, certainly not the degree of conviction that all persons feel concerning the existence of other minds. Whether stronger arguments will be found, whether philosophers must admit that there is a considerable amount of faith required here, or whether they will reformulate their concepts of the mind in a more Materialistic way to bring them in closer accord with observable data remains to be seen.

Artificial intelligence. Remarkable progress in the development of high-speed electronic computers has led many philosophers to conclude that a suitably programmed computer with a sufficient memory capacity would have an actual mind capable of intelligent thought. The term artificial intelligence denotes the area of investigation that aims to develop computers with such capabilities.

Two questions are intensely debated in this field. First, what are the theoretical limits to what can be achieved in the way of artificial intelligence? Despite phenomenal progress in recent years, no computer yet devised even approximates in its capacity the multiplicitous powers of the human mind. However, it would be most unwise at present to make dogmatic predictions about future developments. Second, assuming that the optimistic hopes of artificial intelligence researchers are realized, would such devices literally have minds or would they be mere imitations of minds? It is already common linguistic practice to describe computers as having memories, making inferences, understanding one language or another, and the like, but are such descriptions literally true or simply metaphorical? One group holds that computers will never be more than tools employed by the human intelligence to aid its own thinking. Another group holds that human intelligence itself consists of the very computational processes that could be exemplified by advanced machines, so that it would be unreasonable to deny the attribution of intelligence to such machines. The issue may remain unresolved until researchers in artificial intelligence have had more time to determine the limits of computer capabilities.

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Minerals and Rocks

A mineral is a naturally occurring homogeneous solid with a definite chemical composition and a highly ordered atomic arrangement; it is usually formed by inorganic processes. There are several thousand known mineral species, but only about 100 of them constitute the major mineral components of rocks; these are the so-called rock-forming minerals. Most rocks are aggregates of minerals, although a relatively small number have been found to consist of only a single mineral. Such rocks are known as monomineralic. The many ways in which minerals combine give rise to a large variety of rocks. Rocks are generally divided into three major classes on the basis of their origin: igneous, metamorphic, and sedimentary. Each of these classes, in turn, is subdivided into numerous groups according to mineral composition and texture.

This article provides a summary of the external form, internal structure, chemical composition, physical properties, and origin of minerals and their associations. It treats the principal rock-forming minerals (among which the silicates are of the greatest importance) and discusses the common representatives of other groups—sulfides, oxides, hydroxides, and carbonates, for example—as well. Each of the major classes of rocks is also described, with attention given to their physical and chemical properties, formation, and occurrence. For additional information about precious minerals, see the article DRESS AND ADORNMENT: *Jewelry: Gems*. The study of minerals and rocks is treated in EARTH SCIENCES: *Geologic sciences*.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, sections 121, 124, 214, and 10/33, and the *Index*.

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Definition of a mineral. A mineral, which by definition must be formed through natural processes, is distinct from the synthetic equivalents produced in the laboratory. Man-made versions of minerals, including emeralds, sapphires, diamonds, and other valuable gemstones, are regularly produced in industrial and research facilities and are often nearly identical to their natural counterparts.

By its definition as a homogeneous solid, a mineral is composed of a single solid substance of uniform composition that cannot be physically separated into simpler compounds. Homogeneity is determined relative to the scale on which it is defined. A specimen that megascopically appears homogeneous, for example, may reveal several mineral components under a microscope or upon exposure to X-ray diffraction techniques. Most rocks are composed of several different minerals; *e.g.*, granite consists of feldspar, quartz, mica, and amphibole. In addition, gases and liquids are excluded by a strict interpretation of the above definition of a mineral. Ice, the solid state of water (H_2O), is considered a mineral, but liquid water is not; liquid mercury, though sometimes found in mercury ore deposits, is not classified as a mineral either. Such substances that resemble minerals in chemistry and occurrence are dubbed mineraloids and are included in the general domain of mineralogy.

Since a mineral has a definite composition, it can be expressed by a specific chemical formula. Quartz (silicon dioxide), for instance, is rendered as SiO_2, because the elements silicon (Si) and oxygen (O) are its only constituents and they invariably appear in a 1:2 ratio. The chemical makeup of most minerals is not as well defined as that of quartz, which is a pure substance. Siderite, for example, does not always occur as pure iron carbonate ($FeCO_3$); magnesium (Mg), manganese (Mn), and, to a limited extent, calcium (Ca) may sometimes substitute for the iron. Since the amount of the replacement may vary, the composition of siderite is not fixed and ranges between certain limits, although the ratio of the metal cation to the anionic group remains fixed at 1:1. Its chemical makeup may be expressed by the general formula (Fe, Mn, Mg, Ca)CO_3, which reflects the variability of the metal content.

Crystalline solids

Minerals display a highly ordered internal atomic structure that has a regular geometric form (see Figure 1). Because of this feature, minerals are classified as crystalline solids. Under favourable conditions, crystalline materials may express their ordered internal framework by a well-developed external form, often referred to as crystal form or morphology (see Figure 2). Solids that exhibit no such ordered internal arrangement are termed amorphous. Many amorphous natural solids, such as glass, are categorized as mineraloids.

Traditionally, minerals have been described as resulting exclusively from inorganic processes; however, current mineralogic practice often includes as minerals those compounds that are organically produced but satisfy all other mineral requirements. Aragonite ($CaCO_3$) is an example of an inorganically formed mineral that also has an organically produced, yet otherwise identical, counterpart; the shell (and the pearl, if it is present) of an oyster is composed to a large extent of organically formed aragonite. Minerals also are produced by the human body: hydroxylapatite [$Ca_5(PO_4)_3(OH)$] is the chief component of bones and teeth, and calculi are concretions of mineral substances found in the urinary system.

Mineral nomenclature. While minerals are classified in a logical manner according to their major anionic (negatively charged) chemical constituents into groups such as oxides, silicates, and nitrates, they are named in a far less scientific or consistent way. Names may be assigned to reflect a physical or chemical property, such as colour, or they may be derived from various subjects deemed

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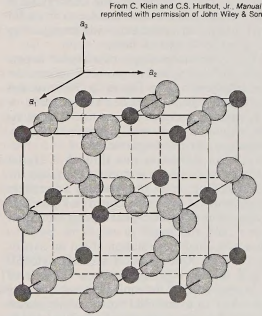


Figure 1: Schematic representation of the structure of pyrite, FeS_2, as based on a cubic array of ferrous iron cations (Fe^{2+}) and sulfur anions (S^-).

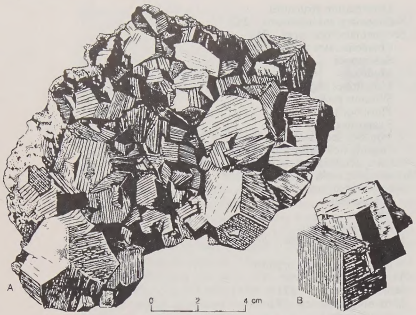


Figure 2: (A) Pyrite crystals with pyritohedral outline. (B) Intergrowth of striated cubes of pyrite. The external shape is a reflection of the internal structure as shown in Figure 1.

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appropriate, as, for example, a locality, public figure, or mineralogist. Some examples of mineral names and their derivations follow: albite ($NaAlSi_3O_8$) is from the Latin word (*albus*) for "white" in reference to its colour; goethite ($FeO \cdot OH$) is in honour of Johann Wolfgang von Goethe, the German poet; manganite ($MnO \cdot OH$) reflects the mineral's composition; franklinite ($ZnFe_2O_4$) is named after Franklin, N.J., U.S., the site of its occurrence as the dominant zinc (Zn) mineral; and sillimanite (Al_2SiO_5) is in honour of the American chemist Benjamin Silliman.

Since 1960, an international committee of nomenclature has reviewed descriptions of new minerals and proposals for new mineral names and has attempted to remove inconsistencies.

Occurrence and formation of minerals. Minerals form in all geologic environments and thus under a wide range of chemical and physical conditions, such as varying temperature and pressure. The four main categories of mineral formation are (1) igneous, or magmatic, in which minerals crystallize from a melt; (2) sedimentary, in which minerals are the result of the processes of weathering, erosion, and sedimentation; (3) metamorphic, in which new minerals form at the expense of earlier ones owing to the effects of changing—usually increasing—temperature or pressure or both on some existing rock type (metamorphic minerals are the result of new mineral growth in the solid state without the intervention of a melt, as in igneous processes); and (4) hydrothermal, in which minerals are chemically precipitated from hot solutions within the Earth. The first three processes generally lead to varieties of rocks in which different mineral grains are closely intergrown in an interlocking fabric. Hydrothermal solutions, and even solutions at very low temperatures (*e.g.*, groundwater), tend to follow fracture zones in rocks that may provide open spaces for the chemical precipitation of minerals from solution. It is from such open spaces, partially filled by minerals deposited from solutions, that most of the spectacular mineral specimens have been collected. If a mineral that is in the process of growth (as a result of precipitation) is allowed to develop in a free space, it will generally exhibit a well-developed crystal form (see Figure 2), which adds to a specimen's aesthetic beauty. Similarly, geodes, which are rounded, hollow, or partially hollow bodies commonly found in limestones, may contain well-formed crystals lining the central cavity. Geodes form as a result of mineral deposition from solutions such as groundwater.

Hydrothermal mineral formation

MINERALS: THEIR NATURE, CLASSIFICATION, AND ASSOCIATIONS

The nature of minerals

MORPHOLOGY

Nearly all minerals have the internal ordered arrangement of atoms and ions that is the defining characteristic of crystalline solids (see Figure 1). Under favourable conditions, minerals may grow as well-formed crystals, characterized by their smooth plane surfaces and regular geometric forms. Development of this good external shape is largely a fortuitous outcome of growth and does not affect the basic properties of a crystal. Therefore, the term crystal is most often used by material scientists to refer to any solid with an ordered internal arrangement, without regard to the presence or absence of external faces.

The external shape, or morphology, of a crystal is perceived as its aesthetic beauty, and its geometry reflects the internal atomic arrangement (see Figure 2). The external shape of well-formed crystals expresses the presence or absence of a number of symmetry elements. Such symmetry elements include rotation axes, rotoinversion axes, a centre of symmetry, and mirror planes.

Symmetry elements

A rotation axis is an imaginary line through a crystal around which it may be rotated and repeat itself in appearance one, two, three, four, or six times during a complete rotation. A sixfold rotation axis is illustrated in Figure 3A. When rotated about this axis, the crystal repeats itself each 60° (six times in a 360° rotation).

A rotoinversion axis combines rotation about an axis of rotation with inversion. Rotoinversion axes are symbolized as $\bar{1}$, $\bar{2}$, $\bar{3}$, $\bar{4}$, and $\bar{6}$. $\bar{1}$ is equivalent to a centre of symmetry (or inversion, *I*), $\bar{2}$ is equivalent to a mirror plane, $\bar{3}$ is equivalent to a threefold rotation axis plus a centre of symmetry, $\bar{4}$ is not composed of other operations and is unique, and $\bar{6}$ is equivalent to a threefold rotation axis with a mirror plane perpendicular to the axis. The morphological expression of a fourfold rotoinversion axis is illustrated in Figure 3B.

A centre of symmetry exists in a crystal if an imaginary line can be extended from any point on its surface through its centre and a similar point is present along the line equidistant from the centre (see Figure 3C). This is equivalent to $\bar{1}$, or inversion. There is a relatively simple procedure for recognizing a centre of symmetry in a well-formed crystal. With the crystal (or a wooden or plaster model thereof) laid down on any face on a tabletop, the presence of a face of equal size and shape, but inverted, in a horizontal position at the top of the crystal proves the existence of a centre of symmetry.

A mirror plane is an imaginary plane that separates a crystal into halves such that, in a perfectly developed crystal, the halves are mirror images of one another. A single mirror in a crystal, also called a symmetry plane, is illustrated in Figure 3D.

Morphologically crystals can be grouped into 32 crystal classes that represent the 32 possible symmetry elements and their combinations. These crystal classes, in turn, are grouped into six crystal systems. In decreasing overall symmetry content, beginning with the system with the highest and most complex crystal symmetry, they are isometric, hexagonal, tetragonal, orthorhombic, monoclinic, and triclinic. The systems may be described in terms of crystallographic axes used for reference. The *c* axis is normally the vertical axis. The isometric system exhibits three mutually perpendicular axes of equal length (a_1, a_2, and a_3). The orthorhombic and tetragonal systems also contain three mutually perpendicular axes; in the former system, all the axes are of different lengths (*a*, *b*, and *c*), and, in the latter, two axes are of equal length (a_1 and a_2) while the third (vertical) axis is either longer or shorter (*c*). The hexagonal system contains four axes: three equal-

Crystal systems

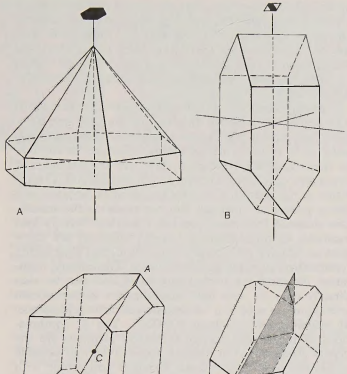


Figure 3: *Translation-free symmetry elements as expressed by the morphology of crystals.*
(A) Sixfold axis of rotation (6). (B) Fourfold axis of inversion (4). (C) Centre of symmetry (*i*). (D) Mirror plane (*m*).
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Table 1: The 32 Crystal Classes and Their Symmetry Contents

crystal system	symmetry content*	crystal class†
Triclinic	none	$\underline{1}$
	i	$\bar{1}$
Monoclinic	$1A_2$	2
	$1m$	m
	i, $1A_2$, $1m$	$2/m$
Orthorhombic	$3A_2$	222
	A_2, $2m$	$mm2$
	i, $3A_2$, $3m$	$2/m2/m2/m$
Tetragonal	$1A_4$	$\underline{4}$
	$1\bar{A}_4$	$\bar{4}$
	i, $1A_4$, m	$4/m$
	$1A_4$, $4A_2$	422
	$1A_4$, $4m$	$4mm$
	$1\bar{A}_4$, $2A_2$, $2m$	$\bar{4}2m$
	i, $1A_4$, $4A_2$, $5m$	$4/m2/m2/m$
Hexagonal	$1A_3$	$\underline{3}$
	$1\bar{A}_3$ (= $i + 1A_3$)	$\bar{3}$
	$1A_3$, $3A_2$	32
	$1A_3$, $3m$	$3m$
	$1\bar{A}_3$, $3A_2$, $3m$ ($1\bar{A}_3 = i + 1A_3$)	$\bar{3}2/m$
	$1A_6$	$\underline{6}$
	$1\bar{A}_6$ (= $1A_3 + m$)	$\bar{6}$
	i, $1A_6$, $1m$	$6/m$
	$1A_6$, $6A_2$	622
	$1A_6$, $6m$	$6mm$
	$1\bar{A}_6$, $3A_2$, $3m$ ($1\bar{A}_6 = 1A_3 + m$)	$\bar{6}m2$
	i, $1A_6$, $6A_2$, $7m$	$6/m2/m2/m$
Isometric	$3A_2$, $4A_3$	23
	$3A_2$, $3m$, $4\bar{A}_3$ ($1\bar{A}_3 = 1A_3 + i$)	$2/m\bar{3}$
	$3A_2$, $4A_3$, $6A_4$	432
	$3A_2$, $4A_3$, $6m$	$\bar{4}3m$
	$3A_2$, $4\bar{A}_3$, $6A_2$, $9m$ ($1\bar{A}_3 = 1A_3 + i$)	$4/m\bar{3}2/m$

*Abbreviations used in column 2: i = inversion (or centre of symmetry); A = axis of rotation; A_2 = axis of twofold rotation; A_3 = axis of threefold rotation; A_4 = axis of fourfold rotation; and A_6 = axis of sixfold rotation; $\bar{A}$ = axis of rotoinversion; $\bar{A}_3$ = axis of threefold rotoinversion; $\bar{A}_4$ = axis of fourfold rotoinversion; $\bar{A}_6$ = axis of sixfold rotoinversion; m = mirror, or symmetry, plane.
†Symbolic representation used in column 3: rotation axes are shown as 1, 2, 3, 4, or 6 (in which 2 = twofold rotation, $\bar{3}$ = threefold rotation, etc.); rotoinversion axes are shown as $\bar{3}$, $\bar{4}$, or $\bar{6}$ (in which $\bar{3}$ is a threefold rotoinversion axis, etc.); centre of symmetry i is equivalent to $\bar{1}$; mirrors are represented by m; rotation axes perpendicular to mirror planes are shown by the notation $2/m$, $4/m$, or $6/m$, in which $2/m$ is a twofold axis perpendicular to a mirror, etc.
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length axes (a_1, a_2, and a_3) intersect one another at 120° and lie in a plane that is perpendicular to the fourth (vertical) axis of a different length. Three axes of different lengths (*a*, *b*, and *c*) are present in both the monoclinic and triclinic systems. In the monoclinic system, two axes intersect one another at an oblique angle and lie in a plane perpendicular to the third axis; in the triclinic system, all axes intersect at oblique angles.

The grouping of the 32 possible crystal classes among the crystal systems is shown in Table 1. Column 1 of the table lists the six crystal systems; column 2 gives the total symmetry content of each of the 32 crystal classes; and column 3 gives a symbolic representation for each of the 32 combinations of symmetry elements known as the Hermann-Mauguin, or international, notation. This compact and very useful notation is discussed in professional literature, such as the references given in the *Bibliography*.

Three different crystals with distinctively dissimilar symmetry contents, as expressed by their external morphology, are given in Figure 4. Figure 4A shows a well-formed monoclinic crystal with symmetry content *i*, $1A_2$, and $1m$ ($2/m$); Figure 4B features a crystal in the tetragonal system with symmetry content *i*, $1A_4$, and $1m$ ($4/m$); and Figure 4C shows a crystal in the isometric system having the highest possible symmetry content of $3A_4$, $4\bar{A}_3$, $6A_2$, and $9m$ ($4/m\bar{3}2/m$). (See Table 1.) Photographs of some well-formed crystal groups are given in Figure 5.

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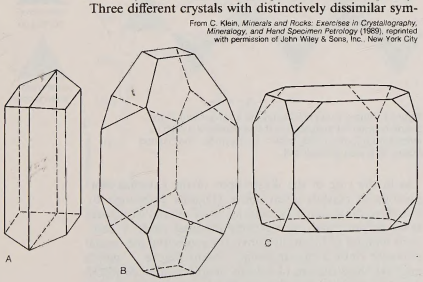


Figure 4: *Well-shaped crystals.*
Each belongs to a different crystal class because of its overall symmetry content. (A) Monoclinic crystal ($2/m$). (B) Tetragonal crystal ($4/m$). (C) Isometric crystal ($4/m\bar{3}2/m$).

If two or more crystals form a symmetrical intergrowth, they are referred to as twinned crystals. A new symmetry operation (called a twin element), which is lacking in a single untwinned crystal, relates the individual crystals in a twinned position. There are three twin elements that may relate the crystals of a twin: (1) reflection by a mirror plane (twin plane), (2) rotation about a crystal direction common to both (twin axis) with the angular rotation typically 180°, and (3) inversion about a point (twin centre). An instance of twinning is defined by a twin law that specifies the presence of a plane, an axis, or a centre of twinning. If a twin has three or more parts, it is referred to as a multiple, or repeated, twin. Examples of various twin types are shown in Figure 6.

INTERNAL STRUCTURE

The external morphology of a mineral is an expression of the fundamental internal architecture of a crystalline substance—*i.e.*, its crystal structure. The crystal structure is the three-dimensional, regular (or ordered) arrangement of chemical units (atoms, ions, and anionic groups in inorganic materials; molecules in organic substances); these



Figure 5: *Minerals displaying good crystal form.*
Although such occurrences are in the minority, they receive considerable attention because of their aesthetic beauty and because they reflect the symmetry content inherent in the external form and in the internal structure of the mineral. (Top left) Wulfenite, $PbMoO_4$, from Mexico. (Top right) Calcite, $CaCO_3$, from Chihuahua, Mex. (Bottom left) Rose quartz from Minas Gerais state, Braz. (Bottom right) Microcline feldspar, $KAlSi_3O_8$, the greenish blue variety known as amazonite, with smoky (dark gray) quartz, from Colorado, U.S.
By courtesy of (top left) Joseph and Helen Guettarman, Belleville, Illinois, (bottom left) the Field Museum of Natural History, Chicago, (bottom right) the Harvard Collection; photographs, (top left, bottom left) John H. Gerard— B Inc., (top right) Floyd R. Getsinger, (bottom right) Benjamin M. Shaub

chemical units (referred to here as motifs) are repeated by various translational and symmetry operations (see below). The morphology of crystals can be studied with the unaided eye in large well-developed crystals and has been historically examined in considerable detail by optical measurements of smaller well-formed crystals through the use of optical goniometers. The internal structure of crystalline materials, however, is revealed by a combination of X-ray, neutron, and electron diffraction techniques, supplemented by a variety of spectroscopic methods, including infrared, optical, Mössbauer, and resonance techniques. These methods, used singly or in combination, provide a quantitative three-dimensional reconstruction of the location of the atoms (or ions), the chemical bond

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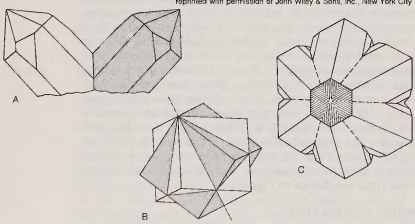


Figure 6: *Illustration of various types of twins.*
(A) Two crystals of quartz, twinned along a mirror plane such that the left crystal is a mirror image of the right crystal. (B) Two interpenetrating cubes of fluorite twinned along a twofold symmetry axis (denoted by the dashed line). (C) A repeated twin in the mineral chrysoberyl. The twin planes, shown by dashed lines, result in a cyclic twin pattern.

types and their positions, and the overall internal symmetry of the structure. The repeat distances in most inorganic structures and many of the atomic and ionic motif sizes are on the order of 1 to 10 angstroms (1 angstrom [Å] is equivalent to 10^{-8} centimetre [cm] or 3.94×10^{-9} inch) or 10 to 100 nanometres (nm; 1 nm is equivalent to 10^{-7} cm or 10 Å).

Symmetry elements that are observable in the external morphology of crystals, such as rotation and rotoinversion axes, mirror planes, and a centre of symmetry, also are present in their internal atomic structure. In addition to these symmetry elements, there are translations and symmetry operations combined with translations. (Translation is the operation in which a motif is repeated in a linear pattern at intervals that are equal to the translation distance [commonly on the 1 to 10 Å level].) Two examples of translational symmetry elements are screw axes (combining rotation and translation) and glide planes (combining mirroring and translation). The internal translation distances are exceedingly small and can be seen directly only by very high magnification electron-beam techniques, as used in a transmission electron microscope, at magnifications of about 600,000×. The 32 combinations of the translation-free symmetry elements are the crystal classes listed in Table 1 above. When all possible combinations of translational elements compatible with the 32 crystal classes (also known as point groups) are considered, one arrives at 230 possible ways in which translations, translational symmetry elements (screw axes and glide planes), and translation-free symmetry elements (rotation and rotoinversion axes and mirror planes) can be combined. These translation and symmetry groupings are known as the 230 space groups, representing the various ways in which motifs can be arranged in an ordered three-dimensional array. The symbolic representation of space groups is closely related to that of the Hermann-Mauguin notation of point groups as listed in column 3 of Table 1. A detailed discussion of space groups, their derivation, and notation is beyond the scope of this article. For more specific information, consult the books on mineralogy cited in the *Bibliography*.

Translation

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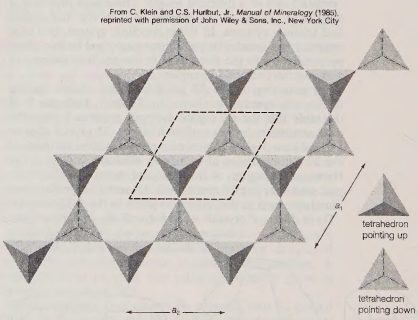


Figure 7: Single sheet displaying the arrangement of the silicon-oxygen tetrahedrons in the structure of a high temperature form of SiO_2 known as tridymite. The dashed outline indicates the unit cell.

As in the case of the illustrations of the external morphology of crystals given above (Figures 2 through 6), the three-dimensional arrangement of crystal structures must be presented on a two-dimensional page. A common method of illustration involves projecting the crystal structure onto a planar surface, as in Figure 7, which portrays the structure of a form of silicon dioxide (SiO_2) known as tridymite. The structural motif units in this case are SiO_4 tetrahedrons composed of a silicon atom surrounded by four oxygen atoms. To further aid the visualization of complex crystal structures, models of such

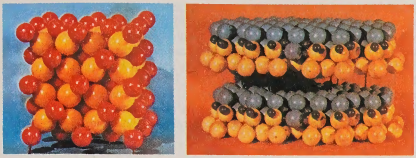


Figure 8: *Crystal structure models of mineral structures.* (Left) Closest-packed model of the crystal structure of fluorite, CaF_2, an example of ionic bonding in a structure with isometric symmetry. Red balls represent calcium and yellow balls fluorine ions. (Right) The structure of kaolinite, $Al_2Si_2O_5(OH)_4$; closely packed atoms in the composite slabs are held together by covalent and ionic forces. The slabs, however, are electrically neutral and only weakly held to one another by van der Waals bonding. Yellow balls represent oxygen atoms arranged in tetrahedrons; silicon atoms occur within the tetrahedral pores and are not visible. Small brown balls are aluminum and blue are hydroxyl ions.
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structures can be built or obtained commercially. Models of this sort reproduce the internal atomic arrangement on an enormously enlarged scale (*e.g.*, one angstrom might be represented by one centimetre). Two types of crystal structure models are illustrated in Figure 8.

POLYMORPHISM

Polymorphism is the ability of a specific chemical composition to crystallize in more than one form. This generally occurs as a response to changes in temperature or pressure or both. The different structures of such a chemical substance are called polymorphic forms, or polymorphs. For example, the element carbon (C) occurs in nature in two different polymorphic forms, depending on the external (pressure and temperature) conditions. These forms are graphite, with a hexagonal structure, and diamond, with an isometric structure. The composition FeS_2 occurs most commonly as pyrite, with an isometric structure, but it is also found as marcasite, which has an orthorhombic internal arrangement. The composition SiO_2 is found in a large number of polymorphs, among them quartz, tridymite, cristobalite, coesite, and stishovite. The stability field (conditions under which a mineral is stable) of these SiO_2 polymorphs is expressed in a stability diagram in Figure 9, with the external parameters of temperature and pressure as the two axes. In the general quartz field, there is additional polymorphism leading to the notation of high quartz and low quartz, each form having a slightly different internal structure. The diagram clearly indicates that cristobalite and tridymite are the high-temperature forms of SiO_2, and indeed these SiO_2 polymorphs occur in high-temperature lava flows. The high-pressure forms of SiO_2 are coesite and stishovite, and these can be found in meteorite craters, formed as a result of high explosive pressures upon quartz-rich sandstones, and in very deep-seated rock formations, as from the Earth's upper mantle.

Polymorphs of SiO_2

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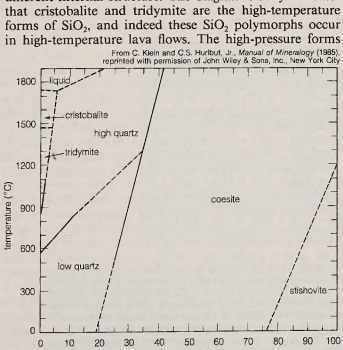


Figure 9: Stability fields, in terms of temperature and pressure, of various polymorphic forms of SiO_2.

CHEMICAL COMPOSITION

The chemical composition of a mineral is of fundamental importance because its properties greatly depend on it. Such properties, however, are determined not only by the chemical composition but also by the geometry of the constituent atoms and ions and by the nature of the electrical forces that bind them. Thus, for a complete understanding of minerals, their internal structure, chemistry, and bond types must be considered.

Various analytical techniques may be employed to obtain the chemical composition of a mineral. Quantitative chemical analyses conducted prior to 1947 mainly utilized so-called wet analytical methods, in which the mineral sample is first dissolved. Various compounds are then precipitated from the solution, which are weighed to obtain a gravimetric analysis. Since 1947 a number of analytical procedures have been introduced that provide faster but somewhat less accurate results. Most analyses performed since 1960 have made use of instrumental methods such as optical emission, X-ray fluorescence, atomic absorption spectroscopy, and electron microprobe analysis. Relatively well-established error ranges have been documented for these methods, and samples must be prepared in a specific manner for each technique. A distinct advantage of wet analytical procedures is that they make it possible to determine quantitatively the oxidation states of positively charged atoms, called cations (*e.g.*, Fe^{2+} versus Fe^{3+}), and to ascertain the amount of water in hydrous minerals. Instrumental techniques, on the other hand, cannot provide this type of information.

Chemical analyses

To ensure an accurate chemical analysis, the selected sample must contain only one mineral species (*i.e.*, the one for which the analysis is being done) and must not have undergone alteration processes. Since it is frequently difficult, and at times impossible, to obtain as much as 0.1 to 1 gram of "clean" material for analysis, the results should be accompanied by specifications on the amount of impurities present. To reduce the effect of the impurities, an instrumental technique, such as electron microprobe analysis, is often employed. In this method, quantitative analysis in situ may be performed on mineral grains only 1 micrometre (10^{-4} centimetre) in diameter.

MINERAL FORMULAS

Elements may exist in the native (uncombined) state, in which case their formulas are simply their chemical symbols: gold (Au), carbon (C) in its polymorphic form of diamond, and sulfur (S) are common examples. Most minerals, however, occur as compounds consisting of two or more elements; their formulas are obtained from quantitative chemical analyses and indicate the relative proportions of the constituent elements. The formula of sphalerite, ZnS, reflects a one-to-one ratio between atoms of zinc and those of sulfur. In bornite (Cu_5FeS_4), there are five atoms of copper (Cu), one atom of iron (Fe), and four atoms of sulfur. There exist relatively few minerals with constant composition; notable examples include quartz (SiO_2) and kyanite (Al_2SiO_5). Minerals of this sort are termed pure substances. Most minerals display considerable variation in the ions that occupy specific atomic sites within their structure. For example, the iron content of rhodochrosite ($MnCO_3$) may vary over a wide range. As ferrous iron (Fe^{2+}) substitutes for manganese cations (Mn^{2+}) in the rhodochrosite structure, the formula for the mineral might be given in more general terms—namely (Mn, Fe)CO_3. The amounts of manganese and iron are variable, but the ratio of the cation to the negatively charged anionic group remains fixed at one Mn^{2+} or Fe^{2+} atom to one CO_3 group.

COMPOSITIONAL VARIATION

As stated above, most minerals exhibit a considerable range in chemical composition. Such variation results from the replacement of one ion or ionic group by another in

a particular structure. This phenomenon is termed ionic substitution, or solid solution. Three types of solid solution are possible, and these may be described in terms of their corresponding mechanisms—namely, substitutional, interstitial, and omission.

Substitutional solid solution

Substitutional solid solution is the most common variety. For example, as described above, in the carbonate mineral rhodochrosite ($MnCO_3$), Fe^{2+} may substitute for Mn^{2+} in its atomic site in the structure.

The degree of substitution may be influenced by various factors, with the size of the ion being the most important. Ions of two different elements can freely replace one another only if their ionic radii differ by approximately 15 percent or less. Limited substitution can occur if the radii differ by 15 to 30 percent, and a difference of more than 30 percent makes substitution unlikely. These limits, calculated from empirical data, are only approximate.

The temperature at which crystals grow also plays a significant role in determining the extent of ionic substitution. The higher the temperature, the more extensive is the thermal disorder in the crystal structure and the less exacting are the spatial requirements. As a result, ionic substitution that could not have occurred in crystals grown at low temperatures may be present in those grown at higher ones. The high-temperature form of $KAlSi_3O_8$ (sanidine), for example, can accommodate more sodium (Na) in place of potassium (K) than can microcline, its low-temperature counterpart.

An additional factor affecting ionic substitution is the maintenance of a balance between the positive and negative charges in the structure. Replacement of a monovalent ion (*e.g.*, Na^+, a sodium cation) by a divalent ion (*e.g.*, Ca^{2+}, a calcium cation) requires further substitutions to keep the structure electrically neutral.

Simple cationic or anionic substitutions are the most basic types of substitutional solid solution. A simple cationic substitution can be represented in a compound of the general form A^+X^- in which cation B^+ replaces in part or in total cation A^+. Both cations in this example have the same valence (+1), as in the substitution of K^+ (potassium ions) for Na^+ (sodium ions) in the NaCl (sodium chloride) structure. Similarly, the substitution of anion X^- by Y^- in an A^+X^- compound represents a simple anionic substitution; this is exemplified by the replacement of Cl^- (chlorine ions) with Br^- (bromine ions) in the structure of KCl (potassium chloride). A complete solid-solution series involves the substitution in one or more atomic sites of one element for another that ranges over all possible compositions and is defined in terms of two end-members. For example, the two end-members of olivine [$(Mg, Fe)_2SiO_4$], forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4), define a complete solid-solution series in which magnesium cations (Mg^{2+}) are replaced partially or totally by Fe^{2+}.

In some instances, a cation B^{2+} may replace some A^{2+} of compound A^+X^{2-}. So that the compound will remain neutral, an equal amount of A^{2+} must concurrently be replaced by a third cation, C^+. This is given in equation form as $2A^{2+} \leftrightarrows B^{3+} + C^+$; the positive charge on each side is the same. Substitutions such as this are termed coupled substitutions. The plagioclase feldspar series exhibits complete solid solution, in the form of coupled substitutions, between its two end-members, albite ($NaAlSi_3O_8$) and anorthite ($CaAl_2Si_2O_8$). Every atomic substitution of Na^+ by Ca^{2+} is accompanied by the replacement of a silicon cation (Si^{4+}) by an aluminum cation (Al^{3+}), thereby maintaining electrical neutrality: $Na^+ + Si^{4+} \leftrightarrows Ca^{2+} + Al^{3+}$.

Interstitial substitution

The second major type of ionic substitution is interstitial solid solution, or interstitial substitution. It takes place when atoms, ions, or molecules fill the interstices (voids) found between the atoms, ions, or ionic groups of a crystal structure. The interstices may take the form of channellike cavities in certain crystals, such as the ring silicate beryl ($Be_3Al_2Si_6O_{18}$). Potassium, rubidium (Rb), cesium (Cs), and water, as well as helium (He), are some of the large ions and gases found in the tubular voids of beryl.

The least common type of solid solution is omission solid solution, in which a crystal contains one or more atomic sites that are not completely filled. The best-known example is exhibited by pyrrhotite ($Fe_{1-x}S$). In this mineral, each iron atom is surrounded by six neighbouring sulfur atoms. If every iron site in pyrrhotite was occupied by ferrous iron, its formula would be FeS. There are, however, varying percentages of vacancy in the iron site, so that the formula is given as Fe_nS_{n+1} through Fe_7S_8, the latter being very near to pure FeS. The formula for pyrrhotite is normally written as $Fe_{1-x}S$, with x ranging from 0 to 0.2. It is one of the minerals referred to as a defect structure, because it has a structural site that is not completely occupied.

CHEMICAL BONDING

Electrical forces are responsible for binding together the atoms, ions, and ionic groups that constitute crystalline solids. The physical and chemical properties of minerals are attributable for the most part to the types and strengths of these binding forces; hardness, cleavage, fusibility, electrical and thermal conductivity, and the coefficient of thermal expansion are examples of such properties. On the whole, the hardness and melting point of a crystal increase proportionally with the strength of the bond, while its coefficient of thermal expansion decreases. The extremely strong forces that link the carbon atoms of diamond, for instance, are responsible for its distinct hardness. Periclase (MgO) and halite (NaCl) have similar structures; however, periclase has a melting point of 2,800° C (5,072° F), whereas halite melts at 801° C (1,474° F). This discrepancy reflects the difference in the bond strength of the two minerals: since the atoms of periclase are joined by a stronger electrical force, a greater amount of heat is needed to separate them.

The electrical forces, called chemical bonds, can be divided into five types: ionic, covalent, metallic, van der Waals, and hydrogen bonds. Classification in this manner is largely one of expediency; the chemical bonds in a given mineral may in fact possess characteristics of more

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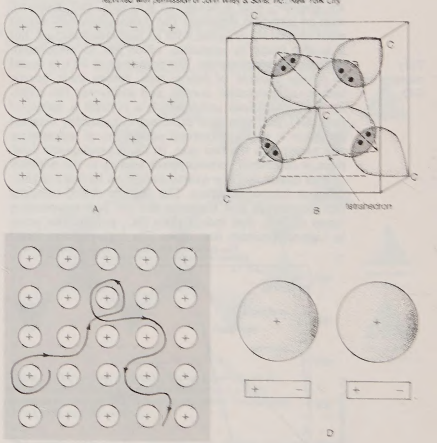


Figure 10: *Chemical bonding in crystalline solids.*
(A) An idealized ionic structure. (B) Schematic representation of covalent bonding in diamond. (C) Schematic cross section of the structure of a metal. Each circle with a positive charge represents the nucleus of a metal atom. Mobile electrons are represented as clouds surrounding the atoms (light gray shading). A possible electron path around the nuclei is shown. (D) Weak dipole attraction of the van der Waals bond. The polarization of an atom, resulting from an increase in the concentration of electrons on one side of the atom, causes the dipole attraction.

Table 2: Examples of Properties Conferred by the Major Types of Chemical Bonding

property	bond type			
	ionic (electrostatic)	covalent (electron-shared)	metallic	van der Waals (residual)
Bond strength	strong	very strong	variable strength, generally moderate	weak
Mechanical	hardness moderate to high, depending on interionic distance and charge; brittle	hardness great; brittle	hardness generally low to moderate; gliding common; high plasticity; sectile, ductile, malleable	crystals soft and somewhat plastic
Electrical	poor conductors in the solid state; melts and solutions conduct by ion transport	insulators in solid state and melt	good conductors; conduction by electron transport	insulators in both solid and liquid states
Thermal (melting point = m.p.; coeffient of thermal expansion = coef.)	m.p. moderate to high, depending on interionic distance and charge; low coef.	m.p. high; low coef.; atoms and molecules in melt	variable m.p. and coef.; atoms in melt	low m.p.; high coef.; liquid crystal molecules in melt
Solubility	soluble in polar solvents to yield solutions containing ions	very low solubilities	insoluble, except in acids or alkalis by chemical reaction	soluble in organic solvents to yield solutions
Structural	nondirected; gives structures of high coordination and symmetry	highly directional; gives structures of lower coordination and symmetry	nondirected; gives structures of very high coordination and symmetry	nondirected; symmetry low because of the shape of the molecules
Examples	halite (NaCl), calcite ($CaCO_3$), fluorite (CaF_2), most minerals	diamond (C), sphalerite (ZnS), molecules of O_2, organic molecules	copper (Cu), silver (Ag), gold (Au), electrum (Au, Ag), most other metals	iodine (I_2), organic compounds, graphite (weak bond)

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than one bond type. For example, the forces that link the silicon and oxygen atoms in quartz exhibit in nearly equal amount the characteristics of both ionic and covalent bonds. As stated above, the electrical interaction between the atoms of a crystal determine its physical and chemical properties. Thus, classifying minerals according to their electrical forces will cause those species with similar properties to be grouped together. This fact justifies classification by bond type.

Ionic bonds. Atoms have a tendency to gain or lose electrons so that their outer orbitals become stable; this is normally accomplished by these orbitals being filled with the maximum allowed number of valence electrons. Metallic sodium, for example, has one valence electron in its outer orbital; it becomes ionized by readily losing this electron and exists as the cation Na^+. Conversely, chlorine gains an electron to complete its outer orbital, thereby forming the anion Cl^-. In the mineral halite, NaCl (common, or rock, salt), the chemical bonding that holds the Na^+ and Cl^- ions together is the attraction between the two opposite charges. This bonding mechanism is referred to as ionic, or electrovalent (see Figure 10A).

Bonding in halite

Ionically bonded crystals typically display moderate hardness and specific gravity, rather high melting points, and poor thermal and electrical conductivity. The electrostatic charge of an ion is evenly distributed over its surface, and so a cation tends to become surrounded with the maximum number of anions that can be arranged around it. Since ionic bonding is nondirectional, crystals bonded in this manner normally display high symmetry (see Table 2).

Covalent bonds. In the discussion of the ionic bond, it was noted that chlorine readily gains an electron to achieve a stable electron configuration. An incomplete outer orbital places a chlorine atom in a highly reactive state, so it attempts to combine with nearly any atom in its proximity. Because its closest neighbour is usually another chlorine atom, the two may bond together by sharing one pair of electrons. As a result of this extremely strong bond, each chlorine atom enters a stable state.

The electron-sharing, or covalent, bond is the strongest of all chemical bond types. Minerals bonded in this manner display general insolubility, great stability, and a high melting point. Crystals of covalently bonded minerals tend to exhibit lower symmetry than their ionic counterparts because the covalent bond is highly directional, localized in the vicinity of the shared electrons (see Table 2).

The Cl_2 molecules formed by linking two neighbouring chlorine atoms are stable and do not combine with other molecules. Atoms of some elements, however, have more than one electron in the outer orbital and thus may bond to several neighbouring atoms to form groups, which in turn may join together in larger combinations. Carbon, in the polymorphic form of diamond, is a good example of this type of covalent bonding. There are four valence electrons in a carbon atom, so that each atom bonds with four others in a stable tetrahedral configuration (see Figure 10B). A continuous network is formed by the linkage of every carbon atom in this manner. The rigid diamond structure results from the strong localization of the bond energy in the vicinity of the shared electrons; this makes diamond the hardest of all natural substances. Diamond does not conduct electricity, because all the valence electrons of its constituent atoms are shared to form bonds and therefore are not mobile (see Table 2).

Metallic bonds. Bonding in metals is distinct from that in their salts, as reflected in the significant differences

between the properties of the two groups. In contrast to salts, metals display high plasticity, tenacity, ductility, and conductivity. Many are characterized by lower hardness and have higher melting and boiling points than, for example, covalently bonded materials. All these properties result from a metallic bonding mechanism that can be envisioned as a collection of positively charged ions immersed in a cloud of valence electrons (see Figure 10C). The attraction between the cations and the electrons holds a crystal together. The electrons are not bound to any particular cation and are thus free to move throughout the structure. In fact, in the metals sodium, cesium, rubidium, and potassium, the radiant energy of light can cause electrons to be removed from their surfaces entirely. (This result, known as the photoelectric effect, is utilized in light meters.) Electron mobility is responsible for the ability of metals to conduct heat and electricity. The native metals are the only minerals to exhibit pure metallic bonding (see Table 2).

Electron mobility in metals

Van der Waals bonds. Neutral molecules may be held together by a weak electric force known as the van der Waals bond. It results from the distortion of a molecule so that a small positive charge develops on one end and a corresponding negative charge develops on the other (see Figure 10D). A similar effect is induced in neighbouring molecules, and this dipole effect propagates throughout the entire structure. An attractive force is then formed between oppositely charged ends of the dipoles. Van der Waals bonding is common in gases and organic liquids and solids, but it is rare in minerals. Its presence in a mineral defines a weak area with good cleavage and low hardness. In graphite, carbon atoms lie in covalently bonded sheets with van der Waals forces acting between the layers (see Figure 11).

Hydrogen bonds. In addition to the four major bond types described above, there is an interaction called hydrogen bonding. This takes place when a hydrogen atom, bonded to an electronegative atom such as oxygen, fluorine, or nitrogen, is also attracted to the negative end of a neighbouring molecule. A strong dipole-dipole interaction is produced, forming a bond between the two molecules. Hydrogen bonding is common in hydroxides and in many of the layer silicates—*e.g.,* micas and clay minerals.

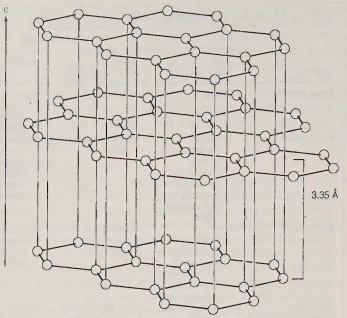


Figure 11: The structure of graphite with strong covalent bonding between the carbon atoms within a layer and weak van der Waals bonding between layers. The large separation distance between layers (3.35 Å) reflects a zone of weakness and easy slippage.

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PHYSICAL PROPERTIES

The physical properties of minerals are the direct result of the structural and chemical characteristics of the minerals. Some properties can be determined by inspection of a hand specimen or by relatively simple tests on such a specimen. Others, such as those determined by optical and X-ray diffraction techniques, require special and often sophisticated equipment and may involve elaborate sample preparation. In the discussion that follows, emphasis is placed on those properties that can be most easily evaluated with only simple tests.

Crystal habit and crystal aggregation. The external shape (habit) of well-developed crystals can be visually studied and classified according to the crystal systems and crystal classes listed in Table 1. The majority of crystal occurrences, however, are not part of well-formed single crystals but are found as crystals grown together in aggregates. Examples of some descriptive terms for such aggregations, illustrated in Figure 12, are given here: *granular,* an intergrowth of mineral grains of approximately the same size; *lamellar,* flat, platelike individuals arranged in layers; *bladed,* elongated crystals flattened like a knife blade; *fibrous,* an aggregate of slender fibres, parallel or radiating; *acicular,* slender, needlelike crystals; *radiating,* individuals forming starlike or circular groups; *globular,* radiating individuals forming small spherical or hemispherical groups; *dendritic,* in slender divergent branches, somewhat plantlike; *mammillary,* large smoothly rounded, masses resembling mammae, formed by radiating crystals; *botryoidal,* globular forms resembling a bunch of grapes; *colloform,* spherical forms composed of radiating indi-

Typical forms of aggregates

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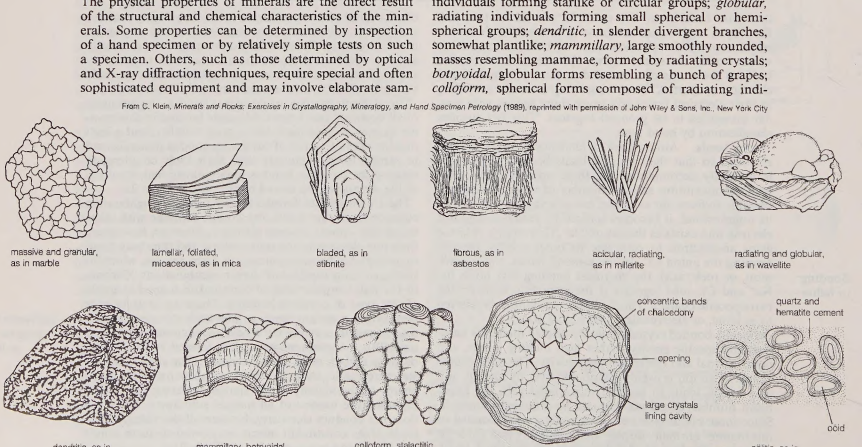


Figure 12: Common crystal aggregations and habits.

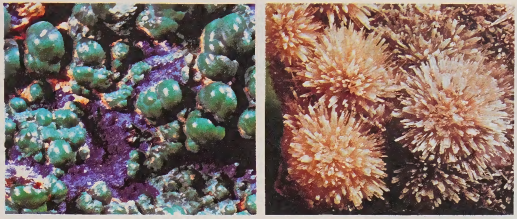


Figure 13: (Left) Reniform (kidney-shaped) masses of green malachite from Zacatecas, Mex. Small crystals of blue azurite coat some of the malachite. (Right) Divergent groupings of needlelike crystals of aragonite from Huttenberg, Austria.

By courtesy of (left) the MacFall collection, (right) Illinois State Museum; photographs, (left) Mary A. Root—EB Inc., (right) John H. Gerard—EB Inc.

viduals without regard to size (this includes botryoidal, reniform, and mammillary forms); *stalactitic,* pendent cylinders or cones resembling icicles; *concentric,* roughly spherical layers arranged about a common centre, as in agate and in geodes; *geode,* a partially filled rock cavity lined by mineral material (geodes may be banded as in agate owing to successive depositions of material, and the inner surface is often covered with projecting crystals); and *oölitic,* an assemblage consisting of small spheres resembling fish roe.

Photographs of two different types of aggregations in minerals are shown in Figure 13.

Cleavage and fracture. Both these properties represent the reaction of a mineral to an external force. Cleavage is breakage along planar surfaces, which are parallel to possible external faces on the crystal. It results from the tendency of some minerals to split in certain directions that are structurally weaker than others. Some crystals exhibit well-developed cleavage, as seen by the planar cleavage in mica; perfect cleavage of this sort is characterized by smooth, shiny surfaces. In other minerals, such as quartz, cleavage is absent. Quality and direction are the general characteristics used to describe cleavage. Quality is expressed as perfect, good, fair, and so forth; cleavage directions of a crystal are consistent with its overall symmetry (see Table 1). Various types of cleavage patterns are illustrated in Figure 14.

Some crystals do not usually break in any particular direction, reflecting roughly equal bond strengths throughout the crystal structure. Breakage in such minerals is known as fracture. The term conchoidal is used to describe fracture with smooth, curved surfaces that resemble the interior of a seashell; it is commonly observed in quartz and glass (see Figure 14G). Splintery fracture is breakage into elongated fragments like splinters of wood, while hackly fracture is breakage along jagged surfaces.

Lustre. The term lustre refers to the general appearance of a mineral surface in reflected light. The main types of lustre, metallic and nonmetallic, are distinguished easily by the human eye after some practice, but the difference between them cannot be quantified and is rather difficult to describe. Metallic refers to the lustre of an untarnished metallic surface such as gold, silver, copper, or steel. These materials are opaque to light; none passes through even at thin edges. Pyrite (FeS_2), chalcopyrite ($CuFeS_2$), and galena (PbS) are common minerals that have metallic lustre. Nonmetallic lustre is generally exhibited by light-coloured minerals that transmit light, either through thick portions or at least through their edges. The following terms are used to distinguish the lustre of nonmetallic minerals: *vitreous,* having the lustre of a piece of broken glass (this is commonly seen in quartz and many other nonmetallic minerals); *resinous,* having the lustre of a piece of resin (this is common in sphalerite [ZnS]); *pearly,* having the lustre of mother-of-pearl (*i.e.,* an iridescent pearllike lustre characteristic of mineral surfaces that are

Non-metallic lustre

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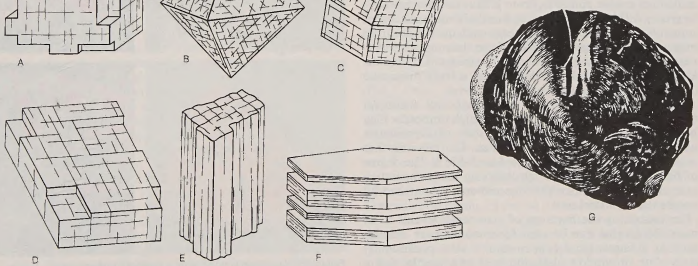


Figure 14: *Cleavage and fracture.*
(A) Cubic cleavage as in halite (NaCl) and galena (PbS). (B) Octahedral cleavage as in carbon (C) occurring in the form of diamond. (C) Dodecahedral cleavage as in sphalerite (ZnS). (D) Rhombohedral cleavage as in calcite ($CaCO_3$). (E) Prismatic cleavage as in members of the pyroxene family (*e.g.,* augite). (F) Basal cleavage as in micas. (G) Conchoidal fracture as in glass and quartz.

parallel to well-developed cleavage planes; the cleavage surface of talc [$Mg_3Si_4O_{10}(OH)_2$] may show pearly lustre); *greasy,* having the appearance of being covered with a thin layer of oil (such lustre results from the scattering of light by a microscopically rough surface; some nepheline [(Na, K)$AlSiO_4$] and milky quartz may exhibit this); *silky,* descriptive of the lustre of a skein of silk or a piece of satin and characteristic of some minerals in fibrous aggregates (examples are fibrous gypsum [$CaSO_4 \cdot 2H_2O$], known as satin spar, and chrysotile asbestos [$Mg_3Si_2O_5(OH)_4$]); and *adamantine,* having the brilliant lustre of diamond, exhibited by minerals with a high refractive index comparable to diamond and which as such refract light as strongly as the latter (examples are cerussite [$PbCO_3$] and anglesite [$PbSO_4$]).

Colour. Minerals occur in a great variety of colours. Because colour varies not only from one mineral to another but also within the same mineral (or mineral group), the observer must learn in which minerals it is a constant property and can thus be relied on as a distinguishing criterion. Most minerals that have a metallic lustre vary little in colour, but nonmetallic minerals can demonstrate wide variance. Although the colour of a freshly broken surface of a metallic mineral is often highly diagnostic, this same mineral may become tarnished with time. Such a tarnish may dull minerals such as galena (PbS), which has a bright, bluish lead-gray colour on a fresh surface but may become dull upon long exposure to air. Bornite (Cu_5FeS_4), which on a freshly broken surface has a brownish bronze colour, may be so highly tarnished on an older surface that it shows variegated purples and blues; hence, it is called peacock ore. In other words, in the identification of minerals with a metallic lustre, it is important for the observer to have a freshly broken surface for accurate determination of colour.

Peacock ore

A few minerals with nonmetallic lustre display a constant colour that can be used as a truly diagnostic property. Examples are malachite, which is green; azurite, which is blue; rhodonite, which is pink; turquoise, which gives its name to the colour turquoise, a greenish blue to blue-green; and sulfur, which is yellow (see Figure 15). Many nonmetallic minerals have a relatively narrow range of colours, although some have an unusually wide range. Members of the plagioclase feldspar series range from almost pure white in albite through light gray to darker gray toward the anorthite end-member. Most common garnets show various shades of red to red-brown to brown. Members of the monoclinic pyroxene group range from almost white in pure diopside to light green in diopside containing a small amount of iron as a substitute for magnesium in the structure through dark green in hedenbergite to almost black in many augites. Members of the orthopyroxene series (enstatite to orthoferrosilite) range from light beige to darker brown. On the other hand, tourmaline may show many colours (red, blue, green, brown, and black) as well as distinct colour zonation, from colourless through pink to green, within a single crystal. Similarly, numerous gem minerals such as corundum, beryl, and quartz occur in many colours; the gemstones cut from them are given varietal names. In short, in nonmetallic minerals of various kinds colour is a helpful, though not a truly diagnostic (and therefore unique), property.

Hardness. Hardness (H) is the resistance of a mineral to scratching. It is a property by which minerals may be described relative to a standard scale of 10 minerals known as the Mohs scale of hardness. The minerals that make up the Mohs scale are listed in Table 3. The degree of hardness is determined by observing the comparative ease or difficulty with which one mineral is scratched by another or by a steel tool.

For measuring the hardness of a mineral, several common objects that can be used for scratching are helpful, such as a fingernail, a copper coin, a steel pocketknife, glass plate or window glass, the steel of a needle, and a streak plate. The approximate hardness of these materials is listed next to the minerals of the Mohs scale in Table 3.

Because there is a general link between hardness and chemical composition, these generalizations can be made:

1. Most hydrous minerals are relatively soft ($H < 5$).

Table 3: Mohs Hardness Scale and Observations on Hardness of Some Additional Materials

mineral	Mohs hardness	other materials	observations on the minerals
Talc	1		very easily scratched by the fingernail; has a greasy feel
Gypsum	2	~2.2 fingernail	can be scratched by the fingernail
Calcite	3	~3.2 copper penny	very easily scratched with a knife and just scratched with a copper coin
Fluorite	4		very easily scratched with a knife but not as easily as calcite
Apatite	5	~5.1 pocketknife	scratched with a knife with difficulty
		~5.5 glass plate	
Orthoclase	6	~6.5 steel needle	cannot be scratched with a knife, but scratches glass with difficulty
Quartz	7	~7.0 streak plate	scratches glass easily
Topaz	8		scratches glass very easily
Corundum	9		cuts glass
Diamond	10		used as a glass cutter

Source: Modified from C. Klein, *Minerals and Rocks: Exercises in Crystallography, Mineralogy, and Hand Specimen Petrology.* Copyright © 1989. Reprinted by permission of John Wiley & Sons, Inc.

2. Halides, carbonates, sulfates, and phosphates also are relatively soft ($H < 5\frac{1}{2}$).
3. Most sulfides are relatively soft ($H < 5$), with marcasite and pyrite being examples of exceptions ($H < 6$ to $6\frac{1}{2}$).
4. Most anhydrous oxides and silicates are hard ($H > 5\frac{1}{2}$).

Because hardness is a highly diagnostic property in mineral identification, most determinative tables use relative hardness as a sorting parameter.

Tenacity. Several mineral properties that depend on the cohesive force between atoms (and ions) in mineral structures are grouped under tenacity. A mineral's tenacity can be described by the following terms: *malleable,* capable of being flattened under the blows of a hammer into thin sheets without breaking or crumbling into fragments (most of the native elements show various degrees of malleability, but particularly gold, silver, and copper); *sectile,* capable of being severed by the smooth cut of a knife (copper, silver, and gold are sectile); *ductile,* capable

Malleability of metals

By courtesy of (top left, top right, bottom right) Ted Boente; photographs, John H. Gerard—EB Inc., (bottom left) Floyd R. Gelsinger

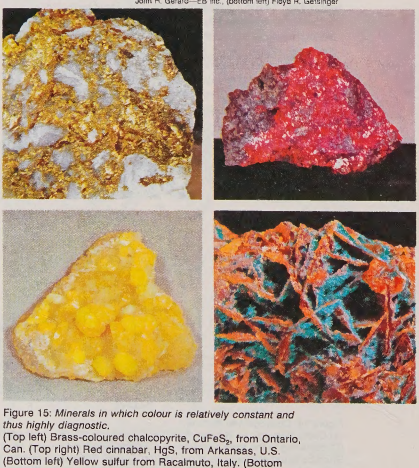


Figure 15: *Minerals in which colour is relatively constant and thus highly diagnostic.*
(Top left) Brass-coloured chalcopyrite, $CuFeS_2$, from Ontario, Can. (Top right) Red cinnabar, HgS, from Arkansas, U.S. (Bottom left) Yellow sulfur from Racalmuto, Italy. (Bottom right) Green dioptase (a hydrous copper silicate) with orange-yellow wulfenite, $PbMoO_4$, from Arizona, U.S.

of being drawn into the form of a wire (gold, silver, and copper exhibit this property); *flexible,* bending easily and staying bent after the pressure is removed (talc is flexible); *brittle,* showing little or no resistance to breakage, and as such separating into fragments under the blow of a hammer or when cut by a knife (most silicate minerals are brittle); and *elastic,* capable of being bent or pulled out of shape but returning to the original form when relieved (mica is elastic).

Specific gravity. Specific gravity (G) is defined as the ratio between the weight of a substance and the weight of an equal volume of water at 4° C. Thus a mineral with a specific gravity of 2 weighs twice as much as the same volume of water. Since it is a ratio, specific gravity has no units.

The specific gravity of a mineral depends on the atomic weights of all its constituent elements and the manner in which the atoms (and ions) are packed together. In mineral series whose species have essentially identical structures, those composed of elements with higher atomic weight have higher specific gravities. If two minerals (as in the two polymorphs of carbon, namely, graphite and diamond) have the same chemical composition, the difference in specific gravity reflects variation in internal packing of the atoms or ions (diamond, with a G of 3.51, has a more densely packed structure than graphite, with a G of 2.23).

Measurement of the specific gravity of a mineral specimen requires the use of a special apparatus. An estimate of the value, however, can be obtained by simply testing how heavy a specimen feels. Most people, from everyday experience, have developed a sense of relative weights for even such objects as nonmetallic and metallic minerals. For example, borax ($G = 1.7$) seems light for a nonmetallic mineral, whereas anglesite ($G = 6.4$) appears heavy. Average specific gravity reflects what a nonmetallic or metallic mineral of a given size should weigh. The average specific gravity for nonmetallic minerals falls between 2.65 and 2.75, which is seen in the range of values for quartz ($G = 2.65$), feldspar ($G = 2.60$ to 2.75), and calcite ($G = 2.72$). For metallic minerals, graphite ($G = 2.23$) feels light, while silver ($G = 10.5$) seems heavy. The average specific gravity for metallic minerals is approximately 5.0, the value for pyrite. With practice using specimens of known specific gravity, a person can develop the ability to distinguish between minerals that have comparatively small differences in specific gravity by merely lifting them.

Jolly balance

Although an approximate assessment of specific gravity can be obtained by the hefting of a hand specimen of a specific monomineral, an accurate measurement can only be achieved by using a specific gravity balance. An example of such an instrument is the Jolly balance, which provides numerical values for a small mineral specimen (or fragment) in air as well as in water. Such accurate measurements are highly diagnostic and can greatly aid in the identification of an unknown mineral sample.

Magnetism. Only two minerals exhibit readily observed magnetism: magnetite (Fe_3O_4), which is strongly attracted to a hand magnet, and pyrrhotite ($Fe_{1-x}S$), which typically shows a weaker magnetic reaction. Ferromagnetic is a term that refers to materials that exhibit strong magnetic attraction when subjected to a magnetic field. Materials that show only a weak magnetic response in a strong applied magnetic field are known as paramagnetic. Those materials that are repelled by an applied magnetic force are known as diamagnetic. Because minerals display a wide range of slightly different magnetic properties, they can be separated from each other by an electromagnet. Such magnetic separation is a common procedure both in the laboratory and on a commercial scale.

Fluorescence. Some minerals, when exposed to ultraviolet light, will emit visible light during irradiation; this is known as fluorescence. Some minerals fluoresce only in shortwave ultraviolet light, others only in longwave ultraviolet light, and still others in either situation. Both the colour and intensity of the emitted light vary significantly with the wavelengths of ultraviolet light. Due to the unpredictable nature of fluorescence, some specimens of a mineral manifest it, while other seemingly similar specimens, even those from the same geographic area, do not.

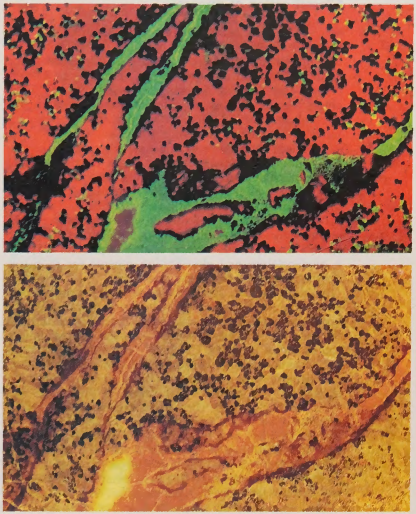


Figure 16: *Fluorescence in minerals.*
(Top) Specimen showing bright fluorescent colours resulting from ultraviolet irradiation of calcite (calcium carbonate; red fluorescence) with grains of franklinite (a zinc, manganese, and iron oxide; black because it is nonfluorescent) and veins and grains of willemite (a zinc silicate; green fluorescence), from Franklin, N.J., U.S. (Bottom) Same specimen in ordinary light, in which the willemite grains and veins are brownish gold and the franklinite grains are dark brown.
Benjamin M. Shaub

Some minerals that may exhibit fluorescence are fluorite, scheelite, calcite, scapolite, willemite, and autunite. Specimens of willemite and calcite from the Franklin district of New Jersey in the United States may show brilliant fluorescent colours (see Figure 16).

Solubility in hydrochloric acid. The positive identification of carbonate minerals is aided greatly by the fact that the carbon-oxygen bond of the CO_3 group in carbonates becomes unstable and breaks down in the presence of hydrogen ions (H^+) available in acids. This is expressed by the reaction $2H^+ + CO_3^{2-} \rightarrow H_2O + CO_2$, which is the basis for the so-called fizz test with dilute hydrochloric acid (HCl). Calcite, aragonite, witherite, and strontianite, as well as copper carbonates, show bubbling, or effervescence, when a drop of dilute hydrochloric acid is placed on the mineral. This "fizz" is due to the release of carbon dioxide (CO_2). Other carbonates such as dolomite, rhodochrosite, magnesite, and siderite will show effervescence only in hot hydrochloric acid.

Fizz test

Radioactivity. Minerals containing uranium (U) and thorium (Th) continually undergo decay reactions in which radioactive isotopes of uranium and thorium form various daughter elements and also release energy in the form of alpha and beta particles and gamma radiation. The radiation produced can be measured in the laboratory or in the field using a Geiger counter or a scintillation counter. A radiation counter therefore is helpful in identifying uranium- and thorium-containing minerals, such as uraninite, pitchblende, thorianite, and autunite.

Several rock-forming minerals contain enough radioactive elements to permit the determination of the time elapsed since the radioactive material was incorporated into the mineral (see GEOCHRONOLOGY: *Absolute dating: Principles of isotopic dating.*)

Classification of minerals

Since the middle of the 19th century, minerals have been classified on the basis of their chemical composition. Under this scheme, they are divided into classes according to their dominant anion or anionic group (*e.g.,* halides, oxides, and sulfides). Several reasons justify use of this criterion as the distinguishing factor at the highest level of mineral classification. First, the similarities in properties of minerals with identical anionic groups are generally more pronounced than those with the same dominant cation. For example, carbonates have stronger resemblences to one another than do copper minerals. Secondly, minerals that have identical dominant anions are likely to be found in the same or similar geologic environments. Therefore, sulfides tend to occur together in vein or replacement deposits, while silicate-bearing rocks make up much of the Earth's crust. Third, current chemical practice employs a nomenclature and classification scheme for inorganic compounds based on similar principles.

Investigators have found, however, that chemical composition alone is insufficient for classifying minerals. Determination of internal structures, accomplished through the use of X rays, allows a more complete appreciation of the nature of minerals. Chemical composition and internal structure together constitute the essence of a mineral and determine its physical properties; thus, classification should rely on both. Crystallochemical principles—*i.e.,* those relating to both chemical composition and crystal structure—were first applied by the British physicist W. Lawrence Bragg and the Norwegian mineralogist Victor Moritz Goldschmidt in the study of silicate minerals. The silicate group was subdivided in part on the basis of composition but mainly according to internal structure. Based on the topology of the SiO_4 tetrahedrons, the subclasses include framework, chain, and sheet silicates, among others. Such mineral classifications are logical and well-defined.

Classification groups

The broadest divisions of the classification used in the present discussion are (1) native elements, (2) sulfides, (3) sulfosalts, (4) oxides and hydroxides, (5) halides, (6) carbonates, (7) nitrates, (8) borates, (9) sulfates, (10) phosphates, and (11) silicates.

NATIVE ELEMENTS

Apart from the free gases in the Earth's atmosphere, some 20 elements occur in nature in a pure (*i.e.,* uncombined) or nearly pure form. Known as the native elements, they are partitioned into three families: metals, semimetals, and nonmetals (see Table 4). The most common native metals, which are characterized by simple crystal structures, make up three groups: the gold group, consisting of gold, silver, copper, and lead; the platinum group, composed of platinum, palladium, iridium, and osmium; and the iron group, containing iron and nickel-iron. Mercury, tantalum, tin, and zinc are other metals that have been found in the native state. The native semimetals are divided into two isostructural groups (those whose members share a common structure type): (1) antimony, arsenic, and bismuth, with the latter two being more common in nature, and (2) the rather uncommon selenium and tellurium. Carbon, in the form of diamond and graphite, and sulfur are the most important native nonmetals.

Metals. Gold, silver, and copper are members of the same group (column) in the periodic table of elements (see CHEMICAL ELEMENTS: *Periodic law and table*) and therefore have similar chemical properties. In the uncombined state, their atoms are joined by the fairly weak metallic bond. These minerals share a common structure type, and their atoms are positioned in a simple cubic closest-packed arrangement. Gold and silver both have an atomic radius of 1.44 angstroms (Å), which enables complete solid solution to take place between them. The radius of copper is significantly smaller (1.28 Å), and as such copper substi-

Table 4: Native Elements

Metals		Semimetals	
Gold group		Arsenic group	
Gold	Au	Arsenic	As
Silver	Ag	Bismuth	Bi
Copper	Cu		
Platinum group		Nonmetals	
Platinum	Pt	Sulfur	S
Iron group		Diamond	C
Iron	Fe	Graphite	C
(Kamacite	Fe, Ni)		
(Taenite	Fe, Ni)		

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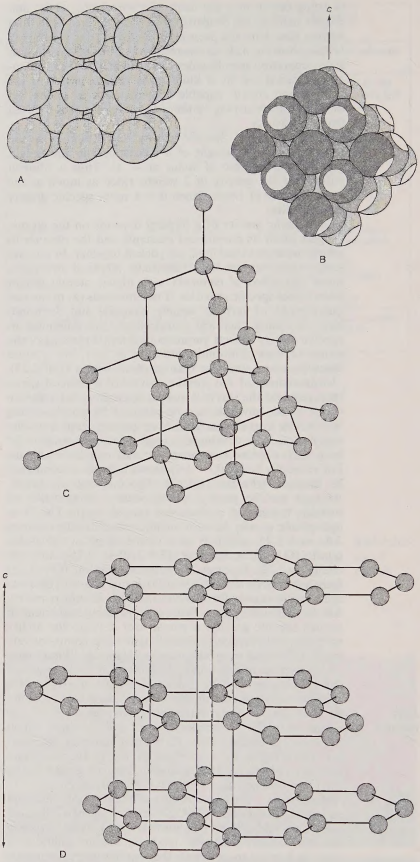


Figure 17: *Structures of some native elements.* (A) Close-packed model of simple cubic packing of equal spheres, as shown by iron. Each sphere is surrounded by eight closest neighbours. (B) Close-packed model of the structure of arsenic and antimony. Flat areas represent overlap between adjoining atoms. (C) Partial representation of the structure of diamond. (D) The structure of graphite with sheets perpendicular to the *c* axis.

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tutes only to a limited extent in gold and silver. Likewise, native copper contains only trace amounts of gold and silver in its structure.

Physical properties

Owing to their similar crystal structure, the members of the gold group display similar physical properties. All are rather soft, ductile, malleable, and sectile; gold, silver, and copper serve as excellent conductors of electricity and heat and exhibit metallic lustre and hackly fracture. These properties are attributable to their metallic bonding. The gold-group minerals crystallize in the isometric system and have high densities as a consequence of cubic closest packing.

In addition to the elements listed above, the platinum group also includes the rarer mineral alloys platiniridium and iridosmine. The members of this group are harder than the metals of the gold group and also have higher melting points.

The iron-group metals are isometric and have a simple cubic packed structure (see Figure 17A). Its members include pure iron, which is rarely found on the surface of the Earth, and two species of nickel-iron (kamacite and taenite), which have been identified as common constituents of meteorites. The atomic radii of iron and nickel are both approximately 1.24 Å, and so nickel is a frequent substitute for iron. The terrestrial core is thought to be composed largely of such iron-nickel alloys.

Semimetals. The semimetals antimony, arsenic, and bismuth have a structure type distinct from the simple-packed spheres of the metals. In these semimetals, each atom is positioned closer to three of its neighbouring atoms than to the rest. The structure of antimony and arsenic, composed of spheres that intersect along flat circular areas, is shown in Figure 17B.

The covalent character of the bonds joining the four closest atoms is linked to the electronegative nature of the semimetals, reflected by their position in the periodic table. Members of this group are fairly brittle, and they do not conduct heat and electricity nearly as well as the native metals. The bond type suggested by these properties is intermediate between metallic and covalent; it is consequently stronger and more directional than pure metallic bonding, resulting in crystals of lower symmetry.

Nonmetals. The native nonmetals diamond, graphite, and sulfur are structurally distinct from the metals and semimetals. The structure of sulfur (atomic radius = 1.04 Å), usually orthorhombic in form, may contain limited solid solution by selenium (atomic radius = 1.16 Å).

The polymorphs of carbon, graphite and diamond, display dissimilar structures, resulting in their differences in hardness and specific gravity. In diamond, each carbon atom is bonded covalently in a tetrahedral arrangement, producing a strongly bonded and exceedingly close-knit but not closest-packed structure (see Figure 17C). The carbon atoms of graphite, however, are arranged in six-membered rings in which each atom is surrounded by three close-by neighbours located at the vertices of an equilateral triangle (see Figure 17D). The rings are linked to form sheets that are separated by a distance exceeding one atomic diameter. Van der Waals forces act perpendicular to the sheets, offering a weak bond, which, in combination with the wide spacing, leads to perfect basal cleavage and easy gliding along the sheets.

Graphite and diamond

SULFIDES

This important class includes most of the ore minerals. The similar but rarer sulfarsenides are grouped here as well (see Table 5). Sulfide minerals consist of one or more metals combined with sulfur; sulfarsenides contain arsenic replacing some of the sulfur.

Sulfides are generally opaque and exhibit distinguishing colours and streaks. (Streak is the colour of a mineral's powder.) The nonopaque varieties (*e.g.*, cinnabar, realgar, and orpiment) possess high refractive indices, transmitting light only on the thin edges of a specimen.

Few broad generalizations can be made about the structures of sulfides, although these minerals can be classified into small groups according to similarities in structure. Ionic and covalent bonding are found in many sulfides, while metallic bonding is apparent in others as evidenced by their metal properties. The simplest and most symmetric sulfide structure is based on the architecture of the sodium chloride structure. A common sulfide mineral that crystallizes in this manner is the ore mineral of lead, galena. Its highly symmetric form consists of cubes modified by octahedral faces at their corners (see Figure 18). The structure of the common sulfide pyrite (FeS_2) also is modeled after the sodium chloride type; a disulfide grouping is located in a position of coordination with six surrounding ferrous iron atoms (see Figure 1). The high symmetry of this structure is reflected in the external morphology of pyrite (see Figure 2). Two other sulfide structures are illustrated in Figure 19. In the sphalerite (ZnS) structure, each zinc atom is surrounded by four sulfur atoms in a tetrahedral coordinating arrangement. In a derivative of this structure type, the chalcopyrite ($CuFeS_2$) structure, copper and iron ions can be thought of as having been regularly substituted in the zinc positions of the original sphalerite atomic arrangement.

Arsenopyrite (FeAsS) is a common sulfarsenide that occurs in many ore deposits. It is the chief source of the element arsenic.

Table 5: Common Sulfides, Sulfarsenides, and Sulfosalts

Sulfides and sulfarsenides	
Chalcocite	Cu_2S
Bornite	Cu_5FeS_4
Galena	PbS
Sphalerite	ZnS
Chalcopyrite	$CuFeS_2$
Pyrrhotite	$Fe_{1-x}S$ ($x = 0$–0.2)
Pentlandite	$(Fe, Ni)_9S_8$
Covellite	CuS
Cinnabar	HgS
Realgar	AsS
Orpiment	As_2S_3
Stibnite	Sb_2S_3
Pyrite	FeS_2
Marcasite	FeS_2
Molybdenite	MoS_2
Arsenopyrite	FeAsS
Sulfosalts	
Pyrargyrite	Ag_3SbS_3
Proustite	Ag_3AsS_3
Tetrahedrite	$(Cu, Fe)_{12}Sb_4S_{13}$
Tennantite	$(Cu, Fe)_{12}As_4S_{13}$
Enargite	Cu_3AsS_4
Bournonite	$PbCuSbS_3$

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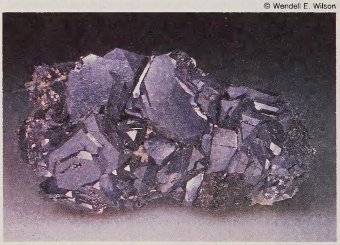


Figure 18: Intergrowth of galena (PbS) crystals, Madan, Bulg. The crystal forms are cubes modified at the corners by octahedral faces.

SULFOSALTS

There are approximately 100 species constituting the rather large and very diverse sulfosalt class of minerals. Some common examples are listed in Table 5. The sulfosalts differ notably from the sulfides and sulfarsenides with regard to the role of semimetals, such as arsenic (As) and antimony (Sb), in their structures. In the sulfarsenides, the semimetals substitute for some of the sulfur in the struc-

Role of semimetals

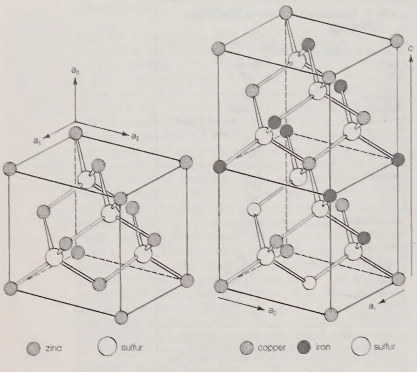


Figure 19: (A) The structure of sphalerite (ZnS). (B) The structure of chalcopyrite ($CuFeS_2$), a derivative of the sphalerite structure.

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ture, while in the sulfosalts they are found instead in the metal site. For example, in the sulfarsenide arsenopyrite (FeAsS), the arsenic replaces sulfur in a marcasite- (FeS_2-) type structure. In contrast, the sulfosalt enargite (Cu_3AsS_4) contains arsenic in the metal position, coordinated to four sulfur atoms. A sulfosalt such as Cu_3AsS_4 may also be thought of as a double sulfide, $3Cu_2S \cdot As_2S_3$.

OXIDES AND HYDROXIDES

These classes consist of oxygen-bearing minerals; the oxides combine oxygen with one or more metals, while the hydroxides are characterized by hydroxyl $(OH)^-$ groups.

The oxides are further divided into two main types: simple and multiple. Simple oxides contain a single metal combined with oxygen in one of several possible metal:oxygen ratios (X_2O): XO, X_2O, X_2O_3, etc. Ice, H_2O, is a simple oxide of the X_2O type that incorporates hydrogen as the cation. Although SiO_2 (quartz and its polymorphs) is the most commonly occurring oxide, it is discussed below in the section on silicates because its structure more closely resembles that of other silicon-oxygen compounds.

Table 6: Common Oxides

X_2O and XO types	
Cuprite	Cu_2O
Zincite	(Zn, Mn)O
X_2O_3 type	
Hematite group	
Corundum	Al_2O_3
Hematite	Fe_2O_3
Ilmenite	$FeTiO_3$
XO_2 type (excluding SiO_2)	
Rutile group	
Rutile	TiO_2
Pyrolusite	MnO_2
Cassiterite	SnO_2
Uraninite	UO_2*
XY_2O_4 type	
Spinel group	
Spinel	$MgAl_2O_4$
Gahnite	$ZnAl_2O_4$
Magnetite	Fe_3O_4
Chromite	$FeCr_2O_4$

*Composition actually ranges from UO_2 through U_3O_8 due to oxidation.

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Two nonequivalent metal sites (X and Y) characterize multiple oxides, which have the form XY_2O_4.

Unlike the minerals of the sulfide class, which exhibit ionic, covalent, and metallic bonding, oxide minerals generally display strong ionic bonding. They are relatively hard, dense, and refractory.

Examples of several oxides are given in Table 6. These minerals generally occur in small amounts in igneous and metamorphic rocks and also as preexisting grains in sedimentary rocks. Several oxides have great economic value, including the principal ores of iron (hematite and magnetite), chromium (chromite), manganese (pyrolusite, as well as the hydroxides, manganite and romanechite), tin (cassiterite), and uranium (uraninite).

Members of the hematite group are of the X_2O_3 type and have structures based on hexagonal closest packing of the oxygen atoms with octahedrally coordinated (surrounded by and bonded to six atoms) cations between them. Corundum and hematite share a common hexagonal architecture (see Table 1). In the ilmenite structure, iron and titanium occupy alternate Fe-O and Ti-O layers.

XO_2-type oxides

The XO_2-type oxides are divided into two groups. The first structure type, exemplified by rutile, contains cations in octahedral coordination with oxygen. The second resembles fluorite (CaF_2); each oxygen is bonded to four cations located at the corners of a fairly regular tetrahedron, and each cation lies within a cube at whose corners are eight oxygen atoms. This latter structure is exhibited by uranium, thorium, and cerium oxides, whose considerable importance arises from their roles in nuclear chemistry.

The spinel-group minerals have type XY_2O_4 and contain oxygen atoms in approximate cubic closest packing. The cations located within the oxygen framework are octahedrally (sixfold) and tetrahedrally (fourfold) coordinated with oxygen (see Figure 20).

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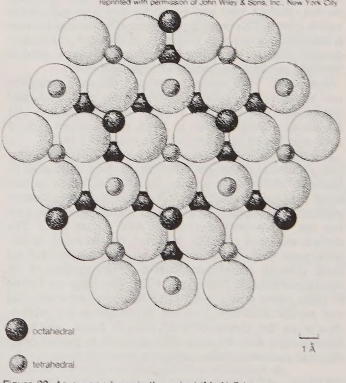


Figure 20: An oxygen layer in the spinel ($MgAl_2O_4$) structure. The large circles represent oxygen in approximate cubic closest packing; the cation layers on each side of the oxygen layer are also shown.

The $(OH)^-$ group of the hydroxides generally results in structures with lower bond strengths than in the oxide minerals. The hydroxide minerals tend to be less dense than the oxides and also are not as hard. All hydroxides form at low temperatures and are found predominantly as weathering products, as, for example, from alteration in hydrothermal veins. Some common hydroxides are brucite $[Mg(OH)_2]$, manganite $[MnO \cdot OH]$, diaspore $[\alpha\text{-}AlO \cdot OH]$, and goethite $[\alpha\text{-}FeO \cdot OH]$. The ore of aluminum, bauxite, consists of a mixture of diaspore, boehmite (γ-$AlO \cdot OH$—a polymorph of diaspore), and gibbsite $[Al(OH)_3]$, plus iron oxides. Goethite is a com-

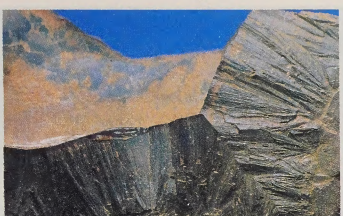


Figure 21: Goethite (α-FeO · OH) from Surrey, N.H., U.S.
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mon alteration product of iron-rich occurrences and is an iron ore in some localities (see Figure 21).

HALIDES

Members of this class are distinguished by the large-sized anions of the halogens chlorine, bromine, iodine, and fluorine. The ions carry a charge of negative one and easily become distorted in the presence of strongly charged bodies. When associated with rather large, weakly polarizing cations of low charge, such as those of the alkali metals, both anions and cations take the form of nearly perfect spheres. Structures composed of these spheres exhibit the highest possible symmetry.

Pure ionic bonding is exemplified best in the isometric halides, for each spherical ion distributes its weak electrostatic charge over its entire surface. These halides manifest relatively low hardness and moderate-to-high melting points. In the solid state they are poor thermal and electric conductors, but when molten they conduct electricity well.

Halogen ions may also combine with smaller, more strongly polarizing cations than the alkali metal ions. Lower symmetry and a higher degree of covalent bonding prevail in these structures. Water and hydroxyl ions may enter the structure, as in atacamite [$Cu_3Cl(OH)_3$].

The halides consist of about 80 chemically related minerals with diverse structures and widely varied origins. The most common are halite (NaCl), sylvite (KCl), chlorargyrite (AgCl), cryolite (Na_3AlF_6), fluorite (CaF_2), and atacamite. The structure of sodium chloride is illustrated in Figure 22A. By the arrangement of the ions, it is evident that no molecules are present in the structure. Each cation and anion is in octahedral coordination with its six closest neighbours. The NaCl structure is found in the crystals of many *XZ*-type halides, including sylvite (KCl) and chlorargyrite (AgCl). Some sulfides and oxides of *XZ* type crystallize in this structure type as well—for example, galena (PbS), alabandite (MnS), and periclase (MgO).

NaCl structure

Several XZ_2 halides have the same structure as fluorite (CaF_2), which is shown in Figure 22B. In fluorite, calcium cations are positioned at the corners and face centres of cubic unit cells. (A unit cell is the smallest group of atoms, ions, or molecules from which the entire crystal structure can be generated by its repetition.) Each fluorine anion is in tetrahedral coordination with four calcium ions, while each calcium cation is in eightfold coordination with eight fluorine ions that form the corners of a cube around it.

Uraninite (UO_2) and thorianite (ThO_2) are two of the several oxides that have a fluorite-type structure.

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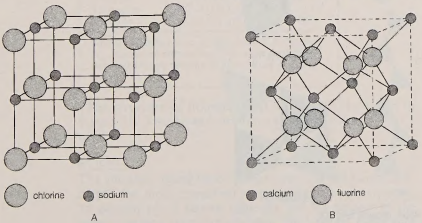


Figure 22: (A) The structure of halite, NaCl. (B) The structure of fluorite, CaF_2.

CARBONATES

The carbonate minerals contain the anionic complex $(CO_3)^{2-}$, which is triangular in its coordination—*i.e.*, with a carbon atom at the centre and an oxygen atom at each of the corners of an equilateral triangle. These anionic groups are strongly bonded, individual units and do not share oxygen atoms with one another. The triangular carbonate groups are the basic building units of all carbonate minerals and are largely responsible for the properties particular to the class.

Carbonates are frequently identified using the effervescence test with acid (see above *Physical properties: Solubility in hydrochloric acid*). The reaction that results in the characteristic fizz, $2H^+ + CO_3^{2-} \rightarrow H_2O + CO_2$, makes use of the fact that the carbon-oxygen bonds of the CO_3 groups are not quite as strong as the corresponding carbon-oxygen bonds in carbon dioxide.

The common anhydrous carbonates are divided into three groups that differ in structure type: calcite, aragonite, and dolomite. The copper carbonates azurite and malachite are the only notable hydrous varieties (see Table 7).

Table 7: Common Carbonates

Calcite group (hexagonal)		Aragonite group (orthorhombic)	
Calcite	$CaCO_3$	Aragonite	$CaCO_3$
Magnesite	$MgCO_3$	Witherite	$BaCO_3$
Siderite	$FeCO_3$	Strontianite	$SrCO_3$
Rhodochrosite	$MnCo_2$	Cerussite	$PbCO_3$
Smithsonite	$ZnCO_3$	Dolomite group (hexagonal)	
Monoclinic carbonates with $(OH)^-$		Dolomite	$CaMg(CO_3)_2$
Malachite	$Cu_2CO_3(OH)_2$	Ankerite	$CaFe(CO_3)_2$
Azurite	$Cu_3(CO_3)_2(OH)_2$		

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The members of the calcite group that are given in the table share a common structure type (see Figure 23A). It can be considered as a derivative of the NaCl structure in which CO_3 groups substitute for the chlorine ions and calcium cations replace the sodium cations. As a result of the triangular shape of the CO_3 groups, the structure is rhombohedral instead of isometric as in NaCl. The CO_3 groups are in planes perpendicular to the threefold *c* axis, and the calcium ions occupy alternate planes and are bonded to six oxygen atoms of the CO_3 groups.

Calcite group structure

Members of the calcite group exhibit perfect rhombohedral cleavage. The well-developed morphology of a group of calcite crystals is shown in Figure 23B. The composition $CaCO_3$ most commonly occurs in two different polymorphs: rhombohedral calcite with calcium surrounded by six closest oxygen atoms and orthorhombic aragonite with calcium surrounded by nine closest oxygen atoms.

When CO_3 groups are combined with large divalent cations (generally with ionic radii greater than 1.0 Å), orthorhombic structures result. This is known as the aragonite structure type. Members of this group include those with large cations: $BaCO_3$, $SrCO_3$, and $PbCO_3$. Each cation is surrounded by nine closest oxygen atoms.

The aragonite group displays more limited solid solution than the calcite group. The type of cation present in aragonite minerals is largely responsible for the differences in physical properties among the members of the group. Specific gravity, for example, is roughly proportional to the atomic weight of the metal ions.

Dolomite $[CaMg(CO_3)_2]$, kutnahorite $[CaMn(CO_3)_2]$, and ankerite $[CaFe(CO_3)_2]$ are three isostructural members of the dolomite group. The dolomite structure can be consid-

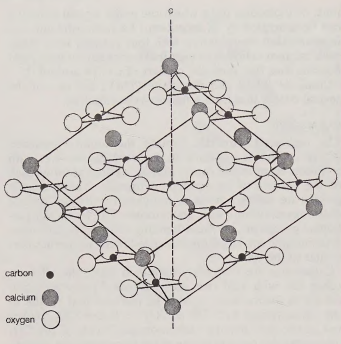




Figure 23: (Left) The structure of calcite, $CaCO_3$. (Right) Grouping of calcite crystals, Cumberland, Eng.
(Left) From C. Klein and C.S. Hurlbut, Jr., *Manual of Mineralogy* (1985), reprinted with permission of John Wiley & Sons, Inc., New York City; (right) © Wendell E. Wilson

ered as a calcite-type structure in which magnesium and calcium cations occupy the metal sites in alternate layers. The calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions differ in size by 33 percent, and this produces cation ordering with the two cations occupying specific and separate levels in the structure. Dolomite has a calcium-to-magnesium ratio of approximately 1:1, which gives it a composition intermediate between $CaCO_3$ and $MgCO_3$.

NITRATES

The nitrates are characterized by their triangular $(NO_3)^-$ groups that resemble the $(CO_3)^{2-}$ groups of the carbonates, making the two mineral classes similar in structure. The nitrogen cation (N^{5+}) carries a high charge and is strongly polarizing like the carbon cation (C^{4+}) of the CO_3 group. A tightly knit triangular complex is created by the three nitrogen-oxygen bonds of the NO_3 group; these bonds are stronger than all others in the crystal. Because the nitrogen-oxygen bond has greater strength than the corresponding carbon-oxygen bond in carbonates, nitrates decompose less readily in the presence of acids.

Nitrate structures analogous to those of the calcite group result when NO_3 combines in a 1:1 ratio with monovalent cations whose radii can accommodate six closest oxygen neighbours. For example, nitratite ($NaNO_3$), also called soda nitre, and calcite exhibit the same structure, crystallography, and cleavage. The two minerals differ in that

Nitratite and nitre

nitratite is softer and melts at a lower temperature owing to its lesser charge; also, sodium has a lower atomic weight than calcium, causing nitratite to have a lower specific gravity as well. Similarly, nitre (KNO_3), also known as saltpetre, is an analogue of aragonite. These are two examples of only seven known naturally occurring nitrates.

BORATES

Minerals of the borate class contain boron-oxygen groups that can link together, in a phenomenon known as polymerization, to form chains, sheets, and isolated multiple groups (see Figure 24). The silicon-oxygen (SiO_4) tetrahedrons of the silicates polymerize in a manner similar to the $(BO_3)^{3-}$ triangular groups of the borates. (For further information on such structures, see below *Silicates*). A single oxygen atom is shared between two boron cations (B^{3+}), thereby linking the BO_3 groups into extended units such as double triangles, triple rings, sheets, and chains. The oxygen atom is able to accommodate two boron atoms because the small boron cation has a bond strength to each oxygen that is exactly one-half the bond energy of the oxygen ion.

Although boron is usually found in triangular coordination with three oxygens, it also occurs in fourfold coordination in tetrahedral groups. In addition, boron may exist as part of complex anionic groups such as $[B_3O_3(OH)_3]^{2-}$, consisting of one triangle and two tetrahedrons (see

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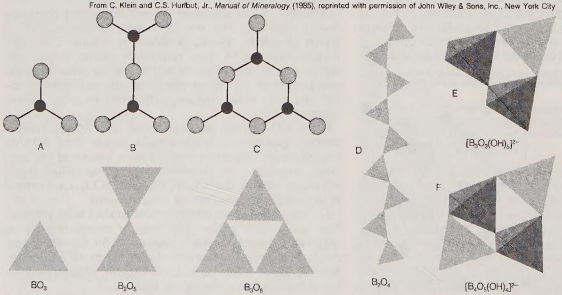


Figure 24: Various possible linkages of (A) BO_3 triangles to form (B,C) multiple groups and (D) chains in borates. Complex (E) triangle and (F) quadrangle groups are also shown. The group depicted in (F) occurs in borax.

Figure 24E). Complex infinite chains of tetrahedrons and triangles are found in the structure of colemanite [$CaB_3O_4(OH)_3 \cdot H_2O$]; a complex ion composed of two tetrahedrons and two triangles, $[B_2O_3(OH)_4]^{2-}$, is present in borax [$Na_2B_4O_5(OH)_4 \cdot 8H_2O$] (see Figure 24F).

SULFATES

This class is composed of a large number of minerals, but relatively few are common. The most frequently occurring sulfates are listed in Table 8. All contain anionic $(SO_4)^{2-}$ groups in their structures. These anionic complexes are formed through the tight bonding of a central S^{6+} ion to four neighbouring oxygen atoms in a tetrahedral arrangement around the sulfur. This closely knit group is incapable of sharing any of its apical oxygen atoms with other SO_4 groups; as such the tetrahedrons occur as individual, unlinked groups in sulfate mineral structures.

Table 8: Common Sulfates

Barite group	
Barite	$BaSO_4$
Celestite	$SrSO_4$
Anglesite	$PbSO_4$
Anhydrite	$CaSO_4$
Gypsum	$CaSO_4 \cdot 2H_2O$

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Barite group

Members of the barite group constitute the most important and common anhydrous sulfates. They have orthorhombic symmetry with large divalent cations bonded to the sulfate ion (see Table 8). In barite ($BaSO_4$), each barium ion is surrounded by 12 closest oxygen ions belonging to seven distinct SO_4 groups.

Anhydrite ($CaSO_4$) exhibits a structure very different from that of barite since the ionic radius of Ca^{2+} is considerably smaller than Ba^{2+}. Each calcium cation can only fit eight oxygen atoms around it from neighbouring SO_4 groups.

Gypsum ($CaSO_4 \cdot 2H_2O$) is the most important and abundant hydrous sulfate.

PHOSPHATES

Although this mineral class is large, most of its members are quite rare. Of the phosphates listed in Table 9, only apatite [$Ca_5(PO_4)_3(F, Cl, OH)$], the most important and abundant, can be considered as truly common. The members of this group are characterized by tetrahedral anionic $(PO_4)^{3-}$ complexes, which are analogous to the $(SO_4)^{2-}$ groups of the sulfates. The phosphorus ion, with a valence of positive five, is only slightly larger than the sulfur ion, which carries a positive six charge.

Table 9: Common Phosphates

Apatite group	
Apatite	$Ca_5(PO_4)_3(F, Cl, OH)$
Pyromorphite	$Pb_5(PO_4)_3Cl$
Amblygonite	$(Li, Na)AlPO_4(F, OH)$
Wavellite	$Al_3(PO_4)_2(OH, F)_3 \cdot 5H_2O$
Turquoise	$CuAl_6(PO_4)_4(OH)_8 \cdot 4H_2O$
Autunite	$Ca(UO_2)_2(PO_4)_2 \cdot 10\text{–}12H_2O$

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The structure of fluorapatite [$Ca_5(PO_4)_3(F)$] is shown in Figure 25. Two phosphate minerals are illustrated in Figure 26.

SILICATES

The silicates, owing to their abundance on the Earth, constitute the most important mineral class. Approximately 25 percent of all known minerals and 40 percent of the most common ones are silicates; the igneous rocks that make up more than 90 percent of the Earth's crust are composed of virtually all silicates.

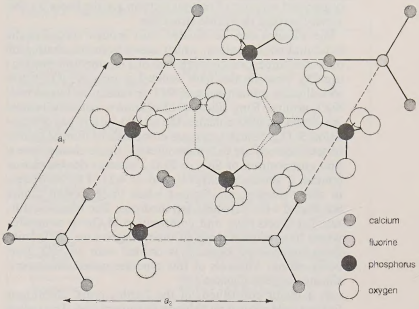


Figure 25: The structure of fluorapatite, $Ca_5(PO_4)_3F$, projected on a plane perpendicular to the *c* axis. The dashed area represents a unit cell of the structure. The tetrahedral PO_4 groups, triangular coordination of fluorine to calcium, and two types of coordination about calcium are shown.

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The fundamental unit in all silicate structures is the silicon-oxygen $(SiO_4)^{4-}$ tetrahedron. It is composed of a central silicon cation (Si^{4+}) bonded to four oxygen atoms that are located at the corners of a regular tetrahedron (see Figure 27). The terrestrial crust is held together by the strong silicon-oxygen bonds of these tetrahedrons. Approximately 50 percent ionic and 50 percent covalent, the bonds develop from the attraction of oppositely charged ions as well as the sharing of their electrons.

By courtesy of the (left) Ted and Elsie Bloeite collection, (right) MacFall collection, photographs, EB Inc. from (left) John H. Gerard, (right) Mary A. Root



Figure 26: (Left) Wavellite from Buckville, Ark., U.S. (Right) Fluorapatite on limestone from Renfrew, Ont., Can.

The positive charge (+4) of each silicon cation is satisfied by its four bonds to oxygen atoms. Each oxygen ion (O^{2-}), however, contributes only one-half of its total bonding energy to a silicon-oxygen bond, so it is capable of also bonding to the silicon cation of another tetrahedron. The SiO_4 tetrahedrons thereby become linked by shared oxygen atoms; this is referred to as polymerization. The

SiO_4 polymerization

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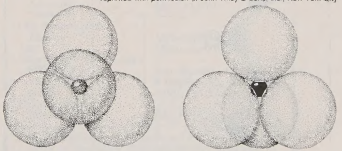


Figure 27: Two views of a closest-packed representation of the silicon-oxygen tetrahedron.

degree and manner of polymerization are the bases for the variety present in silicate structures.

The silicates can be divided into groups according to structural configuration, which arises from the sharing of one, two, three, or all oxygen ions of a tetrahedron (see Figure 28). Nesosilicates have isolated groups of SiO_4, while sorosilicates contain pairs of SiO_4 tetrahedrons linked into Si_2O_7 groups. Ring silicates, also known as cyclosilicates, are closed, ringlike silicates; the sixfold variety has composition Si_6O_{18}. Silicates that are composed of infinite chains of tetrahedrons are called inosilicates; single chains have a unit composition of SiO_3 or Si_2O_6, whereas double chains contain a silicon to oxygen ratio of 4:11. Phyllosilicates, or sheet silicates, are formed when three oxygen atoms are shared with adjoining tetrahedrons. The resulting infinite flat sheets have unit composition Si_2O_5. In structures where tetrahedrons share all their oxygen ions, an infinite three-dimensional network is created with an SiO_2 unit composition. Minerals of this type are called framework silicates or tectosilicates.

As a major constituent of the Earth's crust, aluminum follows only oxygen and silicon in importance. The radius of aluminum, slightly larger than that of silicon, lies close to the upper bound for allowable fourfold coordination in crystals. As a result, aluminum can be surrounded with four oxygen atoms arranged tetrahedrally, but it can also occur in sixfold coordination with oxygen. The ability to maintain two roles within the silicate structure makes aluminum a unique constituent of these minerals. The tetrahedral AlO_4 groups are approximately equal in size to SiO_4 groups and therefore can become incorporated into the silicate polymerization scheme. Aluminum in sixfold coordination may form ionic bonds with the SiO_4 tetrahedrons. Thus, aluminum may occupy tetrahedral sites as a replacement for silicon and octahedral sites in solid solution with elements such as magnesium and ferrous iron.

Several ions may be present in silicate structures in octa-

Table 10: Coordination of Common Elements in Silicates

site*	coordination number†	ion	ionic radius (Å)
Z	4	Si^{4+}	0.42
	4	Al^{3+}	0.51
Y	6	Al^{3+}	0.51
	6	Fe^{3+}	0.64
	6	Mg^{2+}	0.66
	6	Ti^{4+}	0.68
	6	Fe^{2+}	0.74
	6	Mn^{2+}	0.80
X	8	Na^{+}	0.97
	8	Ca^{2+}	0.99
X	8–12	K^{+}	1.33
	8–12	Ba^{2+}	1.34
	8–12	Rb^{+}	1.47

*Site in the general silicate formula given as $X_m Y_n (Z_p O_q) W_r$, where *W* represents other anions such as $(OH)^-$, Cl^-, or F^-.
†Coordination number refers to the number of atoms that can be arranged around and bonded to the central atom.
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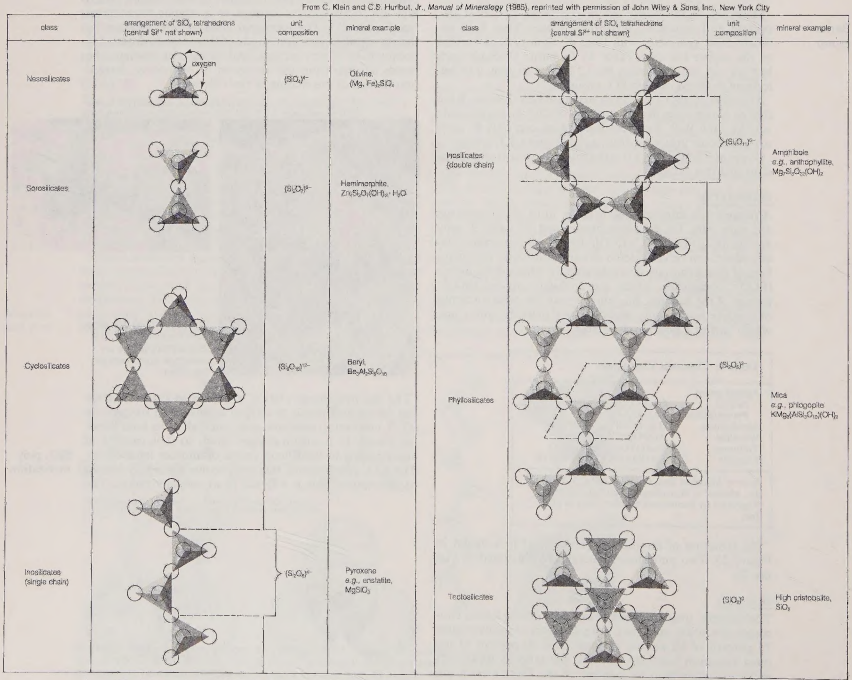


Figure 28: Various structural linkage schemes in silicates.

hedral coordination with oxygen: Mg^{2+}, Fe^{2+}, Fe^{3+}, Mn^{2+}, Al^{3+}, and Ti^{4+} (see Table 10). All cations have approximately the same dimensions and thus are found in equivalent atomic sites, even though their charges range from positive two to positive four. Solid solution involving ions of different charge is accomplished through coupled substitutions, thereby maintaining neutrality of the structures.

Nesosilicates. The silicon-oxygen tetrahedrons of the nesosilicates are not polymerized; they are linked to one another only by ionic bonds of the interstitial cations. As a result of the isolation of the tetrahedral groups, the crystal habits of these minerals are typically equidimensional so that prominent cleavage directions are not present. The size and charge of the interstitial cations largely determine the structural form of the nesosilicates. The relatively high specific gravity and hardness that are characteristic of this group arise from the dense packing of the atoms within the structure. Substitution of aluminum for silicon is normally quite low. Examples of common nesosilicates are given in Table 11.

Isolated tetrahedrons

Table 11: Common Nesosilicates

Olivine group	
Forsterite	Mg_2SiO_4
Fayalite	Fe_2SiO_4
Garnet group $A_3B_2(SiO_4)_3$	
Pyrope	$Mg_3Al_2(SiO_4)_3$
Almandine	$Fe_3Al_2(SiO_4)_3$
Spessartine	$Mn_3Al_2(SiO_4)_3$
Uvarovite	$Ca_3Cr_2(SiO_4)_3$
Grossular	$Ca_3Al_2(SiO_4)_3$
Andradite	$Ca_3Fe^{3+}_2(SiO_4)_3$
Zircon group	
Zircon	$ZrSiO_4$
Al_2SiO_5 group	
Andalusite, Sillimanite, Kyanite	Al_2SiO_5
Topaz	$Al_2SiO_4(F, OH)_2$
Staurolite	$FeAl_9O_6(SiO_4)_4(O, OH)_2$

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Sorosilicates. These minerals contain sets of two SiO_4 tetrahedrons joined by one shared apical oxygen (see Figure 28). A silicon-to-oxygen ratio of 2:7 is consequently present in their structures. More than 70 minerals belong to the sorosilicate group, although most are rare. Only the members of the epidote group and vesuvianite are common. Both independent $(SiO_4)^{4-}$ and double $(Si_2O_7)^{6-}$ groups are incorporated into the epidote structure, as is reflected in its formula: $Ca_2(Al, Fe)Al_2O(SiO_4)(Si_2O_7)(OH)$.

Cyclosilicates. Silicon-oxygen tetrahedrons are linked into rings in cyclosilicate structures, which have an overall Si:O ratio of 1:3. There are three closed cyclic configurations with the following formulas: Si_3O_9, Si_6O_{12}, and Si_6O_{18}. The rare titanosilicate benitoite $(BaTiSi_3O_9)$ is the only mineral that is built with the simple Si_3O_9 ring. Axinite $[(Ca, Fe, Mn)_3Al_2(BO_3)(Si_4O_{12})(OH)]$ contains Si_4O_{12} rings, along with BO_3 triangles and OH groups. The two common and important cyclosilicates, beryl $(Be_3Al_2Si_6O_{18})$ and tourmaline (which has an extremely complex formula), are based on the Si_6O_{18} ring.

Inosilicates. This class is characterized by its one-dimensional chains and bands created by the linkage of SiO_4 tetrahedrons. Single chains may be formed by the sharing of two oxygen atoms from each tetrahedron, resulting in a structure with an Si:O ratio of 1:3. Two such chains that are aligned side by side with alternate tetrahedrons sharing an additional oxygen atom form bands of double chains (see Figure 28). These structures have an Si:O ratio of 4:11. Two significant rock-forming mineral families display these structure types: the single-chain pyroxenes and the double-chain amphiboles (see below *Major rock-forming minerals: Amphiboles* and *Pyroxenes*). Some common examples are given in Table 12.

Amphiboles and pyroxenes

The amphiboles and pyroxenes share the same cations and have many similar crystallographic, chemical, and physical properties: the colour, lustre, and hardness of analogous species are alike. A distinguishing factor between the two groups, the presence of the hydroxyl radical in the amphiboles, generally gives the double-chain members lower specific gravities and refractive indices than their single-chain analogues. Their crystal habits also are different: amphiboles exhibit needlelike or fibrous crystals, while pyroxenes take the form of stubby prisms. In addition, the different chain structures of the two groups result in different cleavage angles.

Table 12: Inosilicates: Common Pyroxenes and Amphiboles

Pyroxenes	
Enstatite-orthoferrosilite series	
Enstatite	$MgSiO_3$
Hypersthene	$(Mg, Fe)SiO_3$
Diopside-hedenbergite series	
Diopside	$CaMgSi_2O_6$
Hedenbergite	$CaFeSi_2O_6$
Augite	$(Ca, Na)(Fe, Mg, Al)(Al, Si)_2O_6$
Sodium pyroxene group	
Jadeite	$NaAlSi_2O_6$
Acmite	$NaFe^{3+}Si_2O_6$
Amphiboles	
Anthophyllite	$(Mg, Fe)_7Si_8O_{22}(OH)_2$
Cummingtonite series	
Cummingtonite	$Fe_2Mg_5Si_8O_{22}(OH)_2$
Grunerite	$Fe_7Si_8O_{22}(OH)_2$
Tremolite series	
Tremolite	$Ca_2Mg_5Si_8O_{22}(OH)_2$
Actinolite	$Ca_2(Mg, Fe)_5Si_8O_{22}(OH)_2$
Hornblende	$(Ca, Na)_2(Mg, Fe, Al)_5(Si, Al)_8O_{22}(OH)_2$
Sodium amphibole group	
Glaucophane	$Na_2Mg_3Al_2Si_8O_{22}(OH)_2$
Riebeckite	$Na_2Fe^{2+}_3Fe^{3+}_2Si_8O_{22}(OH)_2$

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Pyroxenes occur in high-temperature igneous and metamorphic rocks. They crystallize at higher temperatures than their amphibole counterparts. A pyroxene formed early in the cooling of an igneous melt or in a metamorphic fluid may later combine with water at a lower temperature to form amphibole.

Phyllosilicates. These minerals display a two-dimensional framework of infinite sheets of SiO_4 tetrahedrons (see Figure 28). An Si:O ratio of 2:5 results from the sharing of three oxygen atoms in each tetrahedron. Sixfold symmetry is exhibited in undistorted sheets. The silicate sheet framework is largely responsible for the following properties of the phyllosilicates: platy or flaky habit, single pronounced cleavage, low specific gravity, softness, and possible flexibility and elasticity of cleavage layers. Most minerals of this group contain hydroxyls positioned in the middle of the sixfold rings of tetrahedrons.

Many soil constituents, produced through rock weathering, possess a sheet structure. Phyllosilicate properties contribute greatly to the ability of soils to release and retain plant food, to reserve water from wet to dry seasons, and to accommodate organisms and atmospheric gases.

Constituents of soils

The phyllosilicate class includes several important mineral groups (see Table 13).

Tectosilicates. Almost 75 percent of the Earth's crust is composed of minerals with the three-dimensional framework of the tectosilicates. All oxygen atoms of the SiO_4 tetrahedrons of members of this class are shared with nearby tetrahedrons, creating a strongly bound structure

Table 13: Common Phyllosilicates

Serpentine group	
Antigorite, Chrysotile	$Mg_3Si_2O_5(OH)_4$
Clay mineral group	
Kaolinite	$Al_2Si_2O_5(OH)_4$
Talc	$Mg_3Si_4O_{10}(OH)_2$
Mica group	
Muscovite	$KAl_2(Si_3Al)O_{10}(OH)_2$
Phlogopite	$KMg_3(Si_3Al)O_{10}(OH)_2$
Biotite	$K(Mg, Fe)_3(Si_3Al)O_{10}(OH)_2$
Chlorite group	
Chlorite	$(Mg, Fe)_5Al(Si_3Al)O_{10}(OH)_8$

Source: Modified from C. Klein and C.S. Hurlbut, Jr., *Manual of Mineralogy*. Copyright © 1985. Reprinted by permission of John Wiley & Sons, Inc.

Table 14: Common Tectosilicates

SiO_2	
Quartz	
Tridymite	SiO_2
Cristobalite	
Feldspar group	
K-feldspars	
Microcline	
Orthoclase	$KAlSi_3O_8$
Sanidine	
Plagioclase feldspars	
Albite	$NaAlSi_3O_8$
Anorthite	$CaAl_2Si_2O_8$
Feldspathoid group	
Leucite	$KAlSi_2O_6$
Nepheline	$(Na, K)AlSiO_4$
Sodalite	$Na_4(AlSiO_4)_3Cl_2$
Zeolite group	
Natrolite	$Na_2Al_2Si_3O_{10} \cdot 2H_2O$
Chabazite	$CaAl_2Si_4O_{12} \cdot 6H_2O$
Heulandite	$CaAl_2Si_7O_{18} \cdot 6H_2O$
Stilbite	$CaAl_2Si_7O_{18} \cdot 7H_2O$

Source: Modified from C. Klein and C.S. Hurlbut, Jr., *Manual of Mineralogy*. Copyright © 1985. Reprinted by permission of John Wiley & Sons, Inc.

with an Si:O ratio of 1:2 (see Figure 28). The most important tectosilicates are listed in Table 14. Other than the zeolite group, which can accommodate water owing to the open nature of its structure, all members listed in the table are anhydrous.

Mineral associations and phase equilibrium

The preceding sections provided an overview of major mineral groups but did not treat minerals as part of assemblages in rock types nor discuss the experimental study of minerals and rock occurrences. Petrology, the scientific study of rocks, is concerned largely with identifying individual minerals in rocks, along with their abundance, grain size, and texture, because rocks typically consist of a variety of minerals (see Figure 29). Such information is essential to an understanding of the history of any rock.

Petrological research requires a strong understanding of the principles of mineralogy and mineral identification and a thorough familiarity with the theoretical and experimental studies of rock origins. The present section focuses on phase equilibrium, upon which the link between the study of minerals and the study of rocks is largely based.

Phase and phase region

A phase is a homogeneous substance that has a fixed composition and uniform chemical and physical properties. Only a mineral that displays no solid solution may therefore be considered a phase. Quartz (SiO_2), for example, is a low-temperature phase in the $Si\text{-}O_2$ (SiO_2) system, and kyanite (Al_2SiO_5) is a high-pressure phase in the $Al_2O_3\text{-}SiO_2$ (Al_2SiO_5) system. The term phase region is used when a mineral exhibits compositional variation, as in the solid-solution series between forsterite and fayalite. A phase may exist as a solid, liquid, or gas: H_2O, for example, occurs in the form of ice (solid), water (liquid), and steam (gas).

D.L. Weide

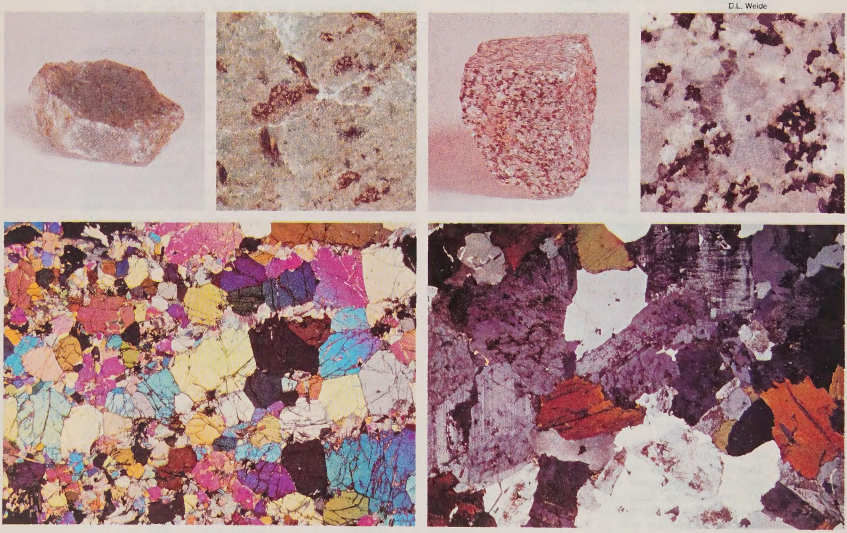


Figure 29: *Two types of crystalline aggregates at three levels of magnification.* Most mineral grains in rocks occur without well-developed crystal faces. (Top left) Olivine grains forming the monomineralic rock dunite, in which the individual grains can scarcely be distinguished. (Centre left) Polished surface of the same rock specimen (magnified 2×). Light green grains are olivine; dark spots are magnetite and serpentine. (Bottom left) Photomicrograph of the same specimen in polarized light. (Centre right) Hand specimen of granite, a polymineralic aggregate of feldspar, quartz, biotite, and hornblende. (Top right) Cut and polished surface of the same granite (magnified 1½×. Large slightly pink grains are microcline feldspar, white grains are sodium-rich plagioclase feldspar, smaller smoky grains are quartz, and black spots are biotite and hornblende. (Bottom right) Photomicrograph of the same granite in polarized light (magnified 12×). Homogeneous white and gray areas are quartz, light to dark bluish gray areas are feldspar. Areas with cross-hatching are microcline, and those with finely ruled parallel lines are sodic plagioclase. Most of the green and brown grains are biotite; the brown one in the centre is hornblende.

Equilibrium refers to the stable coexistence of two or more phases and is established relative to time. If two phases in a mixture of water and ice coexist so that the amount of each is fixed indefinitely, they are said to be in equilibrium. The minerals of some rocks have existed together since their formation for periods of several million years, yet one cannot always ascertain if these rock constituents are in equilibrium or are still undergoing changes.

A determining factor of the equilibrium state of minerals is the presence (or absence) of a reaction rim, which is a region separating two or more minerals consisting of the products of a reaction between them. The absence of any observable reaction rims between minerals that physically touch each other suggests that they were in equilibrium at the time when the rock formed. Additional chemical data regarding elemental distribution between the minerals is necessary to verify this assumption. In contrast, the presence of megascopically or microscopically visible rims indicates that some minerals were not in equilibrium. Garnet, for example, may react with coexisting biotite to produce a chlorite rim between them, revealing that the two minerals were not always in equilibrium. An experimental petrologist must assign some period of time after which the absence of further changes between phases will indicate that equilibrium has been reached. The time period is variable, depending on the speed of the reactions involved and in part on the patience of the investigator; it may range from a few hours to several years.

Components of a system

Components are the minimum number of independent chemical species that are necessary to describe the compositions of all the phases present in a system. The compound H_2O is generally used as the sole component defining the H_2O system, although H_2 and O_2 define the chemical system as well. In examinations of the stability fields of $MgSiO_3$ (enstatite), $MgSiO_3$ is normally used as the component rather than the three elements, Mg, Si, and O, or the two oxides, MgO and SiO_2. The three components generally used in the pyroxene system CaO-MgO-FeO-SiO_2 are $CaSiO_3$-$MgSiO_3$-$FeSiO_3$.

ASSEMBLAGE AND THE PHASE RULE

In the early stages of the study of a rock, the constituent minerals of the rock must be identified. Orthoclase, albite, quartz, and biotite may be found in an igneous granite. By examining the granite's texture, one may conclude that the four minerals crystallized at approximately the same elevated temperature and that orthoclase-albite-quartz-biotite is its mineral assemblage. The term assemblage is frequently applied to all minerals included in a rock but more appropriately should be used for those minerals that are in equilibrium (and are known more specifically as the equilibrium assemblage). The granite discussed above may display surficial cavities that are lined by several clay minerals and limonite (a hydrous iron oxide). The original high-temperature granite was altered to form the low-temperature clay minerals and limonite; there are consequently two distinct assemblages present in the rock: the high-temperature orthoclase-albite-quartz-biotite assemblage and the low-temperature assemblage of clay minerals and limonite.

Metamorphic rocks also may contain separate assemblages. A shale that at low temperatures was composed of a sericite-kaolin-dolomite-quartz-feldspar assemblage can become metamorphosed at higher temperatures to produce a garnet-sillimanite-biotite-feldspar assemblage.

An assemblage thus consists of minerals that formed under the same or quite comparable conditions of pressure and temperature. In practice, minerals that physically touch one another with no reaction rims or alteration products are included in the assemblage. It is likely that the minerals satisfying these conditions are in equilibrium, but additional chemical tests are commonly necessary to define the equilibrium assemblage without ambiguity.

Phase systems are governed by a phase rule, which defines the number of minerals that may coexist in equilibrium: $F = C - P + 2$, where F is the variance, or number of degrees of freedom, C is the number of independent components, and P is the number of phases. Applying this rule to a three-phase, three-component system, F is 2. This indicates that two parameters—*e.g.*, pressure and temperature—may be varied independently of one another without altering the number of phases.

PHASE DIAGRAMS

Phase (or stability) diagrams are used to illustrate the conditions under which certain minerals are stable. The following are examples of phase diagrams employed in the study of igneous, metamorphic, and sedimentary rocks. For more detailed discussions of the applications of phase diagrams in petrology, consult the books cited in the *Bibliography*.

Use in igneous petrology. In the field of igneous petrology, the researcher commonly employs a phase equilibrium approach to compare the mineral assemblages found in naturally occurring and synthetic rocks. Much can be learned from studying the melting of an igneous rock and the reverse process, the crystallization of minerals from a melt (liquid phase). Graphic representations of systems with a liquid phase are called liquidus diagrams. A three-component system (quartz [SiO_2]–kalsilite [$KAlSiO_4$]–forsterite [Mg_2SiO_4]) is illustrated through a liquidus diagram in Figure 30. The dashed contours of the diagram, called isotherms, represent temperatures at which a mineral melts. They define what is known as a liquidus surface. As temperatures decrease, the minerals will crystallize in the manner defined by the arrows on the boundaries separating the different mineral phases. A careful study of the crystalline products formed upon the cooling of melts of specific compositions allows the igneous petrologist to compare such results with minerals observed in natural igneous rocks.

Liquidus diagrams

Use in metamorphic petrology. Pressure-temperature (P-T) phase diagrams are applied in the study of the conditions under which metamorphic rocks originate. They illustrate the equilibrium relationships among various mineral phases in terms of pressure and temperature. A composite P-T diagram that includes reaction curves for several minerals is given in Figure 31. The minerals that are separated by a reaction curve may exist in equilibrium at the conditions occurring along the line. The reaction curves for Al_2SiO_5 and for muscovite + quartz ⇆ potassium-feldspar + sillimanite + H_2O are significant in metamorphic rocks that have a high aluminum oxide (Al_2O_3) content as compared to other components (*e.g.*,

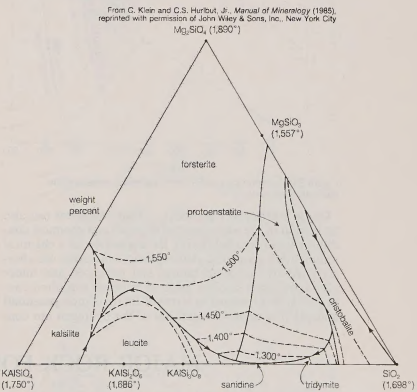


Figure 30: Melting relations among minerals in the system SiO_2 (quartz)–$KAlSiO_4$ (kalsilite)–Mg_2SiO_4 (forsterite). Temperatures next to compositions refer to the melting points of those compositions in °C. Protoenstatite, instead of enstatite, is produced in experiments of this type. The compositions of protoenstatite and enstatite are identical, but their structures differ.

calcium oxide [CaO], magnesium oxide [MgO], and ferrous oxide [FeO]). Shales enriched in clay minerals contain a rather large amount of aluminum oxide, and during metamorphism of the shale mineral reactions and recrystallization occur. In their metamorphic form, shales appear as pelitic schists, and these may include significant amounts of sillimanite, muscovite, and quartz. Such a schist may have equilibrated under the pressure and temperature conditions indicated by the shaded portion of Figure 31.

Theoretical calculations are combined with experimental observations to arrive at phase diagrams such as the one shown in Figure 31. In laboratory experiments conducted on the three polymorphs of Al_2SiO_5, chemicals of high purity are most often used as the starting materials, but extremely pure minerals may be substituted. A specimen of gem-grade kyanite that does not contain any inclusions may be reacted at high temperatures to form sillimanite (see Figure 31). The placement of the reaction curve between the kyanite and sillimanite fields is determined by the first instance of sillimanite formation from kyanite and also the initial stage of the reverse reaction. X-ray powder diffraction and optical microscopic techniques are employed to estimate the conditions under which these reactions commence, but the experimental methods are subject to some degree of uncertainty. Therefore, the reaction curves, although commonly drawn as narrow lines, may actually represent wider reaction zones. Also, the naturally occurring system is more complex than the simplified version devised in the laboratory, and so difficulty arises when attempting to relate the two. A P-T diagram such as the one given in Figure 31 serves mainly as a tool in evaluating the conditions of metamorphism, such as pressure and temperature.

From C. Klein and C.S. Hurlbut, Jr., *Manual of Mineralogy* (1985), reprinted with permission of John Wiley & Sons, Inc., New York City

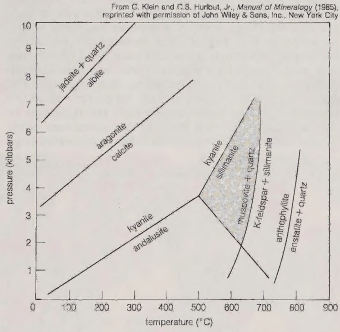


Figure 31: Reaction curves for some common metamorphic minerals (see text).

Use in sedimentary petrology. Phase diagrams can also be helpful in the assessment of physical and chemical conditions that prevailed during the deposition of a chemical sedimentary sequence. Atmospheric conditions are characterized by low temperatures and pressures, and under such conditions stability fields of minerals can often conveniently be expressed in terms of Eh (oxidation potential) and pH (the negative logarithm of the hydrogen ion concentration [H^+]; a pH of 0–7 indicates acidity, a pH of 7–14 indicates basicity, and neutral solutions have a pH of 7). For a discussion of the construction of such Eh-pH diagrams, see the references cited in the *Bibliography*.

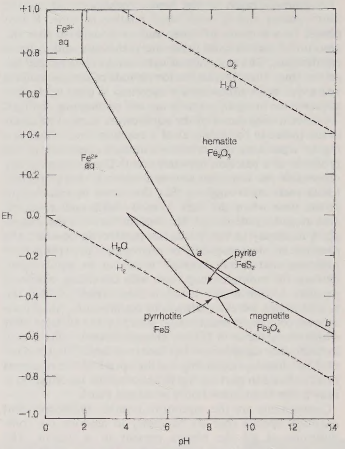


Figure 32: Stability of iron oxides and iron sulfides in water at 25° C and one atmosphere pressure with an activity of total dissolved sulfur equal to 10^{-6}. The pyrrhotite field is calculated on the basis of the formula FeS in this diagram; more correctly it would be $Fe_{1-x}S$.

From C. Klein and C. S Hurlbut, Jr., *Manual of Mineralogy* (1986), reprinted with permission of John Wiley & Sons, Inc., New York City

Eh-pH diagrams

Stability relations for some iron oxides and iron sulfides at atmospheric conditions, 25° C and one atmosphere pressure, are given in Figure 32. (One standard atmosphere of pressure equals 760 millimetres, or 29.92 inches, of mercury.) A high Eh value corresponds to a compound stable under oxidizing conditions, such as hematite, while a low Eh value indicates a mineral that occurs in reducing environments, such as magnetite. Pyrite and pyrrhotite, two sulfide minerals, occur at low Eh values and at pH values of 4–9. Lines separating the fields of an Eh-pH diagram represent conditions under which the two minerals may exist in equilibrium. Hematite and magnetite, for example, are often found together in iron-bearing sediments; line *ab* of Figure 32 indicates the Eh and pH values at which their coexistence can take place. Eh-pH diagrams are valuable in providing information regarding the chemical and physical environments that existed during atmospheric weathering and during chemical sedimentation and diagenesis of sediments deposited by water at temperatures of 25° to about 100° C and approximately one atmosphere pressure. The coexistence of hematite and magnetite common in Precambrian iron-bearing rocks (those formed from 3.96 billion to 570 million years ago) may enable investigators to estimate variables such as Eh and pH that prevailed in the original ancient sedimentary basin. (C.K.)

MAJOR ROCK-FORMING MINERALS

Of the more than 3,000 known mineral species, less than 0.1 percent make up the bulk of the Earth's crust and mantle (see Table 15). These and an additional score of minerals serve as the basis for naming most of the rocks exposed on the Earth's surface (Table 16).

Nearly all common rocks can be named by determining the presence (versus absence) of one, two, or a few of the minerals whose names are given in boldface in Table 16. Most of the less common rocks can be named by similarly identifying the additional half dozen minerals whose names are given in regular type. Essentially all rocks can be named as professional geologists name them if, in ad-

Table 15: Mineral Composition of the Earth's Crust

mineral	weight percent
Feldspar	
Plagioclase feldspars	39
Potassium feldspars	12
Quartz	12
Pyroxenes	11
Micas	5
Amphiboles	5
Clay minerals and chlorites	4.6
Olivines	3
Calcite and aragonite	1.5
Dolomite	0.5
Magnetite	1.5
Others	4.9
	100.0

Source: Modified from A.B. Ronov and A.A. Yaroshevsky, *Chemical Composition of the Earth's Crust*, in Pembroke J. Hart (ed.), *The Earth's Crust and Upper Mantle* (1969), American Geophysical Union.

dition, the presence of the minerals whose names are in italics is known.

Mineral identification

Each of the common rock-forming minerals can be identified on the basis of its chemical composition and its crystal structure (*i.e.*, the arrangement of its constituent atoms and ions). The nonopaque minerals can also be identified by their optical properties. Fairly expensive equipment and sophisticated procedures, however, are required for such determinations. Therefore, it is fortunate that macroscopic examination, along with one or more tests, are sufficient to identify these minerals as they occur in most rocks. The following descriptions include basic chemical and structural data and the properties used in macroscopically based identifications. Optical data, which are not included in these descriptions, are available in mineralogy books.

Table 16: Common Rock-Forming Minerals*

quartz	**calcite**	**biotite**	*hematite*
alkali feldspars	**dolomite**	**muscovite**	*limonite*
plagioclase feldspars	**clay minerals**	**amphiboles**	*epidotes*
pyroxenes	gypsum	**chlorites**	*pyrite*
olivines	anhydrite	*garnets*	*pyrrhotite*
feldspathoids	halite		
magnetite			
chromite			

*See text.

Two important rock-forming materials that are not minerals are major components of a few rocks. These are glass and macerals. Glass forms when magma (molten rock material) is quenched—*i.e.*, cooled so rapidly that the constituent atoms do not have time to arrange themselves into the regular arrays characteristic of minerals. Natural glass is the major constituent of a few volcanic rocks—*e.g.*, obsidian (Figure 33). Macerals are macerated bits of organic matter, primarily plant materials; one or more of the macerals are the chief original constituents of all the diverse coals and several other organic-rich rocks such as oil shales (see FUELS, FOSSIL: *Coal: Genesis of macerals and rock types*).

From R.V. Dietrich and B.J. Skinner, *Gems, Granites and Gravels*, Cambridge University Press; photograph: W. Secco

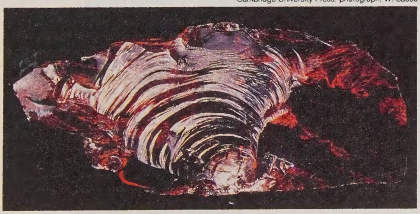


Figure 33: Natural glass, obsidian, from the Jemez Mountains, N.M., U.S.

Feldspars and feldspathoids

GENERAL CONSIDERATIONS

Feldspars make up more than 50 percent of the Earth's crust (see Table 15), and professional literature about the feldspars constitutes a large percentage of the literature of mineralogy. Basic information about the principal rock-forming members of this mineral group is provided in this section.

In the classification of igneous rocks of the International Union of Geological Sciences (IUGS), the feldspars are treated as two groups: the alkali feldspars and the plagioclase feldspars. The alkali feldspars include orthoclase, microcline, sanidine, anorthoclase, and the two-phase intermixtures called perthite. The plagioclase feldspars include members of the albite-anorthite solid-solution series.

From R.V. Dietrich and B.J. Skinner, *Rocks and Rock Minerals* (1979), John Wiley and Sons, Inc., New York; after (A) W.A. Deer, R.A. Howie, and J. Zussman, *Rock Forming Minerals*, vol. 4 (1963), John Wiley and Sons, Inc., New York

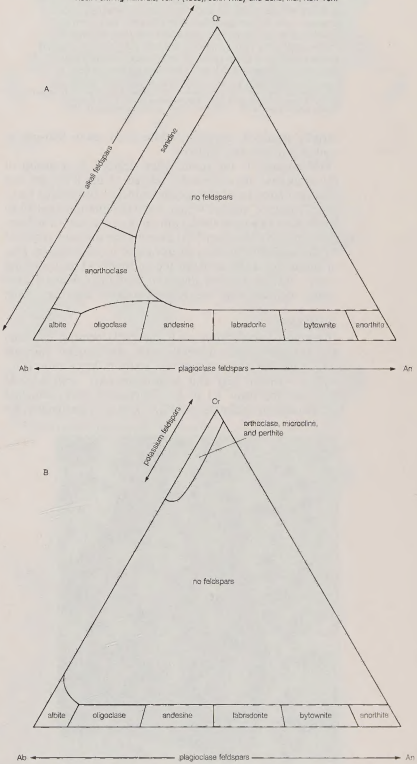


Figure 34: Nomenclature for feldspars in the orthoclase (Or)–albite (Ab)–anorthite (An) system. (A) At high temperatures. (B) At intermediate and low temperatures.

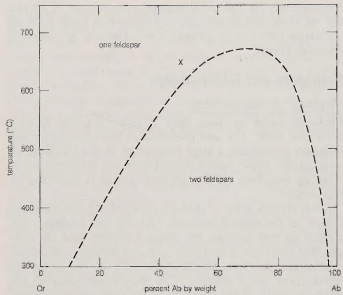


Figure 35: Formation of perthite by exsolution. The solvus (dashed line) is in the subsolidus part of the albite (Ab)–orthoclase (Or) system. A homogeneous alkali (Ab-Or) feldspar is stable at temperatures above the solvus, whereas two phases—one Or-rich and the other Ab-rich—may form by exsolution at temperatures below this line to form perthite. For example, the homogeneous feldspar X (= $Ab_{50}Or_{50}$) would exsolve to form a perthite made up of approximately equal amounts of albite and K-feldspar lamellae at about 630° C.

From L.G. Berry, B. Mason, and R.V. Dietrich, *Mineralogy: Concepts, Descriptions, Determinations*, 2nd ed. (1983), W.H. Freeman and Co., New York, after O.F. Tuttle and N.L. Bowen, "Origin of Granite in the Light of Experimental Studies in the System $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O," *Geological Society of America*, Memoir 74, 1958

Strictly speaking, however, albite is an alkali feldspar as well as a plagioclase feldspar.

Feldspathoid is the name often applied to a group of minerals that are chemically related to the feldspars and are considered to be the specific minerals of igneous rocks usually termed alkalic, which is the designation applied to igneous rocks whose alkali content (*i.e.*, amount of sodium [Na] and/or potassium [K]) exceeds the amount required by the available silica to form one or more feldspars plus or minus mica. Minerals of the feldspathoid group whose silica contents are less than those of their feldspar analogues include nepheline, leucite, sodalite, and cancrinite.

FELDSPARS

Chemical composition. All the rock-forming feldspars are aluminosilicate minerals with the general formula AT_4O_8 in which A = potassium, sodium, or calcium (Ca); and T = silicon (Si) and aluminum (Al), with a Si:Al ratio ranging from 3:1 to 1:1. Microcline and orthoclase are potassium feldspars ($KAlSi_3O_8$), usually designated Or

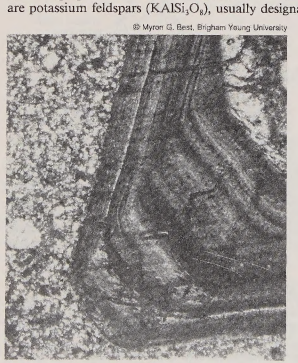


Figure 36: *Zoned plagioclase.*
The zoning displayed in this photomicrograph is in a phenocryst in andesite.

in discussions involving their end-member composition. Albite ($NaAlSi_3O_8$—usually designated Ab) and anorthite ($CaAl_2Si_2O_8$—An) are end-members of the plagioclase series. Sanidine, anorthoclase, and the perthites are alkali feldspars whose chemical compositions lie between Or and Ab.

Solid solution in the feldspars

As is apparent from the preceding statements, solid solution plays an important role in the rock-making feldspars. (Members of solid-solution series are single crystalline phases whose chemical compositions are intermediate to those of two or more end-members; see above *The nature of minerals: Compositional variation.*) The alkali (Or-Ab) series exhibits complete solid solution at high temperatures but only incomplete solid solution at low temperatures; substitution of potassium for sodium is involved. The plagioclase (Ab-An) series exhibits essentially complete solid solution at both high and low temperatures; coupled substitution of sodium and silicon by calcium and aluminum occurs. The An-Or system has only limited solid-solution tendencies (see Figure 34).

From L.G. Berry, B. Mason, and R.V. Dietrich, *Mineralogy: Concepts, Descriptions, Determinations*, 2nd ed. (1983), W.H. Freeman and Co., New York, after N.L. Bowen, "The Melting Phenomena of the Plagioclase Feldspars," *American Journal of Science*, 35 (4th ser.), 1913

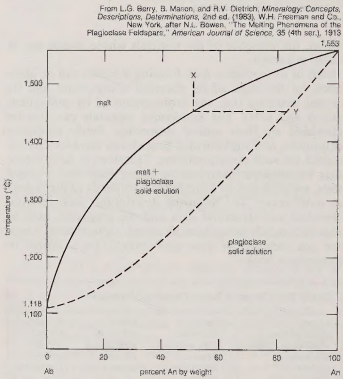


Figure 37: Solid solution in the albite (Ab)–anorthite (An) system (see text).

The most obvious differences between the high- and low-temperature diagrams are along the alkali-feldspar (Or-Ab) join (the boundary line between the phases). As indicated, sanidine and anorthoclase are high-temperature alkali feldspars, and perthite is their low-temperature analogue. Sanidine is a single-phase alkali feldspar; although frequently described chemically by the formula (K, Na)$AlSi_3O_8$, most analyzed specimens of sanidine range between Or_{50} and Or_{60}. (This designation is used to specify the fractions of the constituents. For example, Or_{60} indicates that the mineral is composed of 60 percent $KAlSi_3O_8$ and 20 (*i.e.*, 100 − 80) percent $NaAlSi_3O_8$.) Anorthoclase is a variously used name that is most often applied to apparently homogeneous alkali feldspar masses, at least some of which consist of submicroscopic lamellae (layers) of albite and orthoclase; their bulk compositions typically range between Or_{25} and Or_{60}. Perthite consists of intimate intermixtures of a potassium feldspar—either microcline or orthoclase—and a sodium-rich plagioclase that occurs as microscopic to macroscopic masses within the potassium feldspar host.

Many perthites are formed when high-temperature potassium-sodium feldspars of appropriate compositions are cooled in such a manner that the original solid-solution phase exsolves (*i.e.*, unmixes, so that a homogeneous mineral separates into two or more different minerals) to form intermixtures—sometimes termed intergrowths—of two phases (see Figure 35).

Some perthites, however, appear to have been formed as a result of partial replacement of original potassium

feldspars by sodium-bearing fluids. In any case, perthite is the name properly applied to intimate mixtures in which the potassium feldspar component predominates over the plagioclase constituent, whereas antiperthite is the name given to intimate mixtures in which the plagioclase constituent is predominant. Perthites are common, whereas antiperthites are relatively rare.

Zoned plagioclase

The plagioclase series is essentially continuous at both high and low temperatures. The names of members of the series designate relative proportions of the end-members (see Table 17). Although plagioclase grains in some rocks are essentially homogeneous, those in many rocks are zoned—*i.e.*, different parts of individual grains have different Ab and An contents (see Figure 36). One explanation for zoning in plagioclases formed from magmas can be implied from information known about the Ab-An system (see Figure 37). Upon cooling, the first crystals that form from a melt with the composition X (= An_{50}) will have the composition Y (approximately An_{83}). With further cooling, in some cases the first and subsequently formed crystals will react continuously with the remaining liquid, thereby maintaining equilibrium; when the liquid becomes totally crystallized, the system will consist of homogeneous plagioclase crystals. In cases in which such equilibrium is not maintained during cooling, the early and subsequently formed feldspars have different An contents. For example, zoned crystals may form with differing An contents arranged one on top of another so that their margins are relatively sodium-rich as compared to their earlier-formed, more calcium-rich cores. The resulting zoning may be gradational or well-defined or may assume some combination of these characteristics.

Table 17: The Plagioclase Series

mineral	percent albite	percent anorthite
Albite-$NaAlSi_3O_8$	100–90	0–10
Oligoclase	90–70	10–30
Andesine	70–50	30–50
Labradorite	50–30	50–70
Bytownite	30–10	70–90
Anorthite-$CaAl_2Si_2O_8$	10–0	90–100

Many elements other than those required for the Or, Ab, and An end-member compositions have been recorded in analyses of feldspars. Those that have been recorded to occur as substitutions within the feldspar structures include lithium (Li), rubidium (Rb), cesium (Cs), magnesium (Mg), strontium (Sr), barium (Ba), yttrium (Y), ferrous iron (Fe^{2+}), thallium (Tl), lead (Pb), lanthanum (La) and other rare earth elements, and ammonium (NH_4) in the A position; and titanium (Ti), ferric (Fe^{3+}) and ferrous (Fe^{2+}) iron, boron (B), gallium (Ga), germanium (Ge), and phosphorus (P) in the T position. Of these, substitution of some barium for potassium and some titanium or ferric iron or both for aluminum are especially common in alkali feldspars. Several other elements also have been recorded as traces in feldspar analyses; it seems very likely, however, that some of these elements may reside in impurities—*i.e.*, within unrecognized microscopic or submicroscopic inclusions of other minerals.

Monoclinic and triclinic structures

Crystal structure. Sanidine and orthoclase are monoclinic or nearly so; the plagioclase feldspars are triclinic. All, however, have the same fundamental structure: it consists of a continuous, negatively charged, three-dimensional framework that is made up of corner-sharing SiO_4 and AlO_4 tetrahedrons (each tetrahedron consists of a central silicon or aluminum atom bonded to four oxygen atoms) and positively charged cations (*e.g.*, the potassium, sodium, and/or calcium) that occupy relatively large interstices within the framework (Figure 38). Although the framework is sufficiently elastic to adjust itself to the different sizes of the A cations, the relatively large potassium cations give structures that have a monoclinic or only slightly off-monoclinic symmetry, whereas the smaller sodium and calcium cations lead to distorted structures that have triclinic symmetry.

One aspect of the feldspar—especially the potassium feldspar—structures that is of particular interest is termed

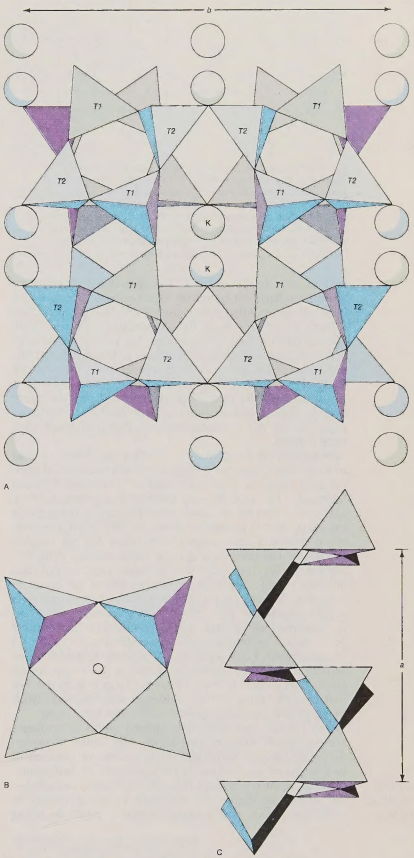


Figure 38: *Basic feldspar structure as exhibited by the structure of high sanidine.*
(A) Projection normal to the *b* axis. (B) Four-membered rings of tetrahedrons, as viewed down the *a* axis. (C) Chains made up of four-membered rings, as viewed parallel to the *a* axis.
From J.J. Papike and M. Cameron: "Crystal Chemistry of Silicate Minerals of Geophysical Interest," *Reviews of Geophysics and Space Physics* (February 1976), after (A) Taylor, 1933, and (C) Frye, 1974.

ordering (see Figure 39). This phenomenon is indicative of the conditions under which the feldspar was formed and its subsequent thermal history. Ordering in feldspars is based on the distributional pattern of silicon and aluminum within the different tetrahedrons. It can be characterized as follows: silicon and aluminum have a random distribution within the tetrahedrons of sanidine, an arrangement termed disordered; they have a regular distribution within the constituent tetrahedrons of microcline, an arrangement termed ordered; and they are distributed within the tetrahedrons of orthoclase in a manner usually character-

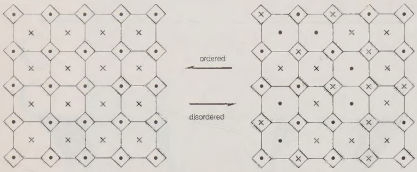


Figure 39: Schematic diagram showing ordered (left) and disordered (right) arrays within a structure having two kinds of sites—namely, the centres of the squares and the centres of the octagons—and two types of occupants—the dots and the crosses. In the ordered structure all dots are positioned within the squares and all crosses are within the octagons, whereas in the disordered structure no regular arrangement obtains.
From J.V. Smith and W.L. Brown, *Feldspar Minerals*, 2nd ed. (1988), Springer-Verlag, New York

ized as only partly ordered. The disordered structure of sanidine reflects formation at high temperatures followed by rapid cooling; the high degree of ordering of microcline reflects either growth at low temperatures or very slow cooling from higher temperatures; the partial ordering of orthoclase indicates either formation at intermediate temperatures or formation at high temperatures followed by fairly slow cooling. With regard to this phenomenon, it is also noteworthy that all plagioclase feldspars are more nearly ordered than their associated potassium feldspars regardless of the temperatures that prevailed when they were formed.

Crystals of all the common rock-forming feldspars tend to look alike (Figure 40); megascopic examination of crystal form typically cannot be used to distinguish between feldspars. The angle between the face that intersects the *b* axis and is parallel to *a* and *c* and the face that intersects the *c* axis and is parallel to *a* and *b* is 90° for the monoclinic feldspars and ranges from about 86° to roughly 89°30′ for the triclinic feldspars; the deviations from 90° are not readily discernible with the naked eye. In any case, feldspar crystals are relatively rare; almost all occur in miarolitic cavities, in pegmatite masses, or as phenocrysts within porphyries. (A porphyry is an igneous rock containing conspicuous crystals, called phenocrysts, surrounded by a matrix of finer-grained minerals or glass or both.) In most rocks, both alkali and plagioclase feldspars occur as irregularly shaped grains with only a few or no crystal faces. This general absence of crystal faces reflects the fact that crystallization of these feldspars was interfered with by previously formed minerals within the same mass.

Both crystals and irregularly shaped grains of feldspars are commonly twinned (see above *The nature of minerals: Morphology*). Some individual grains are twinned in two or more ways. Two common kinds of twinning—those designated Carlsbad twinning and albite twinning—are shown in Figure 41. Carlsbad twinning occurs in both monoclinic and triclinic feldspars; albite twinning occurs only in triclinic feldspars. Albite twinning, which is typically polysynthetic (*i.e.*, multiple or repeated), can be observed as a set of parallel lines on certain crystal or cleavage surfaces of many plagioclase feldspars (Figure 41).

Carlsbad and albite twinning

From R.V. Dietrich and B.J. Skinner, *Rocks and Rock Minerals* (1979), John Wiley and Sons, Inc., New York

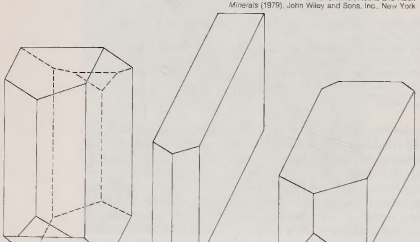


Figure 40: Common crystal forms of the feldspars.

Physical properties. It is important to be able to distinguish feldspar group minerals from other rock-forming minerals and from one another because their presence (versus absence), along with their relative quantities, serves as the basis for classifying and naming many rocks, especially those of igneous origin. In the laboratory, it is relatively easy to identify the feldspars by determining their chemical compositions, their structures, or their optical properties. In some cases, staining techniques are employed. Fortunately, most feldspar grains can also be identified rather easily on the basis of macroscopic examination in the field, using properties such as those described in the remainder of this section.

From R.V. Dietrich and B.J. Skinner, *Rocks and Rock Minerals* (1979), reprinted with permission of John Wiley and Sons, Inc., New York; photograph, Richard V. Dietrich

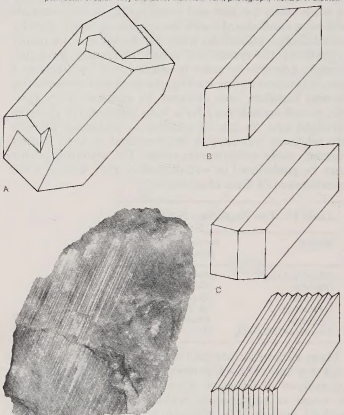


Figure 41: *Twinning in feldspars.*
(A) Carlsbad twinning. (B), (C), (D), and (E) Albite twinning: (B) untwinned crystal, (C) single twin, (D) multiple twins, and (E) albite twinning as it appears on a cleavage surface of a plagioclase specimen from Tvedestrand, Nor.

As might be suspected on the basis of their similar chemical compositions and structures, all of the rock-forming feldspars have several similar properties. As indicated by the fact that they lack inherent colour, feldspars can be colourless, white, or nearly any colour if impure. In general, however, orthoclase and microcline have a reddish tinge that ranges from a pale, fleshlike pink to brick-red, whereas typical rock-forming plagioclases are white to dark gray. As a group, feldspars range from transparent to nearly opaque, have nonmetallic lustres—typically vitreous to subvitreous on fractures and pearly or porcelaneous on cleavage surfaces, exhibit two cleavages—one perfect, the other good—at or near 90° to each other, and have a Mohs hardness of approximately 6.

The presence of two cleavages at or near 90° distinguishes the feldspars from all other common rock-forming minerals except halite and the pyroxenes. The hardness ($2\frac{1}{2}$) and the salty taste of halite make that distinction clear. The gray to black streak of the common rock-forming pyroxenes, which contrasts markedly with the white or slightly tinted hues of the streaks of the feldspars—including those that are dark-coloured—affords a simple way to distinguish between these minerals, even those that are similar in appearance. (Streak is the colour of a mineral's

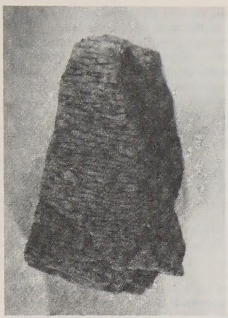


Figure 42: Interdigitated appearance of a perthite specimen from the Limpopo belt of southern Zimbabwe. The light mineral is a flesh-coloured microcline; the darker mineral is a light gray albite. The interdigitated appearance of this fairly typical perthite is quite different from the straight line appearance of the albite twins shown in Figure 41E.

From R.V. Dietrich and B.J. Skinner, *Rocks and Rock Minerals*, copyright ©1979; reprinted by permission of John Wiley and Sons, Inc.; photograph, R.V. Dietrich.

powder, which can be produced readily by pounding or scratching the mineral with a geologic pick or hammer.)

Alkali feldspars can often be distinguished from plagioclase feldspars because most grains of the latter exhibit albite twinning (see above), which is manifested by parallel lines on certain cleavage surfaces, whereas grains of alkali feldspars do not. This criterion is not, however, absolute; some plagioclase feldspars are not polysynthetically twinned. Furthermore, upon only cursory examination some perthitic textures may be mistaken for polysynthetic twinning. Fortunately, this resemblance is seldom confusing once one has thoroughly examined several examples of both features. The two features differ rather markedly: the traces of the polysynthetic twinning are straight, whereas the perthitic textures that are most likely to be mistaken for polysynthetic twinning have an interdigitated appearance (compare Figures 41E and 42).

Another property that is sometimes used to distinguish between alkali and plagioclase feldspars is their different specific gravity values. The ideal value for the potassium-rich alkali feldspars is 2.56, which is less than the lowest value for the plagioclases (namely, 2.62 for albite).

Sanidine is usually distinguished rather easily from the other alkali feldspars because it typically appears glassy—*i.e.,* it tends to be colourless, and much of it is transparent. Microcline and orthoclase, by contrast, are characteristically white, light gray, or flesh- to salmon-coloured and subtranslucent. Except for its green variety, usually called amazopstone or amazonite, microcline can seldom be distinguished from orthoclase by macroscopic means. In the past, much microcline was misidentified as orthoclase because of the incorrect assumption that all microcline is green. Today, prudent geologists identify potassium feldspars other than sanidine simply as alkali, or in some cases potassium, feldspars when describing rocks on the basis of macroscopic examination. That is to say, they do not make a distinction between microcline and orthoclase until they have proved their identity by determining, for example, their optical properties. Upon macroscopic examination, anorthoclase is also generally identified merely as an alkali feldspar except by those who are acquainted with the rocks known to contain anorthoclase.

Identification of plagioclases

The rock-forming plagioclases can seldom be identified as to species by macroscopic means. Nevertheless, some rules of thumb can be employed: White or off-white plagioclase feldspars that exhibit a bluish iridescence (the so-called peristerites) have overall albite compositions, even though they are submicroscopic intergrowths of 70 percent An_7 and 30 percent An_{25}; and dark-coloured plagioclases that exhibit iridescence of such hues as blue, green, yellow, or orange are labradorites. In addition, the identities of associated minerals tend to indicate the approximate An-Ab contents of the plagioclase feldspars—for example, biotite most commonly accompanies albite or oligoclase; hornblende commonly occurs with andesine; and the pyroxenes, augite and/or hypersthene, typically accompany labradorite or bytownite. Additional characteristics for two of the feldspars are as follows: Microcline commonly exhibits "grid twinning." This combination of two kinds of twinning, although best seen by means of a microscope equipped to use doubly polarized light, is sometimes discernible macroscopically. (Polarized refers to light that vibrates in a single plane.) Plagioclase feldspars that constitute lamellar masses in complex pegmatites are albite; this variety is often referred to by the name cleavelandite.

Origin and occurrence. Feldspars occur in all classes of rocks. They are widely distributed in igneous rocks, which indicates that they have formed by crystallization from magma. Physical weathering of feldspar-bearing rocks may result in sediments and sedimentary rocks that contain feldspars; however, this is a rare occurrence because in most environments the feldspars tend to be altered to other substances, such as clay minerals. They also may be found in many metamorphic rocks formed from precursor rocks that contained feldspars and/or the chemical elements required for their formation. In addition, feldspars occur in veins and pegmatites, in which they were apparently deposited by highly tenuous fluids, and within sediments and soils, in which they were probably deposited by groundwater solutions. Some of the typical occurrences for the individual species are given in Table 18.

Table 18: Some Typical Occurrences of the Rock-Forming Feldspars

Potassium feldspars*	
Sanidine	potassium-rich volcanic rocks and near-surface minor intrusions—*e.g.,* rhyolites and trachytes
Orthoclase	potassium-rich dike rocks—*e.g.,* rhyolite and trachyte porphyries; granites, granodiorites, and syenites†; arkose; moderate- to high-grade metamorphic gneisses and schists
Microcline	granitic pegmatites, hydrothermal veins; granites, granodiorites, and syenites†; arkose; low- to moderate-grade metamorphic rocks
Plagioclase feldspars	
Albite	granites; granitic pegmatites; low-grade metamorphic gneisses and schists
Oligoclase	granodiorites and monzonites; arkose; moderate-grade metamorphic rocks
Andesine	diorites; andesites; moderate-grade metamorphic rocks, especially amphibolites
Labradorite	gabbros and anorthosites‡; diabases and basalts
Bytownite	gabbros and anorthosites‡; diabases and basalts
Anorthite	contact-metamorphosed impure limestones

*Including perthites. In addition, anorthoclase occurs only in a few rather abnormal syenites (*e.g.,* larvikite), and adularia—transparent, colourless to white, commonly opalescent potassium feldspar with a pseudo rhombohedral habit—occurs in some low-temperature hydrothermal veins. †Typical syenites consist of nearly 90 percent alkali feldspar. ‡Typical anorthosites consist of about 90 percent plagioclase feldspar.

Uses. Feldspars are used widely in the glass and ceramics industries. The feldspar-rich rocks larvikite and a few anorthosites are employed as both interior and exterior facing slabs. Several feldspars are used as gemstones.

FELDSPATHOIDS

Chemical composition and crystal structure. The feldspathoid group minerals are sodium, potassium, and calcium aluminosilicates, many of which resemble the feldspars in appearance. Like the feldspars, they have framework structures that consist of silica and alumina tetrahedrons. Unlike the feldspars, however, the arrangements of the tetrahedrons differ from species to species,

Comparison to the feldspars

Table 19: Relatively Common Feldspathoids*

name	ideal composition	crystal system
Nepheline group	$(Na, K)AlSiO_4$	hexagonal†
Leucite	$KAlSi_2O_6$	isometric and tetragonal‡
Sodalite§	$Na_4(AlSiO_4)_3Cl$	isometric
Nosean	$Na_8(AlSiO_4)_6(SO_4) \cdot H_2O$	isometric
Haüyne	$(Na, Ca)_{4-8}(AlSiO_4)_6(SO_4, Cl)_{1-2}$	isometric
Cancrinite	$Na_6Ca_2(AlSiO_4)_6(CO_3) \cdot H_2O$	hexagonal

*Some mineralogists consider analcime ($NaAlSi_2O_6 \cdot H_2O$) and melilite group minerals (A_2BZSiO_7, with A = Na, Ca; B = Al, Mg, Zn [zinc]; and Z = Al, Si) also to be feldspathoids. †Nepheline, the species, and other naturally occurring members of the group—kalsilite and kaliophilite—are hexagonal, carnegieite, a synthetic mineral of this group, has a low-temperature triclinic form and a high-temperature isometric form. ‡Leucite's crystal system differs with the temperature of formation, the high-temperature form having an isometric configuration. §Lazurite [$(Na, Ca)_{7-8}(Al, Si)_{12}(O, S)_{24}(SO)_6$ Cl_2 (OH_2)], a sodalite, is the blue constituent of the well-known gemstone lapis lazuli.

and the interstices may contain water and/or other simple or complex anions such as chlorine (Cl^-), carbonate (CO_3^{2-}), or sulfate (SO_4^{2-}), as well as sodium, potassium, and calcium. Consequently, different feldspathoids have somewhat different structures: some are isometric, others are hexagonal, and still others are tetragonal. Chemical formulas and crystal-system data for a few of the feldspathoids are given in Table 19.

Physical properties. The physical properties of the various feldspathoids differ from those of the feldspars and from one another. Properties of nepheline, leucite, sodalite, and cancrinite are summarized below.

Nepheline (hardness [H] 5½–6, specific gravity [G] 2.56–2.67) typically occurs as irregularly shaped, white, gray, or brownish, greasy- to waxy-appearing grains that may exhibit one rather poor cleavage (Figure 43). Simple hexagonal prisms occur as phenocrysts in some volcanic porphyries. On weathered exposures, nepheline grains are commonly weathered more than their associated minerals, thus leaving, for example, feldspar grains of nepheline syenites in relief. A simple test often used to help identify nepheline is based on the fact that it, as well as sodalite and cancrinite, reacts with acids to form gelatinous silica.

Leucite (H 5½–6, G 2.47–2.50) commonly occurs as white to light gray trapezohedrons (Figure 43). The crystal form represents the formation of leucite as an isometric mineral. However, the mineral can be shown to be tetragonal by methods such as optical studies. The crystal form of leucite indicates the conditions under which it was crystallized, and the tetragonal structure shows that it has undergone post-crystallization inversion.

Sodalite (H 5½–6, G 2.27–2.50) consists of a group of minerals. Different species of this group may exhibit different colours. The sodalite of most rocks occurs as irregularly shaped, translucent, bluish-coloured grains with a vitreous to greasy lustre (Figure 43).

Cancrinite (H 5–6, G 2.32–2.51) typically occurs as yellowish grains, some of which exhibit one perfect cleavage, that are closely associated with one or more of the other feldspathoids, most commonly nepheline.

Origin and occurrence. The feldspathoids are relatively rare. As noted previously, they are considered here primarily because they are the specific minerals used in naming alkalic igneous rocks. In this role, the feldspathoids, along with minerals of the melilite group, are referred to as foids in the IUGS classification of igneous rocks. Feldspathoids may occur along with feldspars in igneous rocks. They do not occur in igneous rocks containing original free silica—*i.e.*, in rocks that contain quartz of the same generation. They are, in fact, incompatible with consanguineous quartz (that derived from the same parent magma), as is quite apparent from the following equations:

Use in naming alkalic igneous rocks

$$\underbrace{(Na, K)_2O + Al_2O_3 + 2SiO_2}_{\text{nepheline}} + \underbrace{4SiO_2}_{\text{quartz}} \longrightarrow \underbrace{(Na, K)_2O + Al_2O_3 + 6SiO_2}_{\text{alkali feldspar}}$$

$$\underbrace{K_2O + Al_2O_3 + 4SiO_2}_{\text{leucite}} + \underbrace{2SiO_2}_{\text{quartz}} \longrightarrow \underbrace{K_2O + Al_2O_3 + 6SiO_2}_{\text{potassium feldspar}}$$

As can be seen from these equations, a feldspar would form in lieu of its feldspathoid chemical analogue in any silica-saturated magma.

Nepheline is the most common feldspathoid; it is a major constituent of many alkalic igneous rocks such as nepheline syenites. Feldspathoids also occur in a few other kinds of rocks—*e.g.*, contact-metamorphic skarns.

Uses. Nepheline is sometimes used as a source of soda, silica, and alumina in the manufacture of glass and ceramics. Leucite was formerly used in Italy for fertilizer. Sodalite, once treasured as the basic ingredient of ultramarine pigment, is still used as a gemstone and as the desired constituent of many of the blue rocks used as facing stones. (R.V.Di.)

Amphiboles

GENERAL CONSIDERATIONS

Amphiboles are a group of silicate minerals found principally in metamorphic and igneous rocks. They occur in many metamorphic rocks, especially those derived from mafic igneous rocks (those containing dark-coloured ferromagnesian minerals) and siliceous dolomites. Amphiboles also are important constituents in a variety of plutonic and volcanic igneous rocks that range in composition from granitic to gabbroic. Amphibole, from the Greek *amphibolos*, meaning "ambiguous," was named by the famous French crystallographer and mineralogist René-Just Haüy (1801) in allusion to the great variety of composition and appearance shown by this mineral group. There are 57 chemically defined end-member amphibole compositions according to the British mineralogist Bernard E. Leake. Because of the wide range of chemical substitutions permissible in the crystal structure, amphiboles can crystallize in igneous and metamorphic rocks with a wide range of bulk chemistries. Typically amphiboles form as long prismatic crystals, radiating sprays, and asbestiform (fibrous) aggregates; however, without the aid of chemical analysis, it is difficult to megascopically identify all but a few of the more distinctive end-member amphiboles. The combination of prismatic form and two diamond-shaped directions of cleavage at about 56° and 124° is the diagnostic feature of most members of the amphibole group.

By courtesy of (right) Northwestern University Geology Department, Evanston, Illinois; photographs (left) Katherine H. Jensen—EB Inc.; (right) Mary Root—EB Inc.



Figure 43: (Left) Nepheline (greasy light gray), sodalite (blue), cancrinite (yellow), feldspar (white), and ferromagnesian minerals (black) in an alkalic syenite from Litchfield, Maine, U.S. (Right) Leucite trapezohedron (white) in a volcanic rock from Mount Vesuvius, Italy.

CHEMICAL COMPOSITION

The complex chemical composition of members of the amphibole group can be expressed by the general formula $A_{0-1}B_2C_5T_8O_{22}(OH, F, Cl)_2$, where A = Na, K; B = Na, Li, Ca, Mn, Fe^{2+}, Mg; C = Mg, Fe^{2+}, Mn, Al, Fe^{3+}, Ti; and T = Si, Al. Nearly complete substitution may take place between sodium and calcium and among magnesium, ferrous iron, and manganese (Mn). There is limited substitution between ferric iron and aluminum and between titanium and other C-type cations. Aluminum can partially substitute for silicon in the tetrahedral (T) site. Partial substitution of fluorine (F), chlorine, and oxygen for hydroxyl (OH) in the hydroxyl site is also common. The complexity of the amphibole formula has given rise to numerous mineral names within the amphibole group. In 1978 Leake presented a precise nomenclature of 57 names that encompass the chemical variation within this group. The mineral nomenclature of the amphiboles is divided into four principal subdivisions based on B-group cation occupancy: (1) the iron-magnesium-manganese amphibole group, (2) the calcic amphibole group, (3) the sodic-calcic amphibole group, and (4) the alkali amphibole group. The chemical formulas for selected amphiboles from each of the four compositional groups are given in Table 20.

Amphibole nomenclature

Table 20: Chemical Formulas for Selected Amphiboles from the Four Compositional Groups

amphibole formula	A_{0-1}	B_2	C_5	T_8	$O_{22}(OH, F, Cl)_2$
Fe-Mg-Mn amphiboles					
Magnesio-anthophyllite	0	Mg_2	Mg_5	Si_8	$O_{22}(OH)_2$
Magnesio-cummingtonite	0	Mg_2	Mg_5	Si_8	$O_{22}(OH)_2$
Grunerite	0	Fe^{2+}_2	Fe^{2+}_5	Si_8	$O_{22}(OH)_2$
Magnesio-gedrite	0	Mg_2	Mg_3Al_2	Si_6Al_2	$O_{22}(OH)_2$
Calcic amphiboles					
Tremolite	0	Ca_2	Mg_5	Si_8	$O_{22}(OH)_2$
Ferroactinolite	0	Ca_2	Fe^{2+}_5	Si_8	$O_{22}(OH)_2$
Edenite	Na	Ca_2	Mg_5	Si_7Al	$O_{22}(OH)_2$
Pargasite	Na	Ca_2	Mg_4Al	Si_6Al_2	$O_{22}(OH)_2$
Hastingsite	Na	Ca_2	$Fe^{2+}Fe^{3+}$	Si_6Al_2	$O_{22}(OH)_2$
Alumino-tschermakite	0	Ca_2	Mg_3Al_2	Si_6Al_2	$O_{22}(OH)_2$
Na-Ca amphiboles					
Alumino-winchite	0	CaNa	Mg_4Al	Si_8	$O_{22}(OH)_2$
Richterite	Na	CaNa	Mg_5	Si_8	$O_{22}(OH)_2$
Alkali amphibole					
Glaucophane	0	Na_2	Mg_3Al_2	Si_8	$O_{22}(OH)_2$
Riebeckite	0	Na_2	$Fe^{2+}_3Fe^{3+}_2$	Si_8	$O_{22}(OH)_2$
Eckermannite	Na	Na_2	Mg_4Al	Si_8	$O_{22}(OH)_2$
Arfvedsonite	Na	Na_2	$Fe^{2+}_4Fe^{3+}$	Si_8	$O_{22}(OH)_2$

Numerous common amphiboles can be represented within the $Mg_2Si_8O_{22}(OH)_2$ (magnesio-anthophyllite)–$Fe_2Si_8O_{22}(OH)_2$ (grunerite)–"$Ca_2Si_8O_{22}(OH)_2$" (hypothetical pure calcium amphibole) compositional field (Figure 44). This diagram is commonly referred to as the amphibole quadrilateral. Complete substitution extends from tremolite $[Ca_2Mg_5Si_8O_{22}(OH)_2]$ to ferroactinolite $[Ca_2Fe_5Si_8O_{22}(OH)_2]$. Actinolite is the intermediate member of the tremolite-ferroactinolite series. The compositional range from about 0.9 $Mg_2Si_8O_{22}(OH)_2$ to about $Fe_2Mg_5Si_8O_{22}(OH)_2$ is represented by the orthorhombic amphibole known as anthophyllite. The monoclinic cummingtonite-grunerite series exists from about $Fe_2Mg_5Si_8O_{22}(OH)_2$ to $Fe_2Si_8O_{22}(OH)_2$. Intermediate amphibole compositions do not exist between anthophyllite and the tremolite-actinolite series. Compositional gaps also exist between the cummingtonite-grunerite series and other calcic amphiboles. Consequently, coexisting pairs of anthophyllite-tremolite and grunerite-ferroactinolite are found together in some rocks. Sodium-bearing amphiboles are represented by the glaucophane $[Na_2Mg_3Al_2Si_8O_{22}(OH)_2]$–riebeckite $[Na_2Fe^{2+}_3Fe^{3+}_2Si_8O_{22}(OH)_2]$ series. Additional sodium is contained in the A site of the structure of arfvedsonite $[NaNa_2Fe^{2+}_4Fe^{3+}Si_8O_{22}(OH)_2]$. For amphiboles that are not precisely characterized by their chemistry, it is not possible to assign a specific name. Hornblende is the general name used for calcic amphiboles identified only by physical or optical properties.

The amphiboles differ chemically from the pyroxenes in two major respects. Amphiboles have hydroxyl groups in

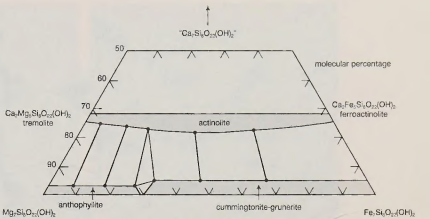


Figure 44: Amphibole compositions in the system $Mg_2Si_8O_{22}(OH)_2$ (anthophyllite)–$Fe_2Si_8O_{22}(OH)_2$ (grunerite)–"$Ca_2Si_8O_{22}(OH)_2$." The general compositional fields are outlined, and coexisting amphibole compositions are shown by tie lines between the actinolite field and the anthophyllite-grunerite field.

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their structure and are considered to be hydrous silicates that are stable only in hydrous environments where water can be incorporated into the structure as $(OH)^-$. The second major compositional difference is the presence of the A site in amphiboles that contains the large alkali elements, typically sodium cations and at times potassium cations. The pyroxenes do not have an equivalent site that can accommodate potassium. The presence of hydroxyl groups in the structure of amphiboles decreases their thermal stability relative to the more refractory (heat-resistant) pyroxenes. Amphiboles decompose to anhydrous minerals (mainly pyroxenes) at elevated temperatures.

CRYSTAL STRUCTURE

The fundamental building block of all silicate mineral structures is the silicon-oxygen tetrahedron $(SiO_4)^{4-}$. It consists of a central silicon atom surrounded by four oxygen atoms in the shape of a tetrahedron. The essential characteristic of the amphibole structure is a double chain of corner-linked silicon-oxygen tetrahedrons that extend indefinitely parallel to the c crystallographic axis, the direction of elongation (Figure 45). The tetrahedrons alternately share two and three oxygen atoms to produce a silicon-to-oxygen ratio of 4:11. The double chains repeat along their length at intervals of approximately 5.3 angstroms (Å), or 2.1×10^{-9} inch, and this defines the ideal c axis of the unit cell. The double chains are separated from other double chains and bonded to each other laterally by planes of cations and hydroxyl ions (Figure 46). This figure illustrates the double chains as well as the octahedral strips to which they are bonded. The structure contains, besides the tetrahedral sites that constitute the chains, additional cation sites labeled *A*, *M4*, *M3*, *M2*, and *M1*. The *A* site contains the large alkali ions, mainly

Amphibole double chains

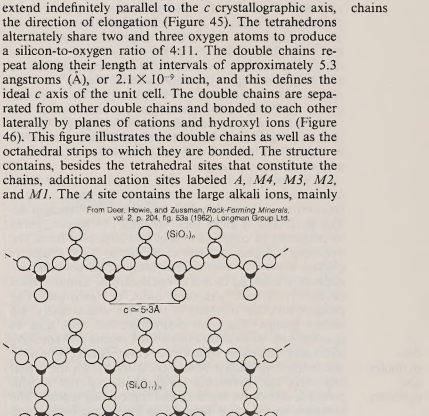


Figure 45: Illustration of pyroxene single-chain silicon-oxygen tetrahedral structure $(SiO_3)_n$ and amphibole double-chain structure $(Si_4O_{11})_n$.

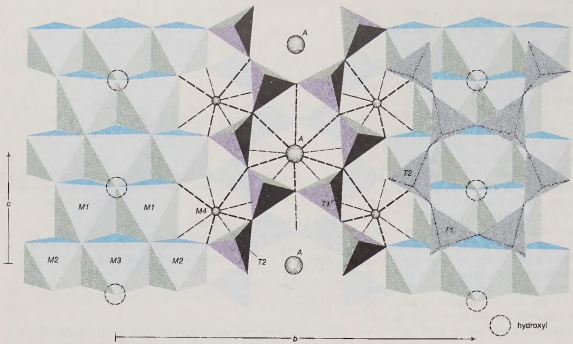


Figure 46: Crystal structure of a monoclinic amphibole projected down the *a* axis. OH groups are located in the centres of the large holes of the rings in the chains. *M1, M2,* and *M3* sites are sixfold coordinated and contain *C* cations. The *M4* site is six- to eightfold coordinated and houses the larger *B* cations. The *A* site is 10- to 12-fold coordinated and lies between the backs of the double chains.

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sodium, and is bonded to 10 to 12 oxygen and hydroxyl ions. The *A* site is filled to the extent necessary to maintain electrical neutrality, but typically the available *A* sites are not completely occupied. The *M1, M2,* and *M3* octahedrons contain the *C*-type cations and share edges to form octahedral bands parallel to the *c* crystallographic direction. *M1* and *M3* bond to four oxygen atoms and two hydroxyl anions. *M2* is coordinated by six oxygen atoms. *M4* has sixfold to eightfold coordination and accommodates the *B*-type cations. The *M4* site is most similar to the *M2* site in pyroxene and accommodates Ca^{2+}, as does the *M2* site in pyroxene. Amphiboles have two each of the *M1, M2,* and *M4* sites and one *M3* site, giving a total of seven octahedral cations in the unit cell. The structure of a monoclinic amphibole viewed down the *c* crystallographic axis is shown in Figure 47A. The tetrahedral-octahedral-tetrahedral (t-o-t) strips, also known as I beams, are approximately twice as wide in the *b* direction as the equivalent t-o-t strips in pyroxenes because of the doubling of the chains in the amphiboles. The t-o-t I beams are schematically shown in Figure 47B. The structure ruptures around the stronger I beams, as shown in Figure 47B, producing the characteristic 56° and 124° amphibole cleavage angles.

The similarity between the crystal structures of the major layer silicates (clays and micas) and the chain silicates (pyroxenes and amphiboles) has long been recognized. The structures of all of these silicates can be considered as consisting of combinations of two structural units, the pyroxene I beams and the mica sheets. Both structures contain a band of octahedrons sandwiched between two oppositely pointing chains of tetrahedrons. Combinations of these two basic structural units, or "modules," can produce all other minerals in the layer silicate and chain silicate groups. The term biopyribole has been used to describe any mineral that has both I beams and sheetlike structures. The name comes from *bio*tite (mica), *pyro*xene, and amph*ibole*. Biopyriboles have chain widths and repeat sequences like pyroxenes (single-chain repeats), amphiboles (double-chain repeats), and triple-chain repeats. The latter are intermediate between an amphibole I beam and the sheet structure of mica. Pyribole refers to any member of the biopyribole group, excluding the sheet silicates (*i.e.,* the pyroxenes and amphiboles together).

Bio-pyriboles and pyriboles

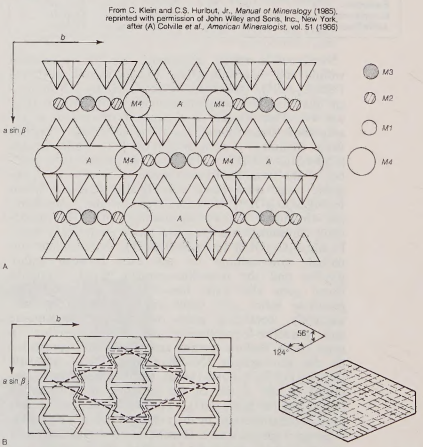


Figure 47: (A) Schematic projection of the monoclinic amphibole structure on a plane perpendicular to the *c* axis. (B) Control of cleavage angles by I beams in the amphibole structure compared with naturally occurring cleavage angles.

PHYSICAL PROPERTIES

Long prismatic, acicular, or fibrous crystal habit, Mohs hardness between 5 and 6, and two directions of cleavage intersecting at approximately 56° and 124° generally suffice to identify amphiboles in hand specimens. The specific gravity values of amphiboles range from about 2.9 to 3.6. Amphiboles yield water when heated in a closed tube and fuse with difficulty in a flame. Their colour ranges extensively from colourless to white, green, brown, black, blue, or lavender and is related to composition, principally the iron content. Magnesium-rich amphiboles such as anthophyllite, cummingtonite, and tremolite are colourless or light in colour. The tremolite-ferroactinolite series ranges from white to dark green with increasing iron content. The finely fibrous and massive variety of actinolite-tremolite known as nephrite jade ranges from green to



Figure 48: *Three important members of the amphibole group.*
(Left) Hornblende (of the pargasite variety) from Pargas, Fin. (Centre) Actinolite crystals from Val Malenco, Italy. (Right) Riebeckite (of the crocidolite variety) from South Africa.
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black. Common hornblende is typically black. Glaucophane and riebeckite are usually blue. Anthophyllite is gray to various shades of green and brown. The cummingtonite-grunerite series occurs in various shades of light brown. Iron-free varieties of tremolite containing manganese can have a lavender colour.

The common crystallographic habit of amphiboles is acicular or prismatic; however, most of the amphiboles are also known to crystallize in the asbestiform habit. The asbestiform variety of riebeckite is called crocidolite or blue asbestos. Amosite is a rare asbestiform variety of grunerite, named from the company Amos (Asbestos Mines of South Africa). The most important commercial asbestos material is chrysotile, the asbestiform variety of serpentine.

In thin sections, amphiboles are distinguished by several properties, including two directions of cleavage at approximately 56° and 124°, six-sided basal cross sections, characteristic colour, and pleochroism (colour variance with the direction of light propagation). Orthorhombic amphiboles exhibit less intense pleochroism than the monoclinic amphiboles. Some members of the amphibole group are shown in Figure 48.

ORIGIN AND OCCURRENCE

Exhibiting an extensive range of possible cation substitutions, amphiboles crystallize in both igneous and metamorphic rocks with a broad range of bulk chemical compositions. Because of their relative instability to chemical weathering at the Earth's surface, amphiboles make up only a minor constituent in most sedimentary rocks.

Igneous rocks. Calcic amphiboles are characteristically contained in igneous rocks. Igneous amphiboles are intermediate in composition between tremolite, tschermakite, edenite, and pargasite end-members. Typically, these amphiboles of intermediate composition are called hornblende. Hornblende occurs in various plutonic igneous rocks, including diorites, quartz diorites, and granodiorites. It also occurs as phenocrysts in andesite lavas that contained enough water for amphiboles to form. Hastingsite is found in granites and alkali-rich intrusives such as syenites. The alkali amphiboles riebeckite and arfvedsonite are found most commonly in granites, syenites, nepheline syenites, and related pegmatites. Richterite occurs as a hydrothermal product and in veins in alkaline igneous rocks.

Hornblende

Contact metamorphic rocks. Amphiboles occur in contact metamorphic aureoles around igneous intrusions. (An aureole is the zone surrounding an intrusion, which is a mass of igneous rock that solidified between other rocks located within the Earth.) The contact aureoles produced in siliceous limestones and dolomites, called skarns or calc-silicate rocks, characteristically contain metamorphic amphiboles such as tremolite or actinolite. The presence of tremolite implies a relatively low grade of metamorphism as tremolite breaks down to form the pyroxene diopside in the presence of calcite and quartz at elevated temperatures. Richterite-winchite occurs in hydrothermally metamorphosed limestones. Magnesium-rich anthophyllites are found along contact zones of granitic dikes intruding ultramafic rocks (those rich in iron and magnesium).

Regional metamorphic rocks. Many different amphiboles may be contained in regional metamorphic rocks. Commonly several amphiboles may coexist with one another in the same sample, depending on the bulk chemistry of the rock and on the pressure and temperature of metamorphism. The amphiboles typically occur with plagioclase feldspar, quartz, and biotite, as well as with chlorite and oxide minerals. In magnesium-rich rocks, tremolite, anthophyllite, and hornblende may exist together. Gedrite and cummingtonite coexist with garnet in rocks enriched in aluminum and iron. Rocks containing cummingtonite or grunerite are characteristic of metamorphosed iron formations associated with iron oxides, iron-rich sheet silicates, carbonates, and quartz. Glaucophane occurs only in such metamorphic rocks as schist, eclogite, and marble. Glaucophane associated with jadeite, lawsonite, and calcite or aragonite is the characteristic assemblage found in high-pressure, low-temperature metamorphic rocks called blueschists, which have a blue colour imparted by the glaucophane. Blueschists have basaltic bulk compositions and may also contain riebeckite. The latter also may occur in regional metamorphic schists. Tremolite-actinolite and the sheet-silicate chlorite are the principal minerals in the low-to-moderate temperature and pressure greenschist metamorphic rocks. Hornblende is characteristic of some medium-grade metamorphic rocks known as amphibolites, in which hornblende and plagioclase are the major constituents.

Coexistence in metamorphic rocks

Dehydration of amphiboles in the lower crust or mantle may be an important source of water that aids in the generation of magmas from partial melting processes.

Pyroxenes

GENERAL CONSIDERATIONS

Pyroxenes are the most significant and abundant group of rock-forming ferromagnesian silicates. They are found in almost every variety of igneous rock and also occur in rocks of widely different compositions formed under conditions of regional and contact metamorphism. The name pyroxene is derived from the Greek *pyro,* meaning "fire," and *xenos,* meaning "stranger," and was given by Haüy to the greenish crystals found in many lavas which he considered to have been accidentally included there.

Pyroxenes crystallize in both the orthorhombic and monoclinic crystal systems. Typically pyroxenes occur as stubby prismatic crystals. They are chemically analogous to the amphiboles except that, as discussed above, hydroxyls are absent in the pyroxene structure. They are similar in colour, lustre, and hardness to the amphiboles but have slightly higher densities owing to the absence of hydroxyls. Pyroxenes have two distinctive planes of cleavage with intersecting angles of about 87° and 93°. Perpendicular to their cleavage planes, pyroxenes have nearly square cross sections, which, together with the cleavage directions, are diagnostic properties.

CHEMICAL COMPOSITION

The chemical composition of minerals of the pyroxene group can be expressed by the general formula XYZ_2O_6, in which $X = Na^+, Ca^{2+}, Mn^{2+}, Fe^{2+}, Mg^{2+}, Li^+$; $Y = Mn^{2+}, Fe^{2+}, Mg^{2+}, Fe^{3+}, Al^{3+}, Cr^{3+}, Ti^{4+}$; and $Z = Si^{4+}, Al^{3+}$. The range of possible chemical substitutions in pyroxene is constrained by the sizes of the available sites in the structure and the charge of the substituting cations. The X cation sites in general are larger than the Y cation sites. Extensive atomic substitution occurs between the ideal end-member compositions. Most pyroxenes have only limited substitution of aluminum for silicon in the Z (tetrahedral) site. When a substituting ion differs in charge, electrical neutrality is maintained by coupled substitutions. For example, the pair consisting of Na^+ and Al^{3+} substitutes for 2 Mg^{2+}. Table 21 shows the five major chemical subdivisions of pyroxenes.

Table 21: Major Chemical Subdivisions of Pyroxenes

Magnesium-iron pyroxenes	
Enstatite	$Mg_2Si_2O_6$
Orthoferrosilite	$Fe^{2+}{}_2Si_2O_6$
Orthopyroxene	$(Mg, Fe^{2+})_2Si_2O_6$
Pigeonite	$(Mg, Fe^{2+}, Ca)_2Si_2O_6$
Calcium pyroxenes	
Augite	$(Ca, Na)(Mg, Fe, Al)(Si, Al)_2O_6$
Diopside	$CaMgSi_2O_6$
Hedenbergite	$CaFe^{2+}Si_2O_6$
Johannsenite	$CaMnSi_2O_6$
Calcium-sodium pyroxenes	
Omphacite	$(Ca, Na)(Mg^{2+}, Fe^{2+}, Al)Si_2O_6$
Aegirine-augite	$(Ca, Na)(Mg^{2+}, Fe^{2+}, Fe^{3+})Si_2O_6$
Sodium pyroxenes	
Jadeite	$NaAlSi_2O_6$
Aegirine (acmite)	$NaFe^{3+}Si_2O_6$
Kosmochlor (ureyite)	$NaCr^{3+}Si_2O_6$
Lithium pyroxenes	
Spodumene	$LiAlSi_2O_6$

Exsolution of lamellae

At high temperatures, pyroxenes have more extensive fields of solid solution than they do at lower ones. Consequently, as temperatures decrease, the pyroxene adjusts its composition in the solid state by exsolving a separate phase in the form of lamellae within the host pyroxene grain. The lamellae are exsolved along specific crystallographic directions, producing oriented intergrowths with parallel and herringbone texture. There are five principal combinations of exsolution pairs: (1) augite with hypersthene lamellae, (2) augite with pigeonite lamellae, (3) augite with both pigeonite and hypersthene lamellae, (4) pigeonite with augite lamellae, and (5) hypersthene with augite lamellae.

The pyroxenes differ compositionally from the amphiboles in two major respects. Pyroxenes contain no essential water in the form of hydroxyls in their structure, whereas amphiboles are considered to be hydrous silicates. The second key chemical difference between the two is the presence of the A site in amphiboles which contains the large alkali elements, typically sodium and at times potassium; the pyroxenes do not have an equivalent site that can accommodate potassium. Hydroxyl groups in the amphibole structure decrease their thermal stability relative to the more refractory pyroxenes. At high temperatures amphiboles decompose to anhydrous minerals.

$CaSiO_3$-$MgSiO_3$-$FeSiO_3$ system

The most common pyroxenes can be represented as part of the chemical system $CaSiO_3$ (wollastonite, a pyroxenoid), $MgSiO_3$ (enstatite), and $FeSiO_3$ (orthoferrosilite; see Figure 49). Since no true pyroxenes exist with calcium contents greater than that of the diopside-hedenbergite join, the part of this system below this join is known as the pyroxene quadrilateral. Ferrous iron and magnesium substitute freely since they have similar ionic sizes and identical charges. Complete substitution exists between enstatite ($Mg_2Si_2O_6$) and orthoferrosilite ($Fe_2Si_2O_6$), and complete solid solution of iron for magnesium exists between diopside ($CaMgSi_2O_6$) and hedenbergite ($CaFeSi_2O_6$). Augite, subcalcic augite, and pigeonite lie within the interior of the pyroxene quadrilateral. Compositionally, augite is related to members of the diopside-hedenbergite series with limited substitution of Na^+ for Ca^{2+}, Al^{3+} for Mg^{2+} and Fe^{2+}, and Al^{3+} for Si^{4+} in the Z (tetrahedral) site. Augites with substantial aluminum or sodium cannot be strictly represented in the quadrilateral plane. Monoclinic pigeonite encompasses a field of magnesium-iron solid solution with a slightly higher calcium content than the orthorhombic enstatite-orthoferrosilite series. The nomenclature for the orthopyroxene series is based on the percentage of $MgSiO_3$: enstatite, 90–100; bronzite, 70–90; hypersthene, 50–70; ferrohypersthene, 30–50; eulite, 10–30; and orthoferrosilite, 0–10.

Coupled substitutions involving Na^+, Li^+, or Al^{3+} for Mg^{2+} in the enstatite structure yield pyroxenes that lie outside the quadrilateral compositional field. The coupled substitution of Na^+ and Al^{3+} for 2 Mg^{2+} in enstatite produces the pyroxene jadeite. The coupled substitution of Na^+ and Fe^{3+} for 2 Mg^{2+} produces the pyroxene aegirine (acmite). Substiution of Li^+ and Al^{3+} for 2 Mg^{2+} yields spodumene. The substitution of Al^{3+} for Mg^{2+} and Al^{3+} for Si^{4+} yields the ideal tschermakite component $MgAlSiAlO_6$.

Other less common pyroxenes with compositions outside the pyroxene quadrilateral include johannsenite [$CaMnSi_2O_6$], a variety of augite called fassaite [$Ca(Mg, Fe^{2+}, Fe^{3+}, Al)(Si, Al)_2O_6$], and kosmochlor (ureyite) [$NaCrSi_2O_6$]. Johannsenite involves the substitution of manganese for iron in hedenbergite. Kosmochlor has chromium (Cr) in place of iron or aluminum in a sodic pyroxene. The fassaite variety of the calcium pyroxene group has a variable but high aluminum content and a high Fe^{3+}:Fe^{2+} ratio.

The nature of aluminum substitution in pyroxenes varies significantly from one pyroxene to another. In the magnesium-iron pyroxene group, aluminum is usually present in only small amounts. In both jadeite and spodumene, which contain essential aluminum in the Y site, the substitution of silicon by aluminum in the Z tetrahedral site is almost negligible. In augite there can be extensive substitution of aluminum for tetrahedral silicon.

CRYSTAL STRUCTURE

The pyroxene group includes minerals that form in both the orthorhombic and monoclinic crystal systems. Or-

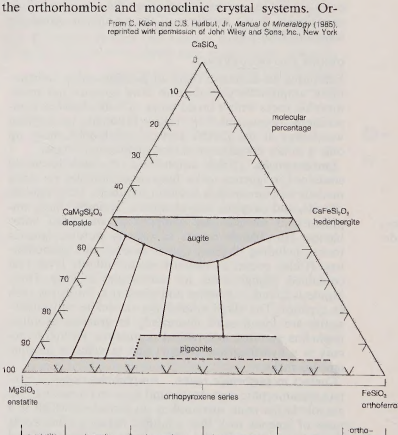


Figure 49: Pyroxene compositions in the system $CaSiO_3$ (wollastonite)–$MgSiO_3$ (enstatite)–$FeSiO_3$ (orthoferrosilite). General compositional fields are outlined, and coexisting pyroxene compositions are shown by tie lines between augite and magnesium-iron-rich pyroxenes. Nomenclature of the enstatite-orthoferrosilite solid-solution series is shown at the bottom of the diagram.

thorhombic pyroxenes are referred to as orthopyroxenes, and monoclinic pyroxenes are called clinopyroxenes. The essential feature of all pyroxene structures is the linkage of the silicon-oxygen (SiO_4) tetrahedrons by sharing two of the four corners to form continuous chains. The chains, which extend indefinitely parallel to the *c* crystallographic axis, have the composition of $(SiO_3)_n$ (Figure 50). A repeat distance of approximately 5.3 Å along the length of the chain defines the *c* axis of the unit cell. The SiO_3 chains are bonded to a layer of octahedrally coordinated cation bands which also extend parallel to the *c* axis. The octahedral layer contains two distinct cation sites called *M1* and *M2*. The size and charge of the cations that occupy the *M2* site chiefly determine the structural type of a pyroxene. Large, singly or doubly charged cations give rise to a diopside (monoclinic) structure, whereas small, singly or doubly charged cations result in an enstatite (orthorhombic) structure.

SiO_3 chains

In most pyroxenes the chains are not exactly straight as shown in Figure 50, but are rotated or kinked so that more than one type of chain is possible. The diopside, jadeite, augite, protoenstatite, and spodumene structures consist of only one chain type. Pigeonite, clinoenstatite, and omphacite have two symmetrically distinct types of tetrahedral chains. Orthopyroxenes also have two distinct types of tetrahedral chains and an octahedral stacking sequence that leads to a doubling of the *a* axis.

A representative pyroxene structure that illustrates the tetrahedral and octahedral chains in jadeite is shown in Figure 51. The octahedral strips consist of *M1* and *M2* octahedrons sandwiched between two oppositely pointing tetrahedral chains. The *M1* sites are occupied by smaller cations such as magnesium, iron, aluminum, and manganese, which are coordinated to six oxygen atoms to form a regular octahedron. In monoclinic pyroxenes, the *M2* site is a large irregular polyhedron occupied by the larger calcium and sodium cations which are in eightfold coordination. In the low-calcium orthorhombic pyroxenes, *M2* contains magnesium and iron, and the polyhedron takes on a more regular octahedral shape. The *M1* cation strip is bonded to oxygen atoms of two oppositely pointing tetrahedral chains. Together, these form a tetrahedral-octahedral-tetrahedral (t-o-t) strip. A schematic projection of the pyroxene structure perpendicular to the *c* axis and the relationship of the pyroxene cleavage to the t-o-t strips or I beams is shown in Figure 52.

The pyroxene quadrilateral

Pyroxenes in the quadrilateral with compositions near the diopside-hedenbergite join exist only in the monoclinic form. Those with compositions near the enstatite-orthoferrosilite join containing less than about 15 percent $CaSiO_3$ can be subdivided into three structural types. Those with approximately 30 percent $FeSiO_3$ are monoclinic at high temperatures (pigeonite) and invert to an orthorhombic structure at low temperatures (hypersthene). Those

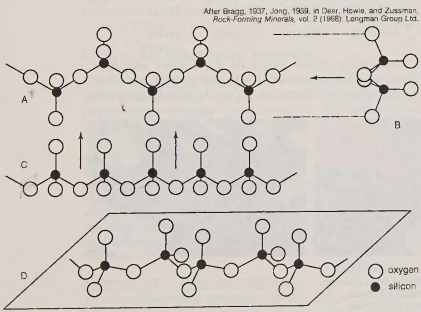


Figure 50: Single pyroxene chain, $(SiO_3)_n$, in three projections (A) on (100), a plane that intersects the *a* axis and is parallel to the *b* and *c* axes, (B) along the *c* axis direction, (C) along the *b* axis direction, and (D) in perspective.

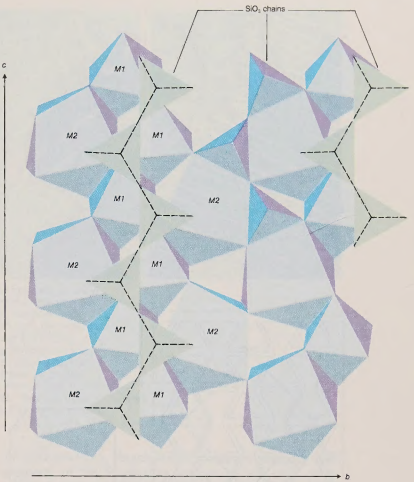


Figure 51: The structure of jadeite, $NaAlSi_2O_6$, a monoclinic pyroxene, in an approximate projection onto (100). The *M2* site is occupied by Na^+ and the *M1* site by Al^{3+}

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with less than 30 percent $FeSiO_3$ can exist as clinoenstatite (monoclinic), protoenstatite (orthorhombic), or enstatite (orthorhombic) polymorphic structures. Pyroxenes outside the quadrilateral all have monoclinic pyroxene structures similar to that of diopside.

The inversion of high-temperature structures to low-temperature structures is often accompanied by the exsolution of lamellae of either a separate calcium-rich or magnesium-iron-rich phase. For example, as high-temperature monoclinic pigeonite slowly cools, it exsolves calcium ions to form augite lamellae and inverts to the orthorhombic hypersthene structure. Consequently, the presence of the exsolution lamellae is evidence of a previous monoclinic structure.

PHYSICAL PROPERTIES

Within hand specimens, pyroxene can generally be identified by the following characteristics: two directions of cleavage intersecting at roughly right angles (approximately 87° and 93°), stubby prismatic crystal habit with nearly square cross sections perpendicular to cleavage directions, and a Mohs hardness between 5 and 7. Specific gravity values of the pyroxenes range from about 3.0 to 4.0. Unlike amphiboles, pyroxenes do not yield water when heated in a closed tube. Characteristically, pyroxenes are dark green to black in colour, but they can range from dark green to apple-green and from lilac to colourless, depending on the chemical composition. Diopside ranges from white to light green, darkening in colour as the iron content increases. Hedenbergite and augite are typically black. Pigeonite is greenish brown to black. Jadeite is white to apple-green to emerald-green or mottled white and green and is a massive aggregate of compact fibres. Aegirine (acmite) forms long, slender prismatic crystals that are brown to green in colour. Enstatite is yellowish or greenish brown; bronzite has a submetallic bronzelike lustre; and hypersthene and more iron-rich orthopyroxenes range from brown to black. Spodumene is colourless, white, gray, pink, yellow, or green. The clear lilac-coloured variety is called kunzite, while the clear emerald-green type is known as hiddenite.

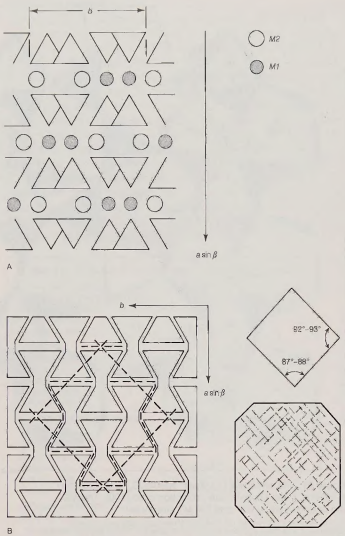


Figure 52: (A) Schematic projection of the monoclinic pyroxene structure perpendicular to the *c* axis. (B) Control of cleavage angles by the I beams in the pyroxene structure compared with naturally occurring pyroxene cleavage.

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In thin sections, monoclinic pyroxenes are distinguished by two directions of cleavage at approximately 87° and 93°, eight-sided basal cross sections, and light brown or green colour (Figure 53). Orthorhombic pyroxenes differ from monoclinic pyroxenes in that they have parallel extinction.

Microscopically, many igneous pyroxenes show exsolution textures of thin lamellae of one pyroxene in a host of a different composition. The lamellae occur as oriented intergrowths that display parallel and herringbone textures (Figure 54). These lamellae result from the exsolution of a separate pyroxene phase from a host grain due to subsolidus re-equilibration (that occurs while the mineral is in the solid state) during slow cooling.

ORIGIN AND OCCURRENCE

Minerals in the pyroxene group are abundant in both igneous and metamorphic rocks. Their susceptibility to both chemical and mechanical weathering makes them a rare constituent of sedimentary rocks. Pyroxenes are classified as ferromagnesian minerals in allusion to their high content of magnesium and iron. Their conditions of formation are almost exclusively restricted to environments of high temperature, high pressure, or both. Characteristically the more common pyroxenes are found in mafic and ultramafic igneous rocks where they are associated with olivine and calcium-rich plagioclase and in high-grade metamorphic rocks such as granulites and eclogites. Enstatite, clinoenstatite, and kosmochlor occur in meteorites.

Abundance in igneous and metamorphic rocks

Igneous rocks. Magnesium-rich orthopyroxenes and calcium-rich clinopyroxenes are important constituents of basalts, gabbros, peridotites, and norites. They are the major minerals in pyroxenites. Magnesium-rich orthopyroxenes occur in the earlier-formed rocks of layered ultramafic complexes.

Uninverted pigeonites (monoclinic) are common as phenocrysts in high-temperature, rapidly cooled lavas and in some intrusives such as diabases. In slowly cooled mafic intrusive rocks, pigeonite inverts to an orthorhombic pyroxene and undergoes exsolution.

Augite is the most common pyroxene and is found primarily in mafic igneous rocks. It occurs in basalts, gabbros, andesites, diorites, and peridotites. The augites in layered ultramafic intrusions show compositional trends of increasing iron and decreasing magnesium contents with fractionation. Augite is also known to occur in lunar basalts. Although more common in metamorphic rocks, diopside is found in some mafic and ultramafic rocks.

Aegirine (acmite) and aegirine-augite occur most commonly as products of the late crystallization of alkaline magmas. They are found in alkalic rocks such as nepheline syenites and phonolites, wherein they are associated with orthoclase, feldspathoids, augite, and sodium-rich amphiboles.

Spodumene is found almost exclusively in lithium-rich granite pegmatites. Some of the world's largest known crystals are spodumene. Single crystals of spodumene exceeding 13 metres (43 feet) in length were mined for their lithium content in the Black Hills of South Dakota, U.S. Spodumene is typically associated with microcline, albite, quartz, muscovite, lepidolite, beryl, and tourmaline.

Metamorphic rocks. Iron-rich orthopyroxenes are found in metamorphosed iron formations in association with the amphibole grunerite. At higher grades of regional metamorphism, the amphibole anthophyllite breaks down to form magnesium-iron orthopyroxenes. The orthopyroxenes hypersthene and enstatite occur in high-temperature and high-pressure granulite facies rocks such as quartz-rich, garnet-bearing granulites.

Diopside results from the thermal metamorphism of siliceous limestones or dolomites according to the following decarbonation reaction:

$$CaMg(CO_3)_2 + 2SiO_2 \rightarrow CaMgSi_2O_6 + 2CO_2.$$

dolomite quartz diopside carbon dioxide

In calc-silicate skarns produced by contact metamorphism, diopside is associated with wollastonite, vesuvianite, grossular, and tremolite. Diopside also forms under

By courtesy of G. Malcolm Brown



Figure 53: Photomicrographs of various pyroxene minerals in thin sections (illuminated with polarized light). (Left) Augite phenocryst (large, individual, gray crystal) in basalt lava, showing characteristic basal octagonal form and square-segmentation cleavage (magnified about 16.5×). (Centre) Titanaugite crystal (yellow) showing typical hourglass zoning (magnified about 13.2×). (Right) Gabbro with two pyroxenes, a calcium-rich augite (blue-red and green) enclosed by a calcium-poor pigeonite crystal; clinohypersthene in thin lamellae has separated from the calcium-rich augite, and augite has separated from the pigeonite before it inverted to hypersthene (gray; magnified about 21.1×).

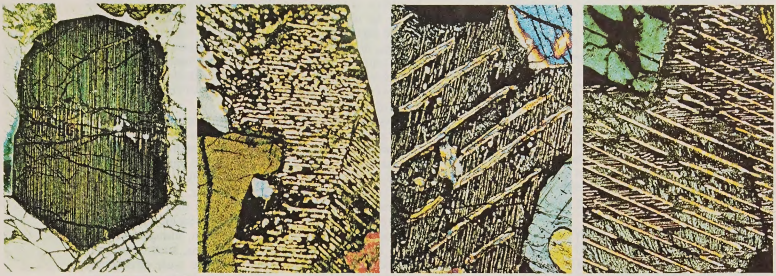


Figure 54: Photomicrographs of various thin sections containing pyroxene minerals; all show separation within a mineral grain of distinct phases due to further cooling after the grain had solidified (illuminated by polarized light). (Far left) Bronzite crystal from an ultramafic rock; thin lamellae of a calcium-rich species, probably pigeonite, have separated from the bronzite, and the host (grayish) thus has a very low calcium content (magnified about 40×). (Left) Twinned crystal of inverted pigeonite from a gabbro. Augite, seen as brightly coloured thin lamellae with herringbone texture because of the twinned relationship, has separated from the pigeonite; further cooling has caused the host, gray-coloured hypersthene, to change symmetry (invert; magnified about 22×). (Right) Inverted pigeonite from a more slowly cooled gabbro than that at left; as a result, the augite lamellae are wider, and after inversion more augite has separated from the hypersthene host (magnified about 70.4×). (Far right) Complex separation of augite from an inverted pigeonite (magnified about 70.4×).
By courtesy of G. Malcolm Brown

conditions of regional metamorphism by the breakdown of tremolite. Hedenbergite is a product of thermal metamorphism of iron-rich sediments where its formation is probably due to the breakdown of ferroactinolite with increasing temperature. The variety of augite called fassaite is found in quartz-free, aluminum-rich skarns associated with spinel, calcite, vesuvianite, garnet, clintonite, and diopside. Johannsenite is associated with rhodonite, bustamite, sphalerite, chalcopyrite, galena, pyrite, and magnetite in metasomatized limestones adjacent to igneous intrusions.

Aegirine (acmite) is associated with glaucophane or riebeckite in some metamorphic rocks. Jadeite is found only in metamorphic rocks. It is associated with albite, glaucophane, aragonite, lawsonite, and quartz in high-pressure, low-temperature metamorphic rocks of blueschist facies. In some localities, jadeite is associated with serpentine in glaucophane-bearing metamorphic rocks.

Omphacite is restricted in occurrence to the high-pressure and high-temperature rocks called eclogites. Eclogites represent the most deep-seated conditions of metamorphism and are characterized by an assemblage of omphacite and magnesium-rich pyrope garnet. Omphacite-bearing eclogite nodules are associated with peridotites in the kimberlite pipes of South Africa. (W.B.Si.)

Quartz and other silica minerals

GENERAL CONSIDERATIONS

Silica minerals make up approximately 12 percent of the Earth's crust and are second only to the feldspars in mineral abundance. Free silica occurs in many crystalline forms with a composition very close to that of silicon dioxide (SiO_2), 46.75 percent by weight being silicon and 53.25 percent oxygen. Quartz is by far the most commonly occurring form. Tridymite, cristobalite, and the hydrous silica mineral opal are uncommon, and vitreous (glassy) silica, melanophlogite, coesite, and stishovite have been reported from only a few localities. Several other forms have been produced in the laboratory but have not been found in nature.

PHYSICAL AND CHEMICAL PROPERTIES

The crystallographic structures of the silica minerals, except stishovite, are three-dimensional arrays of linked tetrahedrons, each consisting of a silicon atom coordinated by four oxygen atoms. The tetrahedrons are usually quite regular, and the silicon-oxygen bond distances are 1.61 ± 0.02 Å. Principal differences are related to the geometry of the tetrahedral linkages, which may cause small distortions within the silica tetrahedrons. High pressure forces silicon atoms to coordinate with six oxygen atoms, producing nearly regular octahedrons in the stishovite structure.

The silica minerals when pure are colourless and transparent and have a vitreous lustre. They are nonconductors of electricity and are diamagnetic. All are hard and strong and fail by brittle fracture under an imposed stress.

Some important physical properties of the silica minerals are compared in Table 22. All except low tridymite and coesite (among the crystalline varieties) have relatively high symmetry. There is a linear relationship between the specific gravity values listed in Table 22 and the arithmetic mean of the indices of refraction (measures of the velocity of light that is transmitted in different crystallographic directions) for silica minerals composed of linked tetrahedrons. This relationship (Figure 55) does not extend to stishovite because it is not made up of silica tetrahedrons. Melanophlogite is notable because it plots below vitreous silica on the graph. The specific gravities of silica minerals are less than those of most of the dark-coloured silicate minerals associated with them in nature; in general, the lighter-coloured rocks have lower specific gravity for this reason. Silica minerals are insoluble to sparingly soluble in strong acids except hydrofluoric acid, in which there is a correlation between specific gravity and solubility.

Relationship between refractive index and specific gravity

Table 22: Some Physical Properties of Silica Minerals

phase	symmetry	specific gravity	hardness
Quartz (α-quartz)	hexagonal; trigonal trapezohedral	2.651	7
High quartz (β-quartz)	hexagonal; hexagonal trapezohedral	2.53 at 600° C	7
Low tridymite	monoclinic?	2.26	7
High tridymite	orthorhombic	2.20 at 200° C	7?
Low cristobalite	tetragonal	2.32	6–7
High cristobalite	isometric	2.20 at 500° C	6–7
Keatite	tetragonal	2.50	?
Melanophlogite	isometric	1.99	6–7
Coesite	monoclinic	2.93	7.5
Stishovite	tetragonal	4.28	?
Vitreous silica	amorphous	2.203	6
Opal	poorly crystalline or amorphous	1.99–2.05	5½–6½

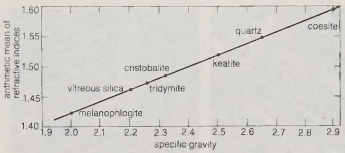


Figure 55: The linear plot obtained for silica minerals made up of linked tetrahedrons (see text).
From B.J. Skinner and D.E. Appleman, *American Mineralogist* (1963); Mineralogical Society of America

INDIVIDUAL SILICA MINERALS

Quartz. Quartz occurs in many varieties in almost all types of igneous, sedimentary, and metamorphic rocks. It has also been found in meteorites and in some lunar rocks.

Quartz crystals lack a centre of symmetry or planes of symmetry and have one crystallographic axis (*c*) perpendicular to three polar axes (*a*) that are 120° apart. One end of a polar axis is different from its other end; when mechanical stress is applied on such an axis, opposite electrical charges develop on each end. This leads to important applications in electronics as a frequency control and in pressure gauges and other devices. The lack of symmetry planes parallel to the vertical axis allows quartz crystals to occur as two types: left-handed or right-handed (enantiomorphism). Left-handed quartz is less than 1 percent more abundant than right-handed quartz. The structural tetrahedrons spiral upward through the crystal in the sense of the handedness parallel to the *c* axis. Similarly, if polarized light is transmitted by a quartz crystal along the *c*-axis direction, the plane is rotated in the direction of the handedness by tens of degrees per millimetre, the amount depending on the wavelength of the light. This property is used in optical instruments such as monochromators.

Left-handed and right-handed quartz crystals

The requirements for high-purity crystals for electronic frequency applications have led to the development of industrial synthesis methods based on the differences in silica solubility with temperature. Nutrient crystals are placed in the hot portion of a solution-filled autoclave, and an oriented seed crystal free from twinning is placed in the cooler portion. Crystals weighing thousands of grams can be grown in a few weeks.

Quartz shows less range in chemical composition than do most other minerals, but it commonly contains tens to hundreds of parts per million of aluminum atoms substituting for silicon atoms, with charge balance maintained by the incorporation of small atoms, such as hydrogen, lithium, or sodium. Titanium, magnesium, or iron atoms substituting for silicon atoms also have been reported, but anionic substitution (*i.e.,* substitution for the negative ion, oxygen) is limited because the linkage of the tetrahedrons is disrupted.

Colours of quartz varieties

Coloured varieties of quartz are numerous and have many causes. Most colours result from mechanically incorporated admixtures within fine-crystallized or granular quartz, but some coarse-crystallized varieties, such as amethyst (violet), citrine (yellow), milky quartz, smoky quartz or morion (black), or rose quartz, may be coloured by ions other than silicon and oxygen that occur within the crystal structure (see Figure 56). Small fractions of 1 percent by weight of iron, aluminum, manganese, titanium, hydrogen, and small alkali atoms, such as lithium and sodium, have been shown to be the cause of different colours. Heat treatment or various irradiation treatments under oxidizing or reducing atmospheres are used to change one coloured variety to another. Citrine is commonly produced by heat-treating amethyst at 250°–400° C (482°–752° F), for example.

Quartz may contain inclusions of other minerals, such as rutile (rutilated quartz), tourmaline, asbestiform amphiboles, or platy minerals, such as mica, iron oxides, or chlorite (aventurine).

Chalcedony. Chalcedony is a white, buff, or light tan, finely crystallized or fibrous quartz that forms rounded crusts, rinds, or stalactites (mineral deposits suspended from the roofs of caverns) in volcanic and sedimentary rocks as a precipitate from moving solutions. If chalcedony is conspicuously colour-banded, it may be called agate; onyx is agate with alternate bands of white and black or dark brown. Some concentrically banded "eye" agate nodules contain cores of coarsely crystalline quartz, and other agates are mottled or variegated in colour. Arborescent or dendritic (branching) dark-coloured patterns set in a lighter field are called moss agate or Mocha stone. Translucent red chalcedony is called carnelian, and translucent brown shades are referred to as sard; both are pigmented by admixed iron oxides.

Chrysoprase, plasma, and prase are names for green varieties of chalcedony coloured by admixed green minerals, such as chlorite, fibrous amphiboles, or hydrous nickel silicates. Bloodstone and heliotrope are green chalcedony with red spots.

By courtesy of (top right, bottom right) the Field Museum of Natural History, Chicago, (bottom left) Joseph and Helen Guetterman collection; photographs, (top right, bottom left, bottom right) John H. Gerard—EB Inc., (top left) Emil Javorsky—EB Inc.

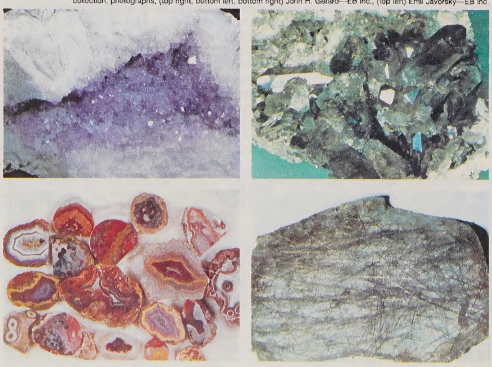


Figure 56: *Quartz varieties.*
(Top left) Amethyst geode from Nova Scotia, Can. (Top right) Smoky quartz from St. Gotthard, Switz. (Bottom left) Quartz agate from Mexico. (Bottom right) Rutilated quartz from Madagascar.

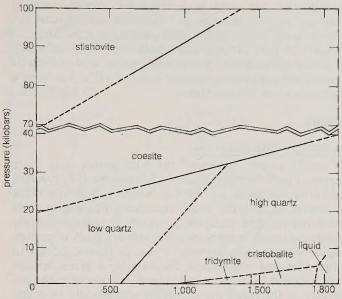


Figure 57: Silica phase diagram.
From F.R. Boyd and J.L. England, *Journal of Geophysical Research*, vol. 65, p. 752 (1960)

Jasper, chert, and flint. Jasper is opaque red, brown, or yellow quartz that is pigmented by admixed iron oxides. Chert and flint are finely crystallized varieties of gray to black quartz that occur as nodules or bands in sedimentary rocks.

High quartz (β-quartz). High quartz, or β-quartz, is the more symmetrical form quartz takes at sufficiently high temperatures (about 573° C at one atmosphere of pressure), but the relationship is pressure-sensitive (see Figure 57). High quartz may be either left- or right-handed, and its *c* axis is one of sixfold symmetry rather than threefold; thus, many twin laws of ordinary quartz cannot occur. High quartz twins typically involve inclined sets of axes. High quartz can form directly from silicate magma or from high-temperature gases or solutions. It invariably undergoes the transition to ordinary quartz (low quartz) on cooling, and all ordinary quartz, when heated above the transition temperature, is transformed into high quartz. The transformation involves displacement of the linkage between the tetrahedrons; no bonds are broken.

Tridymite. Tridymite may occur as a primary magmatic phase (*i.e.*, as a direct result of crystallization from a silicate melt) in siliceous rocks but is most abundant in voids in volcanic rocks where it probably was deposited metastably from hydrous gases. Tridymite also forms in contact-metamorphosed rocks. It has been found in meteorites and is common in lunar basalts. It occurs in quantity in firebricks and other siliceous refractories. Natural tridymite has no specific commercial use.

Cristobalite. Cristobalite is probably more abundant in nature than tridymite, although it seldom forms as distinctive crystals. The devitrification (transformation from the glassy to the crystalline state) of siliceous volcanic glasses yields abundant tiny crystallites of cristobalite, and the mineral is also deposited metastably from hot hydrous gases in cavities and cracks of many volcanic rocks. It has been found in lunar basalts and in meteorites and is common in silica refractories exposed to very high temperatures.

Opal. Opal is poorly crystalline or amorphous hydrous silica that is compact and vitreous and most commonly translucent white to colourless. Precious opal reflects light with a play of brilliant colours across the visible spectrum, red being the most valued. Opal forms by precipitation from silica-bearing solutions near the Earth's surface. Electron microscopy has shown that many opals are composed of spheres of tens to a few thousand angstroms in size that are arranged in either hexagonal or cubic close packing. The spheres are composed of hydrous silica that may be either almost cristobalite-like, tridymite-like, mixtures of both, or random and nondiffracting. The specific gravity and refractive index are lower than those of pure silica minerals. The play of colours in precious opal arises from the diffraction of light from submicroscopic layers of regularly oriented silica spheres. When heated, opal may lose as much as 20 percent of its weight of water, fracture, and then crystallize to one of the silica minerals described above.

Arrangement of spheres in opal

Opal usually contains 4 to 9 percent water, but lower and much higher values have been observed. The contents of alumina, ferric oxide, and alkalis are variable but may amount to several percent in light-coloured opals and more if pigmenting minerals are also present. Precious opal has been synthesized. Opaline silica is a friable hydrous silica found near hot springs and geysers.

Vitreous silica. Vitreous silica, lechatelierite, is supercooled liquid silica. It has been observed in nature as the result of fusion of quartz by lightning strikes (fulgurites) or by shock associated with large meteorite impacts and may approach artificial, very pure silica glass in composition and physical properties.

Melanophlogite. Melanophlogite is a cubic silica mineral with a gas-hydrate structure containing many large voids. In nature these are filled with 6 to 12 percent by weight of compounds of hydrogen, carbon, and sulfur, which may be necessary for mineral growth. If these compounds are destroyed by heating, they do not cause the crystal to collapse, but the free carbon formed does darken it. Melanophlogite occurs with bitumen and forms at temperatures below 112° C on native sulfur crystals in Sicily.

Keatite. Keatite is a tetragonal form of silica known only from the laboratory, where it can be synthesized metastably over the range of temperatures from about 300° to 600° C and 400 to 4,000 bars (standard atmospheric pressure at sea level is 1,013.3 millibars, or slightly more than 1 bar, which equals 760 millimetres of mercury) in the presence of steam. It has negative thermal expansion along the *a* axis and positive thermal expansion along the *c* axis, so that the overall expansion is very low or negative.

Coesite and stishovite. Coesite and stishovite are rare dense forms of silica observed in nature only where quartz-bearing rocks have been severely shocked by a large meteorite impact, such as Meteor Crater in Arizona, U.S. Coesite is made up of tetrahedrons arranged like those in feldspars. Stishovite is the densest form of silica and consists of silicon that is octahedrally coordinated with oxygen. Both coesite and stishovite have been synthesized and found to be stable only at high pressures (Figure 57).

ORIGIN AND OCCURRENCE

Occurrence of free silica

Silicon and oxygen are the two most abundant elements in the Earth's crust, in which they largely occur in combination with other elements as silicate minerals. Free silica (SiO_2) appears as a mineral in crystallizing magma only when the relative abundance of SiO_2 exceeds that of all other cations available to form silicates. Silica minerals thus occur only in magmas containing more than about 47 percent by weight of SiO_2 and are incompatible with minerals with low cation:silica ratios—such as olivine, nepheline, or leucite. Basaltic and alkalic igneous magmas therefore can crystallize only minor amounts of silica minerals, and sometimes none are produced. The gas released from such rocks can dissolve the silica components, however, and later precipitate silica minerals upon cooling. The amount of silica minerals crystallized from magma increases with increasing silica content of magma, reaching 40 percent in some granites and rhyolites.

Solubility of silica minerals. The solubility of silica minerals in natural solutions and gases is of great importance. The solubility of all silica minerals increases regularly with increasing temperature and pressure except in the region of 340°–550° C and 0–600 bars, where retrograde solubility occurs because of changes in the physical state of water. The solubility of silica increases in the presence of anions such as OH^- and CO_3^{2-}, which form chemical complexes with it.

Quartz is the least soluble of the forms of silica at room temperature. In pure water its solubility at 25° C is about 6 parts per million, that of vitreous silica being at least 10 times greater. Typical temperate-climate river water contains 14 parts per million of silica, and enormous tonnages of silica are carried away in solution annually from weathering rocks and soils. The amount so removed may

be equivalent to that transported mechanically in many climates. Silica dissolved in moving groundwater may partially fill hollow spheroids and precipitate crystals to form geodes, or it may cement loose sand grains together to form concretions and nodules or even entire sedimentary beds into sandstone, which, when all pore space is eliminated by selective solution and nearby deposition during metamorphism, form tough, pore-free quartzite.

Rock crystal, spring deposits, and glass sands

Gases or solutions escaping from cooling igneous rocks or deep fractures commonly are saturated with silica and other compounds that, as they cool, precipitate quartz along their channelways to form veins. It may be fine-grained (as chalcedony), massive granular, or in coarse crystals as large as tens of tons. Most natural colourless quartz crystals, "rock crystal," were formed in this way.

The emergence of heated silica-bearing solutions onto the surface results in rapid cooling and the loss of complexing anions. Rapid precipitation of fine-grained silica results in formation of siliceous sinter or geyserite, as at Mammoth Hot Springs in Yellowstone National Park in the western United States.

Quartz is mechanically resistant and relatively inert chemically during rock weathering in temperate and cold climates. Thus, it becomes enriched in river, lake, and beach sediments, which commonly contain more than one-half quartz by weight. Some strata consist almost entirely of quartz over large lateral distances and tens or hundreds of metres in thickness. Known as glass sands, these strata are important economic sources of silica for glass and chemical industries. Quartz-bearing strata are abundant in metamorphic terrains. The reincorporation of free silica into complex silicates and the solution and redeposition of silica into veins is characteristic of such terrains.

The silica phase diagram. The pressure-temperature fields of stability of silica minerals are shown in Figure 57. The experimentally determined boundaries are drawn with heavy lines. Stability fields are not shown for keatite, melanophlogite, opal, or the low forms of tridymite and cristobalite because they have not been demonstrated. Quartz is the stable phase of silica under the physical conditions that prevail over most of the Earth's crust. Coesite is possible at depths of about 100 kilometres (60 miles) in the Earth's mantle, but free silica is not thought to be abundant there. Stishovite would require even greater depths of burial, and no rocks that occur on the terrestrial surface have been buried so deeply.

USES

Quartz is the only natural silica mineral used in significant quantities; millions of tons are consumed annually by many industries. The sand that is an essential ingredient of concrete and mortar is largely quartz, as are the sandstone and quartzite used as building stones. Crushed sandstone and quartzite are used for road and railway construction, roofing granules, and riprap—erosion-control linings of river channels. Quartz is hard (7 on the Mohs scale) and resists fracture because it lacks easy cleavage. These properties, combined with its ready availability, lead to its use as a sandpaper abrasive and in sandblasting; for polishing and cutting glass, stone, and metal; and for providing traction on stairs, streets, and rails. Large amounts of relatively pure quartz are used in refractory products, such as insulation and firebricks, foundry molds, and electrical insulators, because of the combination of its high melting temperatures, low coefficients of expansion, inertness of the high-temperature forms of silica, and low costs.

Relatively pure quartz is required in large tonnages as an ingredient for glass and porcelain manufacture. High purity quartz is fused to make premium grades of chemical and optical glass for which one or more of its desirable properties of low thermal expansion, high-shape stability, elasticity, low solubility, and transparency to various kinds of light can justify the greatly increased costs involved. Fibres of vitreous silica are essential for precision instruments, such as balances, galvanometers, and gravimeters. Tons of quartz of various qualities are used as raw materials for processes in which silica is not the final product. These include the production of water glass, or sodium silicate, various sols—very fine dispersions of solids in liquids—that are used as hydrophobic (water-repelling) coatings, organic silicates and silicones, silicon carbide, silicon metal, smelting flux, and alloying in metallurgy.

Quartz and its varieties have been used since antiquity as semiprecious gems, ornamental stones, and collector's items. Precious opal, a hydrous form of silica, has been a gemstone since Roman times. (D.B.S./W.B.Si.)

Micas

GENERAL CONSIDERATIONS

Of the 28 known species of the mica group, only 6 are common rock-forming minerals. Muscovite, the common light-coloured mica, and biotite, which is typically black or nearly so, are the most abundant. Phlogopite, typically brown, and paragonite, which is macroscopically indistinguishable from muscovite, also are fairly common. Lepidolite, generally pinkish to lilac in colour, occurs in lithium-bearing pegmatites. Glauconite, a green species that does not have the same general macroscopic characteristics as the other micas, occurs sporadically in many marine sedimentary sequences. All of these micas except glauconite exhibit easily observable perfect cleavage into flexible sheets. Glauconite, which most often occurs as pelletlike grains, has no apparent cleavage.

Mica nomenclature

The names of the rock-forming micas constitute a good example of the diverse bases used in naming minerals: Biotite was named for a person—Jean-Baptiste Biot, a 19th-century French physicist who studied the optical properties of micas; muscovite was named, albeit indirectly, for a place—it was originally called "Muscovy glass" because it came from the Muscovy province of Russia; glauconite, although typically green, was named for the Greek word for blue; lepidolite, from the Greek word meaning "scale," was based on the appearance of the mineral's cleavage plates; phlogopite, from the Greek word for firelike, was chosen because of the reddish glow (colour and lustre) of some specimens; paragonite, from the Greek "to mislead," was so named because it was originally mistaken for another mineral, talc.

CHEMICAL COMPOSITION

The general formula for minerals of the mica group is $XY_{2-3}Z_4O_{10}(OH, F)_2$ with X = K, Na, Ba, Ca, Cs, (H_3O), (NH_4); Y = Al, Mg, Fe^{2+}, Li, Cr, Mn, V, Zn; and Z = Si, Al, Fe^{3+}, Be, Ti. Compositions of the common rock-forming micas are given in Table 23.

Table 23: End-Member Chemical Compositions of Rock-Forming Micas*

Biotite	$K(Mg, Fe^{2+})_3(Al, Fe^{3+})Si_3O_{10}(OH, F)_2$
Phlogopite	$KMg_3Si_3AlO_{10}(F, OH)_2$
Lepidolite	$K(Li, Al)_3(Si, Al)_4O_{10}(F, OH)_2$
Muscovite	$KAl_2(Si_3Al)O_{10}(OH, F)_2$
Paragonite	$NaAl_2(Si_3Al)O_{10}(OH)_2$
Glauconite	$(K, Na)(Fe^{3+}, Al, Mg)_2(Si, Al)_4O_{10}(OH)_2$

*The micas above the broken line are trioctahedral—*i.e.*, they have three atoms in the *Y* position; those below the line are dioctahedral—*i.e.*, they have two atoms in the *Y* position.

Few natural micas have end-member compositions. For example, most muscovites contain sodium substituting for some potassium, and diverse varieties have chromium or vanadium or a combination of both replacing part of the aluminum; furthermore, the Si:Al ratio may range from the indicated 3:1 up to about 7:1. Similar variations in composition are known for the other micas. Thus, as in some of the other groups of minerals (*e.g.*, the garnets), different individual pieces of naturally occurring mica specimens consist of different proportions of ideal end-member compositions. There are, however, no complete series of solid solutions between any dioctahedral mica and any trioctahedral mica.

CRYSTAL STRUCTURE

Micas have sheet structures whose basic units consist of two polymerized sheets of silica (SiO_4) tetrahedrons. Two such sheets are juxtaposed with the vertices of their tetra-

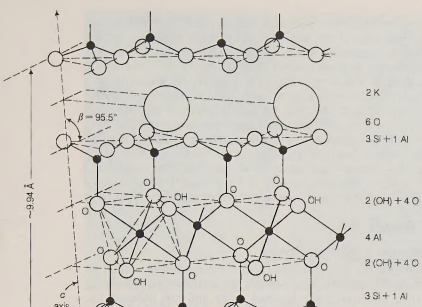


Figure 58: *The structure of mica as exemplified by muscovite.* The tabulation giving the layer by layer population of elements—to the right of the diagram—correlates with the doubled formula $K_2Al_4(Si_6Al_2)O_{20}(OH)_4$.

From L.G. Berry, B. Mason, and R.V. Dietrich, *Mineralogy: Concepts, Descriptions, Determinations*, 2nd ed. (1983), W.H. Freeman and Co., New York City

hedrons pointing toward each other; the sheets are cross-linked with cations—for example, aluminum in muscovite—and hydroxyl pairs complete the coordination of these cations (see Figure 58). Thus, the cross-linked double layer is bound firmly, has the bases of silica tetrahedrons on both of its outer sides, and has a negative charge. The charge is balanced by singly charged large cations—for example, potassium in muscovite—that join the cross-linked double layers to form the complete structure. The differences among mica species depend upon differences in the *X* and *Y* cations.

Polytypes

Although the micas are generally considered to be monoclinic (pseudohexagonal), there also are hexagonal, orthorhombic, and triclinic forms generally referred to as polytypes (see Table 24). The polytypes are based on the sequences and number of layers of the basic structure in the unit cell and the symmetry thus produced. Most biotites are 1M and most muscovites are 2M; however, more than one polytype is commonly present in individual specimens. This feature cannot, however, be determined macroscopically; polytypes are distinguished by relatively sophisticated techniques such as those employing X rays.

Table 24: Mica Polytypes

designation	crystal system	number of layers per unit cell
1M	monoclinic	1
$2M_1$	monoclinic	2
$2M_2$	monoclinic	2
2O	orthorhombic	2
3T	hexagonal (trigonal)	3
6H*	hexagonal	6
8TC	triclinic	8
12M	monoclinic	12
18M	monoclinic	18

*This polytype has not been recorded for natural micas.

The micas other than glauconite tend to crystallize as short pseudohexagonal prisms. The side faces of these prisms are typically rough, some appearing striated and dull, whereas the flat ends tend to be smooth and shiny. The end faces are parallel to the perfect cleavage that characterizes the group (Figure 59).

PHYSICAL PROPERTIES

The rock-forming micas (other than glauconite) can be divided into two groups: those that are light-coloured (muscovite, paragonite, and lepidolite) and those that are dark-coloured (biotite and phlogopite). Most of the properties of the mica group of minerals, other than those of glauconite, can be described together; here they are described as pertaining simply to micas, meaning the micas other than glauconite. Properties of the latter are described separately later in the discussion.

The perfect cleavage into thin elastic sheets is probably the most widely recognized characteristic of the micas (see Figure 59). The cleavage is a manifestation of the sheet structure described above. (The elasticity of the thin sheets distinguishes the micas from similarly appearing thin sheets of chlorite and talc.) The rock-forming micas exhibit certain characteristic colours. Muscovites range from colourless, greenish to blue-green to emerald-green, pinkish, and brownish to cinnamon-tan. Paragonites are colourless to white; biotites may be black, brown, red to red-brown, greenish brown, and blue-green. Phlogopites resemble biotites but are not black. Lepidolites are nearly colourless, pink, lavender, or tan. Biotites and phlogopites also exhibit the property termed pleochroism (or, more properly for these minerals, dichroism): When viewed along different crystallographic directions, especially using transmitted polarized light, they exhibit different colours or different absorption of light or both.

The lustre of the micas is usually described as splendent, but some cleavage faces appear pearly. The minutely crystalline variety consisting of muscovite or paragonite (or both), generally referred to as sericite, is silky.

Ward's Natural Science Establishment, Inc., Rochester, New York

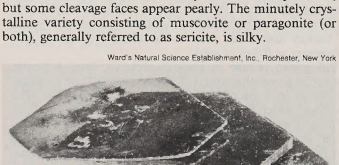


Figure 59: *Muscovite cleavage.* The perfect cleavage of muscovite permits its splitting into thin flakes.

Mohs hardness of the micas is approximately 2½ on cleavage flakes and 4 across cleavage. Consequently, micas can be scratched in either direction with a knife blade or geologic pick. Hardness is used to distinguish micas from chloritoid, which also occurs rather commonly as platy masses in some metamorphic rocks; chloritoid, with a Mohs hardness of 6½, cannot be scratched with a knife blade or geologic pick.

Specific gravity for the micas varies with composition. The overall range is from 2.76 for muscovite to 3.2 for iron-rich biotite.

Glauconite occurs most commonly as earthy to dull, subtranslucent, green to nearly black granules generally referred to as pellets. It is attacked readily by hydrochloric acid. The colour and occurrence of this mineral in sediments and sedimentary rocks formed from those sediments generally are sufficient for identification.

ORIGIN AND OCCURRENCE

Micas may originate as the result of diverse processes under several different conditions. Their occurrences, listed below, include crystallization from consolidating magmas, deposition by fluids derived from or directly associated with magmatic activities, deposition by fluids circulating during both contact and regional metamorphism, and formation as the result of alteration processes—perhaps even those caused by weathering—that involve minerals such as feldspars. The stability ranges of micas have been investigated in the laboratory, and in some associations their presence (as opposed to absence) or some aspect of their chemical composition may serve as geothermometers or geobarometers.

Distinct crystals of the micas occur in a few rocks—*e.g.*, in certain igneous rocks and in pegmatites. In most

rocks, micas occur as irregular tabular masses or thin plates (flakes), which in some instances appear bent. Although some mica grains are extremely small, all except those constituting sericitic masses have characteristic shiny cleavage surfaces.

Glauconite is formed in marine environments. It can be found on seafloors where clastic sedimentation, which results from the relocation of minerals and organic matter to sites other than their places of origin, is lacking or nearly so. Although some glauconite has been interpreted to have been formed from preexisting layered silicates (*e.g.*, detrital biotite), most of it appears to have crystallized from aluminosilicate gels—perhaps under the influence of biochemical activities that produce reducing environments.

The common rock-forming micas are distributed widely. The more important occurrences follow: Biotite occurs in many igneous rocks (*e.g.*, granites and granodiorites), is common in many pegmatite masses, and constitutes one of the chief components of many metamorphic rocks (*e.g.*, gneisses, schists, and hornfelses). It alters rather easily during chemical weathering and thus is rare in sediments and sedimentary rocks. One stage in the weathering of biotite has resulted in some confusion. During chemical weathering, biotite tends to lose its elasticity and become decolorized to silvery gray flakes. In a fairly common intermediate stage, weathered biotite is golden yellow, has a bronzy lustre, and may be mistaken by inexperienced observers as flakes of gold.

Phlogopite is rare in igneous rocks; it does, however, occur in some ultrabasic (silica-poor) rocks. For example, it occurs in some peridotites, especially those called kimberlites, which are the rocks in which diamonds occur. Phlogopite also is a rare constituent of some magnesium-rich pegmatites. Its most common occurrence, however, is in impure limestones that have undergone contact metasomatism, a process through which the chemical composition of rocks is changed.

Sources of muscovite

Muscovite is particularly common in metamorphic gneisses, schists, and phyllites. In fine-grained foliated rocks, such as phyllites, the muscovite occurs as microscopic grains (sericite) that give these rocks their silky lustres. It also occurs in some granitic rocks and is common in complex granitic pegmatites and within miarolitic druses, which are late-magmatic, crystal-lined cavities in igneous rocks. Much of the muscovite in igneous rocks is thought to have been formed late during, or immediately after, consolidation of the parent magma. Muscovite is relatively resistant to weathering and thus occurs in many soils developed over muscovite-bearing rocks and also in the clastic sediments and sedimentary rocks derived from them.

Paragonite is known definitely to occur in only a few gneisses, schists, and phyllites, in which it appears to play essentially the same role as muscovite. It may, however, be much more common than generally thought. Until fairly recently nearly all light-coloured micas in rocks were automatically called muscovite without checking their potassium:sodium ratios, so some paragonites may have been incorrectly identified as muscovites. Its weathering is essentially the same as that of muscovite.

Lepidolite occurs almost exclusively in complex lithium-bearing pegmatites but has also been recorded as a component of a few granites.

Glauconite, as noted above, is forming in some present-day marine environments. It also is a relatively common constituent of sedimentary rocks, the precursor sediments of which were apparently deposited on the deeper parts of ancient continental shelves. The name greensand is widely applied to glauconite-rich sediments. Most glauconite occurs as granules, which are frequently referred to as pellets. It also exists as pigment, typically as films that coat such diverse substrates as fossils, fecal pellets, and clastic fragments.

USES

Because of their perfect cleavage, flexibility and elasticity, infusibility, low thermal and electrical conductivity, and high dielectric strength, muscovite and phlogopite have found widespread application. Most "sheet mica" with these compositions has been used as electrical condensers, as insulation sheets between commutator segments, or in heating elements. Sheets of muscovite of precise thicknesses are utilized in optical instruments. Ground mica is used as a dusting medium to prevent, for example, asphalt tiles from sticking to each other and also as a filler, absorbent, and lubricant. Lepidolite has been mined as an ore of lithium, with rubidium generally recovered as a by-product. Glauconite-rich greensands have found use within the United States as fertilizer—*e.g.*, on the coastal plain of New Jersey—and some glauconite has been employed as a water softener because it has a high base-exchange capacity and tends to regenerate rather rapidly. (R.V.Di.)

Olivines

GENERAL CONSIDERATIONS

Olivines are an important rock-forming silicate mineral group. Magnesium-rich olivines are abundant in low-silica mafic and ultramafic igneous rocks and are believed to be the most abundant constituent of the Earth's upper mantle. Olivine also occurs in high-temperature metamorphic rocks, lunar basalts, and some meteorites. The name olivine derives from the unusual yellow-green to deep bottle-green colour of the magnesium-iron olivine series. Typically the name olivine is given to members of the forsterite-fayalite solid-solution series. In addition to these magnesium and ferrous iron end-members, the olivine group contains manganese (tephroite), calcium-manganese (glaucochroite), calcium-magnesium (monticellite), and calcium-iron (kirschsteinite) end-members (Table 25). Gem-quality forsterite olivine is known as peridot (Figure 60). Because of its high melting point and resistance to chemical reagents, magnesium olivine is an important refractory material—*i.e.*, it can be used in furnace linings and in kilns when other materials are subjected to heat and chemical processes.

Table 25: Some Physical Properties of the Olivines

end-members	composition	specific gravity	hardness on the Mohs scale
Forsterite	Mg_2SiO_4	3.22	7
Fayalite	Fe_2SiO_4	4.39	7
Tephroite	Mn_2SiO_4	3.78	6
Monticellite	$CaMgSiO_4$	3.08	5½
Kirschsteinite	$CaFeSiO_4$	—	—
Glaucochroite	$CaMnSiO_4$	3.41	6

CHEMICAL COMPOSITION

The composition of most olivines can be represented in the system Ca_2SiO_4-Mg_2SiO_4-Fe_2SiO_4 (Figure 61). The most abundant olivines occur in the system from forsterite (Mg_2SiO_4) to fayalite (Fe_2SiO_4). Most of the naturally occurring olivines are intermediate in composition to these two end-members and have the general formula $(Mg, Fe)_2SiO_4$. Members of the series monticellite ($CaMgSiO_4$) to kirschsteinite ($CaFeSiO_4$) are rare.

The forsterite-fayalite series

The name forsterite is restricted to those species with no more than 10 percent iron substituting for magnesium; fayalite (from Fayal Island in the Azores, where it was believed to occur in a local volcanic rock but probably was obtained from slag brought to the island as ship's ballast) is restricted to species with no more than 10 percent magnesium substituting for iron. Species intermediate in composition to forsterite and fayalite are also named; from most magnesium-rich to most iron-rich they are chrysolite (70–90 percent Mg), hyalosiderite (50–70 percent Mg), hortonolite (50–70 percent Fe), and ferrohortonite (70–90 percent Fe).

The continuity in the forsterite-fayalite series has been verified experimentally (Figure 62). At the magnesium-rich end of the solid-solution series, natural crystals may contain very small amounts of calcium, nickel, and chromium; the iron-rich members near the other end of the series may incorporate small amounts of manganese and calcium. Apart from ferrous iron, the crystalline structure of the olivines is also capable of accommodating relatively small



Figure 60: Peridot crystals (gem-quality forsterite) and faceted peridot from Zabarjad Island, Egypt.
(Left) © Violet Anderson/Western Enterprises; (right) Institute of Geological Sciences, London/Western Enterprises; photograph, Martin Polsford

amounts of ferric iron; dendrites (small branching crystals) of magnetite or chromite found oriented with respect to some crystallographic direction within such olivines may be attributed to exsolution. The presence of relatively large amounts of ferric oxide in the analyses of olivines, however, clearly indicates either an advanced state of oxidation or the mechanical inclusion of co-precipitating magnetite upon crystallization from the magma.

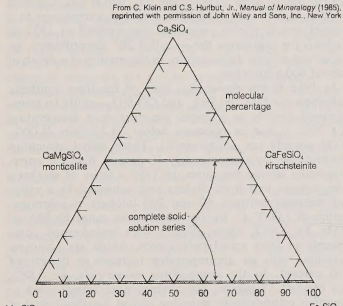


Figure 61: Olivine compositions in the system Ca_2SiO_4–Mg_2SiO_4 (forsterite)–Fe_2SiO_4 (fayalite).

In addition to the forsterite-fayalite series, other complete solid-solution series exist among the various olivine minerals. Fayalite is soluble in all proportions with ashgray tephroite (from Greek *tephros*, "ashen"), pure manganese silicate (Mn_2SiO_4); the intermediate in the series is knebelite ($FeMnSiO_4$). Tephroite and knebelite come from manganese and iron ore deposits, from metamorphosed manganese-rich sedimentary rocks, and from slags.

CRYSTAL STRUCTURE

Orthorhombic crystal system

All olivines crystallize in the orthorhombic crystal system. Olivine is classified as a nesosilicate which has isolated SiO_4 tetrahedrons bound to each other only by ionic bonds from interstitial cations. The structure of olivine can be viewed as a layered closest-packed oxygen network, with silicon ions occupying some of the tetrahedral voids and the calcium, ferrous iron, and magnesium cations occupying some of the octahedral voids (Figure 63). The layers consist of octahedrons cross-linked by independent SiO_4 tetrahedrons. There are two symmetrically nonequivalent octahedral sites, *M1* and *M2*. In magnesium-iron olivines there is no *M1* or *M2* site preference for magnesium or ferric iron. However, in calcic olivines like monticellite, calcium preferentially enters the *M2* site and magnesium occupies the *M1* site.

MINERALOGICAL CHARACTERISTICS

Physical properties. The specific gravity and hardness of the olivines are listed in Table 25. There are at least two cleavages—*i.e.*, the tendency to split along preferred crystallographic directions (perpendicular to the *a* and *b* axes in this case)—both of which are better-developed in the iron-rich varieties. Forsterite contained in certain ultrabasic rocks may show a banded structure when observed in thin sections with a polarizing microscope; in some dunites (a variety of rock consisting nearly entirely of olivine), for example, olivine is preferentially oriented so that the cleavage plane perpendicular to the *b* axis is parallel to the microscopic laminated structure of the rock. Individual grains of olivine within such rocks typically appear as oriented bands with angles of up to 10° between them. Such banding, which is undoubtedly the product of incipient mechanical deformation, also can be observed within the olivine nodules of some basalts.

Banded structures

To the unaided eye, pure forsterite appears colourless, but, as the content of ferrous oxide increases, specimens show yellow-green, dark green, and eventually brown to black tints. In thin sections under the microscope, however, even pure fayalite appears pale yellow. Pure tephroite is gray, and monticellite also appears gray or colourless.

Some variations of optical properties observed in natural olivine crystals probably result from small but varying replacements of magnesium and iron by calcium and manganese and of silicon by titanium, chromium, and ferric iron.

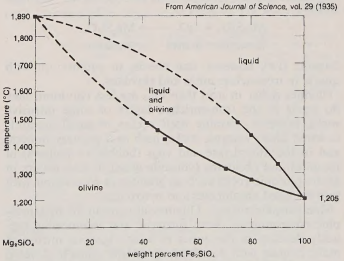


Figure 62: Equilibrium diagram of the system Mg_2SiO_4-Fe_2SiO_4 showing complete solid solution.

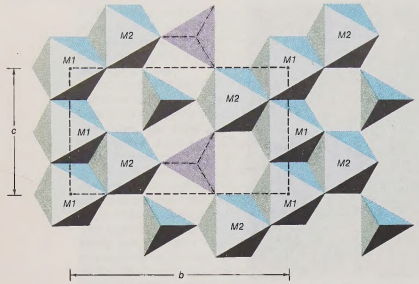


Figure 63: Portion of the idealized structure of olivine projected perpendicular to the *a* axis showing the positions of the *M1* and *M2* octahedral sites.

From C. Klein and C.S. Hurlbut, Jr., *Manual of Mineralogy* (1985), reprinted with permission of John Wiley and Sons, Inc., New York

Crystal habit and form. The magnesium-iron olivines occur most commonly as compact or granular masses. Except for the well-shaped phenocrysts (single crystals) of such olivines found embedded in the fine-grained matrices (groundmass) of basalts, distinctly developed crystals are relatively rare. The phenocrysts in basalts are characterized by six- or eight-sided cross sections. With fayalite the morphology is often simple. Monticellite and tephroite commonly show prominent pyramidal faces. Twinning is rare. When twinning does occur, trillings (the intergrowth of three grains) may be produced, and, in monticellite, six-pointed star shapes are reported from the Highwood Mountains in Montana, U.S.

ORIGIN AND OCCURRENCE

Igneous rocks. Olivines are found most commonly in mafic and ultramafic igneous rocks such as peridotites, dunites, gabbros, and basalts. Forsteritic olivines, which have 88 to 92 percent forsterite, are the dominant phase of dunites and are common in peridotites. Gabbros and basalts typically contain forsteritic to intermediate-composition olivine ranging from 50 to 80 percent forsterite. Olivine is typically associated with calcic plagioclase, magnesium-rich pyroxenes, and iron-titanium oxides such as magnetite and ilmenite. This mineralogical association is diagnostic of the relatively high temperatures of crystallization of mafic rock types. Forsterite and protoenstatite crystallize together from about 1,550° C to roughly 1,300° C and are among the first minerals to crystallize from a mafic melt. Magnesium-rich olivine is unstable in a high-silica environment and is never found in equilibrium with quartz. The chemical reaction that precludes the stable coexistence of forsterite and quartz due to the formation of the orthopyroxene enstatite in the presence of excess silica is

$$\underset{\text{forsterite}}{Mg_2SiO_4} + \underset{\text{quartz}}{SiO_2} \longrightarrow \underset{\text{enstatite}}{Mg_2Si_2O_6}.$$

Fayalite (Fa), however, can coexist in equilibrium with quartz in iron-rich granites and rhyolites.

Olivines richer in iron than Fa_{50} are less common; they do occur in the iron-enriched layers of some intrusive rocks, however. Fayalite itself occurs in small amounts in some silicic volcanic rocks, both as a primary mineral and in the lithophysae and vugs (bubblelike hollows) of rhyolites and obsidians (volcanic glass). It also occurs in acidic plutonic rocks such as granites in association with iron-enriched amphiboles and pyroxenes.

Metamorphic rocks. Olivines also occur in metamorphic environments. Both forsterite and monticellite typically develop in the zones in which igneous intrusions make contact with dolomites. Forsterite tends to develop at lower temperatures than monticellite as the process of decarbonation in the contact zone progresses. Fayalitic olivines develop within metamorphosed iron-rich sediments. In the quaternary (*i.e.*, four-component) system Fe_2O_3-FeO-SiO_2-H_2O, fayalite is associated with the minerals greenalite (iron-serpentine), minnesotaite (iron-talc), and grunerite (iron-amphibole) in various metamorphic stages. In chemically more complex environments, which, in addition to the above components, also involve lime (CaO) and alumina (Al_2O_3), fayalite may be associated with hedenbergite, eulite (iron-rich orthopyroxene), grunerite, and almandine (iron-garnet).

Meteorites and the Earth's mantle. In meteorites, the olivine is usually a forsteritic variety containing only Fa_{15} to Fa_{30}. In the Nakhla (Egypt) meteorite (an achondrite meteorite), the olivine is more ferrous, however, containing as much as Fa_{65}. In the chondrites (stony meteorites), the olivine is commonly incorporated in the distinctive spheroidal bodies referred to as chondrules, which range up to one millimetre in diameter.

Because the rocks of the upper mantle directly below the Mohorovičić discontinuity (Moho) are believed to consist of peridotite and garnetiferous peridotite that contain olivines as their most abundant minerals, it is important to establish their behaviour when subjected to high pressures. Study of the olivine-like compound magnesium germanate, Mg_2GeO_4, showed that it has polymorphs that have both olivine and spinel structure. In the spinel structure, the oxygen atoms are arranged in cubic closest packing (in which the position of every third layer repeats that of the initial layer) instead of hexagonal closest packing (in which the position of every second layer repeats that of the initial layer) of the olivine structure. The spinel form of Mg_2GeO_4 was found to have a density exceeding that of the olivine form by 9 percent. In 1936 it was suggested that at high pressures Mg_2SiO_4 might also transform to a spinel structure; this suggestion was adopted in 1937 as a basis for explaining the so-called 20° discontinuity, an observed seismic discontinuity in the mantle at a depth of about 400 kilometres.

Relation to the spinel structure

In 1966 it was shown that each of the three synthetic olivines—Fe_2SiO_4, Ni_2SiO_4, and CO_2SiO_4—could be transformed directly to a spinel structure at a temperature of 700° C and at pressures below 70 kilobars (1,000,000 pounds per square inch). These spinel structures were denser by approximately 10 percent than the corresponding olivine structures. In 1968 a series of synthetic magnesium and iron olivines was subjected to a range of pressures between 50 and 200 kilobars at a temperature of 1,000° C. In the composition range Fe_2SiO_4 to $(Mg_{0.8}Fe_{0.2})_2SiO_4$, these olivines were transformed completely to their spinel polymorphs, which are isometric crystals, with an accompanying increase in density of 10 percent. In the composition range $(Mg_{0.8}Fe_{0.2})_2SiO_4$ to Mg_2SiO_4, however, the olivines were transformed to another orthorhombic structure (called β-orthosilicate) at a pressure of about 130 kilobars and a temperature of 1,000° C. This β-phase polymorph, with a density only 8 percent greater than that of the corresponding olivine structure, is believed to be the stable phase in the field of its synthesis. The change in the crystalline structure of olivine to its spinel polymorph, accompanied by a change in the structure of magnesium-iron pyroxenes to a new garnetlike structure at depths of 350 to 450 kilometres in the mantle, is believed to be responsible for the observed abrupt change in the velocity of seismic waves at these depths (see also EARTHQUAKES).

The spinel polymorph of olivine has been recorded in the Tenham (Queensland, Australia) chondrite as pseudomorphs after olivine. Portions of some large grains of olivine immediately adjacent to black, shock-generated veins are recognized as transforms to the spinel phase; the associated plagioclase feldspar was converted to maskelynite. The composition of the spinel phase in the meteorite has been analyzed by means of an electron probe and found to be $(Mg_{0.75}Fe_{0.25})_2SiO_4$; in thin sections it appears blue-gray to violet-blue. It has been named ringwoodite after Alfred E. Ringwood, an Australian earth scientist who synthesized spinel phases with compositions and properties close to those of the mineral found in the meteorite. More recently, ringwoodite also has been found in the Coorara

(Western Australia) meteorite in association with a garnet phase. The β-phase polymorph has not yet been observed in shocked meteorites—*i.e.*, those that have undergone impact shock—but it is highly probable that it, too, exists in relative abundance within the Earth's mantle.

Other occurrences. Knebelite olivines are restricted to iron-manganese ore deposits, to their associated skarn (lime-bearing silicate rocks) zones, and to metamorphosed manganiferous sediments. At Franklin, N.J., U.S., tephroite and glaucochroite occur in the same deposit as roepperite, a knebelite containing 10.7 percent by weight of zinc oxide (ZnO).

Sources of monticellite

Monticellite occurs in some alkali peridotites and within limestones near their contact with peridotites. Pure kirschsteinite is known only from slags and has not yet been observed as part of a natural mineral assemblage. The most plausible natural environments for kirschsteinite are altered limestones; it is possible the mineral has remained unrecognized in such rocks because its optical properties (the chief means of identification) are similar to those of the much more common magnesium-iron olivines. A kirschsteinite containing 31 percent by weight of other olivines, particularly monticellite, has been reported from a nepheline-melilite in north Kivu region, Zaire.

Glaucochroite, pure calcium and manganese silicate ($CaMnSiO_4$), is rare, reported only from a deposit in Franklin, N.J., where it occurs with tephroite. The limited availability of manganese in parent magmas is thought to account for the rarity of minerals intermediate in the solid-solution series between the calcium-rich olivines monticellite, glaucochroite, and kirschsteinite.

Alteration products and weathering. Olivines gelatinize in even weak acids and offer little resistance to attack by weathering agents and hot mineralizing (hydrothermal) solutions. The forsteritic olivines are altered principally through leaching, which results in the removal of magnesium and the addition of water and some iron. The chemical reactions are usually complex and involve hydration, oxidation, and carbonation. The fayalitic olivines are altered principally through oxidation and the removal of silica. The usual products of alteration are the minerals serpentine, iddingsite, and bowlingite, all of which may occur as pseudomorphs (forms with the outward appearance of the original mineral but which have been completely replaced by another mineral). Serpentine, which is the most common alteration product of olivine in ultramafic rocks, often is accompanied by magnesite. Iddingsite and bowlingite are variable in composition, and, even though they appear optically homogeneous, each actually consists of an intimate mixture of several distinct minerals. X-ray diffraction analyses of iddingsite show that the mineral goethite ($FeO \cdot OH$) is an important component. Also included with the mixture may be hematite (Fe_2O_3), as well as a silicate phase related to vermiculite or montmorillonite. Iddingsite develops almost exclusively from the olivines of extrusive or shallow intrusive rocks and practically never from the olivines of plutonic and metamorphic rocks. The process of "iddingsitation" of olivine may set in even before the complete consolidation of the lava or the hypabyssal magma. This is evident from the observation of rock textures in which shells of iddingsite surrounding a core of olivine are, in turn, surrounded by more unaltered olivine.

Olivine in beach sands

The mechanical weathering of olivine-rich rocks leads to the release of olivine particles that, in the absence of much chemical weathering, may accumulate to produce green or greenish black sands. Conspicuous examples of such sands occur on the beaches of the islands of Oahu and Hawaii, particularly at Diamond Head (Oahu) and South Point (Hawaii). Alluvial sands rich in olivine are also known from Navajo county of Arizona and from New Mexico in the United States; these sands provide the clear olivine (peridot) used in jewelry. (C.E.T./W.B.Si.)

Garnets

GENERAL CONSIDERATIONS

Garnets, a group of minerals favoured by lapidaries since ancient times and used widely as an abrasive, occur in rocks of each of the major classes. In most rocks, however, garnets occur in only minor amounts—*i.e.*, they are accessory minerals. Nevertheless, as a consequence of their distinctive appearances, they are frequently recognized in hand specimens and become part of the name of the rock in which they are contained—*e.g.*, garnet mica schist.

CHEMICAL COMPOSITION

Garnets comprise a group of silicates with the general formula $A_3B_2(SiO_4)_3$ in which A = Ca, Fe^{2+}, Mg, Mn^{2+}; B = Al, Cr, Fe^{3+}, Mn^{3+}, Si, Ti, V, Zr; and Si may be replaced partly by Al, Ti, and/or Fe^{3+}. In addition, many analyses indicate the presence of trace to minor amounts of Na, beryllium (Be), Sr, scandium (Sc), Y, La, hafnium (Hf), niobium (Nb), molybdenum (Mo), cobalt (Co), nickel (Ni), copper (Cu), silver (Ag), Zn, cadmium (Cd), B, Ga, indium (In), Ge, tin (Sn), P, arsenic (As), F, and rare earth elements. Grossular is often recorded as having a composition containing water, but the true substitution seems to involve 4 H^+ for Si^{4+}; and a complete series appears to exist between grossular $[Ca_3Al_2(SiO_4)_3]$ and hydrogrossular $[Ca_3Al_2(SiO_4)_{3-x}(H_4O_4)_x]$. Other hydrogarnets have been reported—*e.g.*, hydroandradite and hydrospessartine; the general formula for hydrogarnets would be $A_3B_2(SiO_4)_{3-x}(H_4O_4)_x$, and the general formula for an end-member hydrogarnet would be $A_3B_2(H_4O_4)_3$.

Nearly all natural garnets exhibit extensive substitution; solid-solution series—some complete, others only partial—exist between several pairs of the group. In practice, the name of the end-member that makes up the largest percentage of any given specimen is usually applied—*e.g.*, a garnet with the composition $Al_{45}Py_{25}Sp_{15}Gr_9An_6$ would be called almandine. End-member compositions of the garnets that are relatively common in rocks are given in Table 26.

Table 26: End-Member Compositions of the Common Rock-Forming Garnets

name	formula	subgroup
Pyrope (Py)	$Mg_3Al_2(SiO_4)_3$	pyralspite
Almandine (Al)*	$Fe_3Al_2(SiO_4)_3$	pyralspite
Spessartine (Sp)†	$Mn_3Al_2(SiO_4)_3$	pyralspite
Grossular (Gr)‡	$Ca_3Al_2(SiO_4)_3$	ugrandite
Andradite (An)	$Ca_3Fe_2(SiO_4)_3$	ugrandite
Uvarovite (U)§	$Ca_3Cr_2(SiO_4)_3$	ugrandite

*†‡In some reports these species are recorded, respectively, as almandite, spessartite, and grossularite. §This garnet is not a common rock-forming garnet; it is, however, noteworthy from the standpoint of solid-solution considerations.

Solid-solution series

Analyses of natural specimens suggest that the following solid-solution series exist: in the pyralspite subgroup, a complete series between almandine and both pyrope and spessartine (Figure 64); in the ugrandite subgroup, a continuous series between grossular and both andradite and uvarovite; less than a complete series between any member of the pyralspite subgroup and any member of the ugrandite subgroup; and an additional series between pyrope and andradite and one or more of the less common

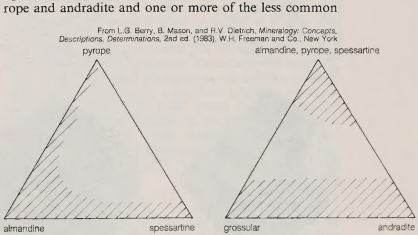


Figure 64: *Common rock-forming garnets.*
Shaded areas indicate compositions represented by natural garnets; unshaded areas indicate compositions essentially unrepresented by natural garnets.

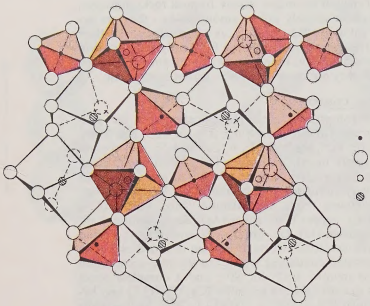


Figure 65: *The structure of garnet.*
This schematic diagram of part of the garnet structure shows the distorted silicon-oxygen tetrahedrons and BO_6 octahedrons (both shaded) and the distorted cubes with central *A* cations. The large open circles represent oxygen atoms.
From G. Novak and G.V. Gibbs, "The Crystal Chemistry of the Silicate Garnets," *American Mineralogist*, 56 (1971).

garnets (*e.g.*, pyrope with knorringite [$Mg_3Cr_2(SiO_4)_3$] and andradite with schorlomite [$Ca_3Ti_2(Fe_2, Si)O_{12}$]).

A few well-studied garnets from metamorphic rocks have been shown to be chemically zoned with layers of differing compositions. Most of the differences thus far described appear to reflect, for the most part, differences in occupants of the *A* structural positions. Laboratory experiments have indicated that some series involving garnets exist at high pressures or high temperatures or when both conditions prevail, but such series are not known to be represented by natural specimens. This may suggest that the required conditions do not obtain during the genesis of common rocks.

CRYSTAL STRUCTURE

Garnets consist of groups of independent, distorted SiO_4 tetrahedrons, each of which is linked, by sharing corners, to distorted BO_6 (*e.g.*, aluminum- and/or iron-centred) octahedrons, thus forming a three-dimensional framework. The interstices are occupied by *A* divalent metal ions (*e.g.*, Ca, Fe^{2+}, Mg, and Mn), so that each one is surrounded by eight oxygen atoms that are at the corners of a distorted cube. Therefore, each oxygen is coordinated by two *A*, one *B*, and one silicon cation (see Figure 65). The configuration of the array is such that garnets are isometric (cubic).

Garnets other than pyrope commonly occur as well-developed crystals; pyrope only rarely exists as good crystals. The typical forms of the crystals have 12 or 24 sides and are called dodecahedrons and trapezohedrons, respectively, or they are combinations of such forms (see Figure 66). All tend to be nearly equant. A few studies have led to the suggestion that these crystal habits can be correlated with chemical composition—*i.e.*, that dodecahedrons are most likely to be grossular-rich; that trapezohedrons tend to be pyrope-, almandine-, or spessartine-rich; and that combinations are generally andradite-rich. In any case, many garnets have individual faces that are not well developed, and thus the crystals are roughly spherical. Garnet also occurs in fine to coarse granular masses.

Dodecahedrons and trapezohedrons

PHYSICAL PROPERTIES

The diverse garnets can be distinguished from other common rock-forming minerals rather easily since they do not physically resemble any of them. All garnets have vitreous to resinous lustres. Most are translucent, although they may range from transparent to nearly opaque. Garnets lack cleavage but tend to be brittle. They have Mohs hardness values of 6½ to 7½; their specific gravities, which vary with composition, range from about 3.58 (pyrope) to 4.32 (almandine). Their habits, also noteworthy, have already been described (Figure 66).

A garnet's predominant end-member constituent can only be defined absolutely by, for example, chemical analysis or differential thermal analysis (DTA), a method based on the examination of the chemical and physical changes resulting from the application of heat to a mineral. Nonetheless, in many rocks a garnet can be named tentatively as to its probable composition after only macroscopic examination if its colour is considered in conjunction with the identity of its associated minerals and geologic occurrence. This is true despite the fact that even individual garnet species may assume several different colours: almandine's colour range is deep red to dark brownish red; pyrope may be pink to purplish or deep red to nearly black; spessartine may be brownish orange, burgundy, or reddish brown; grossular may be nearly colourless, white, pale green, yellow, orange, pink, yellowish brown, or brownish red; and andradite may be honey yellow or greenish yellow, brown, red, or nearly black.

Garnet colours

The availability of garnets of several colours, along with properties that make them rather durable and relatively easily worked, is responsible for their widespread use as gemstones.

From L.G. Berry, B. Mason, and R.V. Dietrich, *Mineralogy: Concepts, Descriptions, Determinations*, 2nd ed. (1983), W.H. Freeman and Co., New York; photographs, (D,F) specimens from the Miller Museum of Geology and Mineralogy, Queen's University at Kingston, Ont., Can.; (E) © Wendell E. Wilson

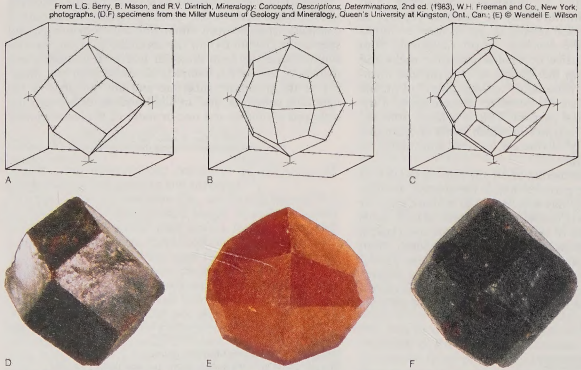


Figure 66: Common crystal forms of garnets. (A,D) Dodecahedrons. (B,E) Trapezohedrons. (C,F) Dodecahedron-trapezohedron combinations.

Table 27: Common Occurrences of Rock-Forming Garnets

Almandine	metamorphic rocks—especially mica schists, amphibolites, and granulites; granites, aplites, and granitic pegmatites
Spessartine	granitic pegmatites; silica-rich skarns; metamorphosed manganese-bearing rocks
Grossular	impure calcite and dolomite marbles, especially those in contact metamorphic zones; amphibolites; basic igneous rocks
Andradite	large masses associated with tactites, some of which constitute ore deposits, in calcareous rocks of contact metasomatic origin
Pyrope	ultramafic rocks such as pyroxenites and peridotites and serpentinites derived from them; eclogites (high-pressure metamorphic rocks)

ORIGIN AND OCCURRENCE

The rock-forming garnets are most common in metamorphic rocks. A few occur in igneous rocks, especially granites and granitic pegmatites. Garnets derived from such rocks occur sporadically in clastic sediments and sedimentary rocks. Typical occurrences of the common rock-forming garnets are given in Table 27.

Inclusions in garnets

Garnets commonly contain many inclusions—*i.e.*, fragments of other rocks and minerals (see Figure 67). Pinwheel garnet and snowball garnet are designations sometimes applied to those garnets whose inclusions appear to have been rotated. These garnets occur sporadically in foliated metamorphic rocks. Although their presence in diverse rocks has been interpreted variously, present-day consensus appears to be that they represent rotation during growth under conditions of dynamic metamorphism that involved differential pressures (see below *Metamorphic rocks: Origin of metamorphic rocks*).

Iron-rich garnets are frequently weathered to rusty masses that consist largely of limonite, and spessartine has weathered to masses of manganese oxide ores under tropical conditions (*e.g.*, in India and Brazil). Garnets as a group, however, are relatively resistant to most weathering processes. Consequently, they occur in some sandy sediments and sandstones. Indeed, the red-coloured grains that are commonly found along some beaches after storms are garnets.

USES

Use as gemstones

The hardness, lack of cleavage, and tendency to break into irregular grains have led to the recovery, crushing, and size-sorting of garnet for use in abrasives such as sandpaper. In addition, as previously mentioned, garnets are used as gemstones. Transparent red and reddish purple pyrope from the Middle East and from Czechoslovakia have been utilized in this capacity for centuries. Green andradite is cut, polished, and marketed as the highly prized stone demantoid. Synthetic garnets with certain compositions, many of which do not have natural representatives, serve important functions because they are ferrimagnetic or antiferromagnetic or because they possess properties particularly suitable for use in lasers. (R.V.Di.)

From R.V. Dietrich and B.J. Skinner, *Rocks and Rock Minerals* (1979), reprinted with permission of John Wiley and Sons, Inc., New York

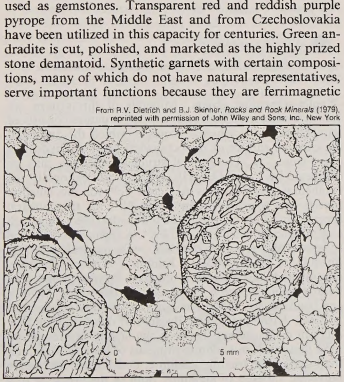


Figure 67: *Inclusions in garnets*
More or less randomly arranged inclusions of quartz and feldspar are present within this garnet from a sample of gneiss found in Floyd county, Va., U.S.

Clay minerals

GENERAL CONSIDERATIONS

The term clay is generally applied to (1) a natural material with plastic properties, (2) particles of very fine size, customarily those defined as particles smaller than two micrometres (7.9×10^{-5} inch), and (3) very fine mineral fragments or particles composed mostly of hydrous-layer silicates of aluminum, though occasionally containing magnesium and iron. Although, in a broader sense, clay minerals can include virtually any mineral of the above-cited particle size, the definition adapted here is restricted to represent hydrous-layer silicates and some related short-range ordered aluminosilicates, both of which occur either exclusively or frequently in very fine-size grades.

The development of X-ray diffraction techniques in the 1920s and the subsequent improvement of microscopic and thermal procedures enabled investigators to establish that clays are composed of a few groups of crystalline minerals. The introduction of electron microscopic methods proved very useful in determining the characteristic shape and size of clay minerals. More recent analytical techniques such as infrared spectroscopy, neutron diffraction analysis, Mössbauer spectroscopy, and nuclear magnetic resonance spectroscopy have helped advance scientific knowledge of the crystal chemistry of these minerals.

Clay minerals are composed essentially of silica, alumina or magnesia or both, and water, but iron substitutes for aluminum and magnesium in varying degrees, and appreciable quantities of potassium, sodium, and calcium are frequently present as well. Some clay minerals may be expressed using ideal chemical formulas as the following: $2SiO_2 \cdot Al_2O_3 \cdot 2H_2O$ (kaolinite), $4SiO_2 \cdot Al_2O_3 \cdot H_2O$ (pyrophyllite), $4SiO_2 \cdot 3MgO \cdot H_2O$ (talc), and $3SiO_2 \cdot Al_2O_3 \cdot 5FeO \cdot 4H_2O$ (chamosite). The SiO_2 ratio in a formula is the key factor determining clay mineral types. These minerals can be classified on the basis of variations of chemical composition and atomic structure into nine groups: (1) kaolin-serpentine (kaolinite, halloysite, lizardite, chrysotile), (2) pyrophyllite-talc, (3) mica (illite, glauconite, celadonite), (4) vermiculite, (5) smectite (montmorillonite, nontronite, saponite), (6) chlorite (sudoite, clinochlore, chamosite), (7) sepiolite-palygorskite, (8) interstratified clay minerals (*e.g.*, rectorite, corrensite, tosudite), and (9) allophane-imogolite. Information and structural diagrams for these groups are given below.

Classification groups

Kaolinite is derived from the commonly used name kaolin, which is a corruption of the Chinese Gaoling (Pinyin; Wade-Giles: Kao-ling) meaning "high ridge," the name of a hill near Ching-te-chen where the occurrence of the mineral is known as early as the 2nd century BC. Montmorillonite and nontronite are named after the localities Montmorillon and Nontron, respectively, in France, where these minerals were first reported. Celadonite is from the French *céladon* (meaning grayish yellow-green) in allusion to its colour. Because sepiolite is a light and porous material, its name is based on the Greek word for cuttlefish, the bone of which is similar in nature. The name saponite is derived from the Latin *sapon* (meaning soap), owing to its appearance and cleaning ability. Vermiculite is from the Latin *vermiculari* ("to breed worms"), because of its physical characteristic of exfoliation upon heating, which causes the mineral to exhibit a spectacular volume change from small grains to long wormlike threads. Baileychlore, brindleyite, corrensite, sudoite, and tosudite are examples of clay minerals that were named after distinguished clay mineralogists—Sturges W. Bailey, George W. Brindley, Carl W. Correns, and Toshio Sudō, respectively. (R.E.G./Hi.K.)

STRUCTURE

General features. The structure of clay minerals has been determined largely by X-ray diffraction methods. The essential features of hydrous-layer silicates were revealed by various scientists including Charles Mauguin, Linus C. Pauling, W.W. Jackson, J. West, and John W. Gruner

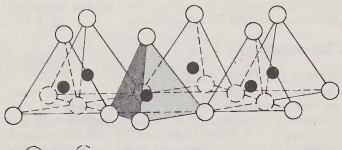


Figure 68: Single silica tetrahedron (shaded) and the sheet structure of silica tetrahedrons arranged in a hexagonal network.
From R. Grim, *Clay Mineralogy* (Copyright 1968); used with permission of McGraw-Hill Book Company

through the late 1920s to mid-1930s. These features are continuous two-dimensional tetrahedral sheets of composition Si_2O_5, with SiO_4 tetrahedrons (Figure 68) linked by the sharing of three corners of each tetrahedron to form a hexagonal mesh pattern (Figure 69A). Frequently, silicon atoms of the tetrahedrons are partially substituted for by aluminum and, to a lesser extent, ferric iron. The apical oxygen at the fourth corner of the tetrahedrons, which is usually directed normal to the sheet, forms part of an adjacent octahedral sheet in which octahedrons are linked by sharing edges (Figure 70). The junction plane between tetrahedral and octahedral sheets consists of the shared apical oxygen atoms of the tetrahedrons and unshared hydroxyls that lie at the centre of each hexagonal ring of tetrahedrons and at the same level as the shared apical oxygen atoms (Figure 71). Common cations that coordinate the octahedral sheets are Al, Mg, Fe^{3+}, and Fe^{2+}; but occasionally Li, V, Cr, Mn, Ni, Cu, and Zn substitute in considerable amounts. If divalent cations (M^{2+}) are in the octahedral sheets, the composition is $M^{2+}(OH)_2O_4$ and all the octahedrons are occupied. If there are trivalent cations (M^{3+}), the composition is $M^{3+}_2(OH)_2O_4$ and two-thirds of the octahedrons are occupied, with the absence of the third octahedron (Figure 72). The former type of octahedral sheet is called trioctahedral, and the latter dioctahedral. If all the anion groups are hydroxyl ions in the compositions of octahedral sheets, the resulting sheets may be expressed by $M^{2+}(OH)_2$ and $M^{3+}(OH)_3$, respectively. Such sheets, called hydroxide sheets, occur singly, alternating with silicate layers in some clay minerals. Brucite, $Mg(OH)_2$, and gibbsite, $Al(OH)_3$, are typical examples of minerals having similar structures. There are two major types for the structural "backbones" of clay minerals called silicate layers. The unit silicate layer formed by aligning one octahedral sheet to one tetrahedral sheet is referred to as a 1:1 silicate layer, and the exposed surface of the octahedral sheet consists of hydroxyls. In another type, the unit silicate layer consists of one octahedral sheet sandwiched by two tetrahedral sheets that are oriented in opposite directions and is termed a 2:1 silicate layer (Figure 73). These structural features, however, are limited to idealized geometric arrangements.

Trioctahedral and dioctahedral sheets

From F. Liebau, *Structural Chemistry of Silicates: Structure, Bonding, and Classification* (1985), Springer-Verlag, New York City

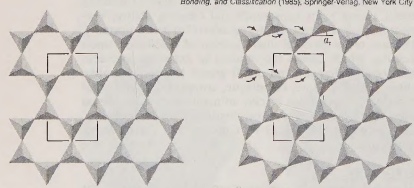


Figure 69: (A) Ideal hexagonal tetrahedral sheet. (B) Contracted sheet of ditrigonal symmetry owing to the reduction of mesh size of the tetrahedral sheet by rotation of the tetrahedrons.

Real structures of clay minerals contain substantial crystal strains and distortions, which produce irregularities such as deformed octahedrons and tetrahedrons rather than polyhedrons with equilateral triangle faces, ditrigonal symmetry modified from the ideal hexagonal surface symmetry, and puckered surfaces instead of the flat planes made up by the basal oxygen atoms of the tetrahedral sheet. One of the major causes of such distortions is dimensional "misfits" between the tetrahedral and octahedral sheets. If the tetrahedral sheet contains only silicon in the cationic site and has an ideal hexagonal symmetry, the longer unit dimension within the basal plane is 9.15 Å, which lies between the corresponding dimensions 8.6 Å of gibbsite and 9.4 Å of brucite. To fit the tetrahedral sheet into the dimension of the octahedral sheet, alternate SiO_4 tetrahedrons rotate (up to a theoretical maximum of 30°) in opposite directions to distort the ideal hexagonal array into a doubly triangular (ditrigonal) array (Figure 69B). By this distortion mechanism, tetrahedral and octahedral sheets of a wide range of compositions resulting from ionic substitutions can link together and maintain silicate layers. Among ionic substitutions, those between ions of distinctly different sizes most significantly affect geometric configurations of silicate layers.

Distortion of structural units

Another significant feature of layer silicates, owing to their similarity in sheet structures and hexagonal or near-hexagonal symmetry, is that the structures allow various ways to stack up atomic planes, sheets, and layers, which may be explained by crystallographic operations such as translation or shifting and rotation, thereby distinguishing them from polymorphs (*e.g.*, diamond-graphite and calcite-aragonite). The former involves one-dimensional variations, but the latter generally three-dimensional ones. The variety of structures resulting from different stacking sequences of a fixed chemical composition are termed polytypes. If such a variety is caused by ionic substitutions that are minor but consistent, they are called polytypoids.

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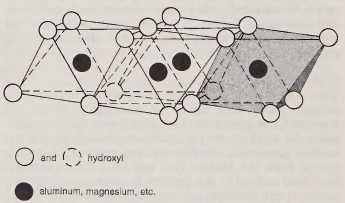


Figure 70: Single octahedron (shaded) and the sheet structure of octahedral units.

Kaolin-serpentine group. Minerals of this groups are 1:1 layer silicates. Their basic unit of structure consists of tetrahedral and octahedral sheets in which the anions at the exposed surface of the octahedral sheet are hydroxyls (see Figure 71). The general structural formula may be expressed by $Y_{2-3}Z_2O_5(OH)_4$, where Y are cations in the octahedral sheet such as Al^{3+} and Fe^{3+} for dioctahedral species and Mg^{2+}, Fe^{2+}, Mn^{2+}, and Ni^{2+} for trioctahedral species, and Z are cations in the tetrahedral sheet, largely Si and, to a lesser extent, Al and Fe^{3+}. A typical dioctahedral species of this group is kaolinite, with an ideal structural formula of $Al_2Si_2O_5(OH)_4$. Kaolinite is electrostatically neutral and has triclinic symmetry. Oxygen atoms and hydroxyl ions between the layers are paired with hydrogen bonding (see above *The nature of minerals: Chemical bonding: Hydrogen bonds*). Because of this weak bonding, random displacements between the layers are quite common and result in kaolinite minerals of lower crystallinity than that of the triclinic kaolinite. Dickite and nacrite are polytypic varieties of kaolinite. Both of them consist of a double 1:1 layer and have monoclinic symmetry, but they distinguish themselves by different stacking sequences of the two 1:1 silicate layers.

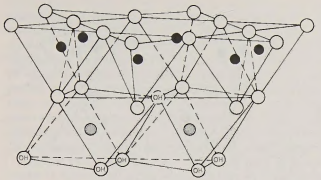


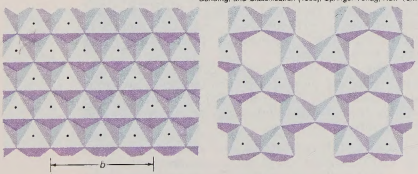
Figure 71: Structure of 1:1 layer silicate (kaolinite) illustrating the connection between tetrahedral and octahedral sheets.

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Halloysite also has a composition close to that of kaolinite and is characterized by its tubular nature in contrast to the platy nature of kaolinite particles. Although tubular forms are the most common, other morphological varieties are also known: prismatic, rolled, pseudospherical, and platy forms. The structure of halloysite is believed to be similar to that of kaolinite, but no precise structure has been revealed yet. Halloysite has a hydrated form with a composition of $Al_2Si_2O_5(OH)_4 \cdot 2H_2O$. This hydrated form irreversibly changes to a dehydrated variety at relatively low temperatures (60° C) or upon being exposed to conditions of low relative humidity. The dehydrated form has a basal spacing about the thickness of a kaolinite layer (approximately 7.2 Å), and the hydrated form has a basal spacing of about 10.1 Å. The difference of 2.9 Å is approximately the thickness of a sheet of water one molecule thick. Consequently, the layers of halloysite in the hydrated form are separated by monomolecular water layers that are lost during dehydration.

Hydrated and dehydrated forms of halloysite

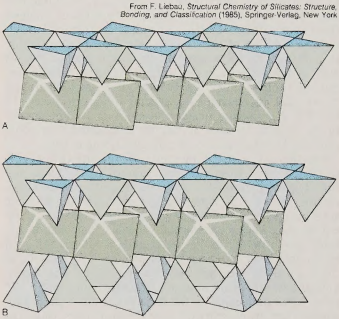
In trioctahedral magnesium species, chrysotile, antigorite, and lizardite are commonly known; the formula of these three clay minerals is $Mg_3Si_2O_5(OH)_4$. Chrysotile crystals have a cylindrical roll morphology, while antigorite crystals exhibit an alternating wave structure. These morphological characteristics may be attributed to the degree of fit between the lateral dimensions of the tetrahedral and octahedral sheets. On the other hand, lizardite crystals are platy and often have a small amount of substitution of aluminum or ferric iron for both silicon and magnesium. This substitution appears to be the main reason for the platy nature of lizardite. Planar polytypes of the trioctahedral species are far more complicated than those of dioctahedral ones, owing to the fact that the trioctahedral silicate layer has a higher symmetry because all octahedral cationic sites are occupied. In addition, recent detailed structural investigations have shown that there are considerable numbers of hydrous-layer silicates whose structures are periodically perturbed by inversion or revision of SiO_4 tetrahedrons. Modulated structures therefore produce two characteristic linkage configurations: strips and islands. Antigorite is an example of the strip configuration in the modulated 1:1 layer silicates. Greenalite, a species rich in ferrous iron, also has a modulated layer structure containing an island configuration.



From F. Liebau, *Structural Chemistry of Silicates: Structure, Bonding, and Classification* (1985), Springer-Verlag, New York

Figure 72: (A) Trioctahedral and (B) dioctahedral sheets in clay minerals.

Pyrophyllite-talc group. Minerals of this group have the simplest form of the 2:1 layer with a unit thickness of approximately 9.2 to 9.6 Å—*i.e.*, the structure consists of an octahedral sheet sandwiched by two tetrahedral sheets (Figure 73B). Pyrophyllite and talc represent the dioctahedral and trioctahedral members, respectively, of the group. In the ideal case, the structural formula is expressed by $Al_2Si_4O_{10}(OH)_2$ for pyrophyllite and by $Mg_3Si_4O_{10}(OH)_2$ for talc. Therefore, the 2:1 layers of these minerals are electrostatically neutral and are held together with van der Waals bonding (see above *The nature of minerals: Chemical bonding: Van der Waals bonding*). One-layer triclinic and two-layer monoclinic forms are known for polytypes of pyrophyllite and talc. The ferric iron analogue of pyrophyllite is called ferripyrophyllite.



From F. Liebau, *Structural Chemistry of Silicates: Structure, Bonding, and Classification* (1985), Springer-Verlag, New York

Figure 73: Schematic presentation of (A) 1:1 layer structures and (B) 2:1 layer structures.

Mica mineral group. Mica minerals have a basic structural unit of the 2:1 layer type like pyrophyllite and talc, but some of the silicon atoms (ideally one-fourth) are always replaced by those of aluminum. This results in a charge deficiency that is balanced by potassium ions between the unit layers. The sheet thickness (basal spacing or dimension along the direction normal to the basal plane) is fixed at about 10 Å. Typical examples are muscovite, $KAl_2(Si_3Al)O_{10}(OH)_2$, for dioctahedral species, and phlogopite, $KMg_3(Si_3Al)O_{10}(OH)_2$, and biotite, $K(Mg, Fe)_3(Si_3Al)O_{10}(OH)_2$, for trioctahedral species. (Formulas rendered may vary slightly due to possible substitution within certain structural sites.) Various polytypes of the micas are known to occur. Among them, one-layer monoclinic (1M), two-layer monoclinic (2M, including $2M_1$ and $2M_2$), and three-layer trigonal (3T) polytypes are most common. The majority of clay-size micas are dioctahedral aluminous species; those similar to muscovite are called illite and generally occur in sediments. The illites are different from muscovite in that the amount of substitution of aluminum for silicon is less; sometimes only one-sixth of the silicon ions are replaced. This reduces a net unbalanced-charge deficiency from 1 to about 0.65 per unit chemical formula. As a result, the illites have a lower potassium content than the muscovites. To some extent, octahedral aluminum ions are replaced by magnesium (Mg^{2+}) and iron ions (Fe^{2+}, Fe^{3+}). In the illites, stacking disorders of the layers are common, but their polytypes are often unidentifiable.

Substitution of aluminum

Celadonite and glauconite are ferric iron-rich species of dioctahedral micas. The ideal composition of celadonite may be expressed by $K(Mg, Fe^{3+})(Si_{4-x}Al_x)O_{10}(OH)_2$,

where $x = 0$–0.2. Glauconite is a dioctahedral mica species with tetrahedral Al substitution greater than 0.2 and octahedral Fe^{3+} or R^{3+} (total trivalent cations) greater than 1.2. Unlike illite, a layer charge deficiency of celadonite and glauconite arises largely from the unbalanced charge due to ionic substitution in the octahedral sheets.

Vermiculite. The vermiculite unit structure consists of sheets of trioctahedral mica or talc separated by layers of water molecules; these layers occupy a space about two water molecules thick (approximately 4.8 Å). Substitutions of aluminum cations (Al^{3+}) for silicon cations (Si^{4+}) constitute the chief imbalance, but the net charge deficiency may be partially balanced by other substitutions within the mica layer; there is always a residual net charge deficiency commonly in the range from 0.6 to 0.8 per $O_{10}(OH)_2$. This charge deficiency is satisfied with interlayer cations that are closely associated with the water molecules between the mica layers. In the natural mineral, the balancing cation is magnesium (Mg^{2+}). The interlayer cation, however, is readily replaced by other inorganic and organic cations. A number of water molecules are related to the hydration state of cations located at the interlayer sites. Therefore, the basal spacing of vermiculite changes from about 10.5 to 15.7 Å, depending on relative humidity and the kind of interlayer cation. Heating vermiculite to temperatures (depending on its crystal size) as high as 500° C drives the water out from between the mica layers, but the mineral quickly rehydrates at room temperature to maintain its normal basal spacing of approximately 14 to 15 Å if potassium or ammonium ions are not present in the interlayer sites. It has been reported that some dioctahedral analogues of vermiculite occur in soils.

Interlayer cations

Smectite. The structural units of smectite (Figure 74) can be derived from the structures of pyrophyllite and talc. Unlike pyrophyllite and talc, the 2:1 silicate layers of smectite have a slight negative charge owing to ionic substitutions in the octahedral and tetrahedral sheets. The net charge deficiency is normally smaller than that of vermiculite—from 0.2 to 0.6 per $O_{10}(OH)_2$—and is balanced by the interlayer cations as in vermiculite. This weak bond offers excellent cleavage between the layers. The distinguishing feature of the smectite structure is that water and other polar molecules (in the form of certain organic substances) can, by entering between the unit layers, cause the structure to expand in the direction normal to the basal plane. Thus this dimension may vary from about 9.6 Å,

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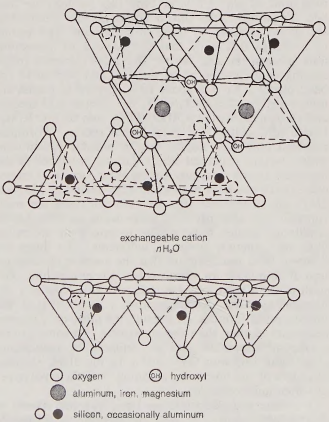


Figure 74: The structure of smectite.

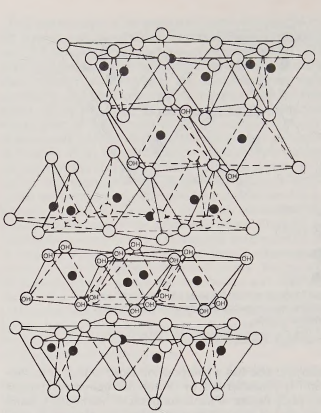


Figure 75: The structure of chlorite.

From R. Grim, Clay Mineralogy (Copyright 1968); used with permission of McGraw-Hill Book Company

when there are no polar molecules between the unit layers, to nearly complete separation of the individual layers.

The structural formula of smectites of the dioctahedral aluminous species may be represented by $(Al_{2-y}Mg_y^{2+})(Si_{4-x}Al_x)O_{10}(OH)_2M_{x+y}^{+} \cdot nH_2O$, where M^+ is the interlayer exchangeable cation expressed as a monovalent cation and where x and y are the amounts of tetrahedral and octahedral substitutions, respectively ($0.2 \leq x + y \leq 0.6$). The smectites with $y > x$ are called montmorillonite and those with $x > y$ are known as beidellite. In the latter type of smectites, those in which ferric iron is a dominant cation in the octahedral sheet instead of aluminum and magnesium, are called nontronite. Although less frequent, chromium (Cr^{3+}) and vanadium (V^{3+}) also are found as dominant cations in the octahedral sheets of the beidellite structure, and chromium species are called volkonskoite. The ideal structural formula of trioctahedral ferromagnesian smectites, the series saponite through iron saponite, is given by $(Mg, Fe^{2+})_3(Si_{4-x}Al_x)O_{10}(OH)_2M_x^{+} \cdot nH_2O$. The tetrahedral substitution is responsible for the net charge deficiency in the smectite minerals of this series. Besides magnesium and ferrous iron, zinc, cobalt, and manganese are known to be dominant cations in the octahedral sheet. Zinc-dominant species are called sauconite. There are other types of trioctahedral smectites in which the net charge deficiency arises largely from the imbalanced charge due to ionic substitution or a small number of cation vacancies in the octahedral sheets or both conditions. Ideally x is zero, but most often it is less than 0.15. Thus, the octahedral composition varies to maintain similar amounts of the net charge deficiency as those of other smectites. Typical examples are $(Mg_{3-y}\square_y)$ and $(Mg_{3-y}\,Li_y)$ for stevensite and hectorite, respectively. [The $\square$ denotes a vacant site in the structure. $(Mg_{3-y}\square_y)$ indicates, therefore, that y sites out of three are vacant.]

Tetrahedral and octahedral substitutions

Chlorite. The structure of the chlorite minerals consists of alternate micalike layers and brucitelike hydroxide sheets about 14 Å thick (Figure 75). Structural formulas of most trioctahedral chlorites may be expressed by four end-member compositions:

$(Mg_5Al)(Si_3Al)O_{10}(OH)_8$	(clinochlore)
$(Fe_5^{2+}Al)(Si_3Al)O_{10}(OH)_8$	(chamosite)
$(Mn_5Al)(Si_3Al)O_{10}(OH)_8$	(pennantite)
$(Ni_5Al)(Si_3Al)O_{10}(OH)_8$	(nimite)

The unbalanced charge of the micalike layer is compen-

sated by an excess charge of the hydroxide sheet that is caused by the substitution of trivalent cations (Al^{3+}, Fe^{3+}, etc.) for divalent cations (Mg^{2+}, Fe^{2+}, etc.). Chlorites with a muscovite-like silicate layer and an aluminum hydroxide sheet are called donbassite and have the ideal formula of $Al_{4.33}(Si_2Al)O_{10}(OH)_8$ as an end-member for the dioctahedral chlorite. In many cases, the octahedral aluminum ions are partially replaced by magnesium, as in magnesium-rich aluminum dioctahedral chlorites called sudoite. Cookeite is another type of dioctahedral chlorite, in which lithium substitutes for aluminum in the octahedral sheets.

Thermal stability of chlorite

Chlorite structures are relatively thermally stable compared to kaolinite, vermiculite, and smectite minerals and are thus resistant to high temperatures. Because of this, after heat treatment at 500°–700° C, the presence of a characteristic X-ray diffraction peak at 14 Å is widely used to identify chlorite minerals.

Interstratified clay minerals. Many clay materials are mixtures of more than one clay mineral. One such mixture involves the interstratification of the layer clay minerals where the individual component layers of two or more kinds are stacked in various ways to make up a new structure different from those of its constituents. These interstratified structures result from the strong similarity that exists between the layers of the different clay minerals (Figure 76), all of which are composed of tetrahedral and octahedral sheets of hexagonal arrays of atoms, and from the distinct difference in the heights (thicknesses) of clay mineral layers.

From T. Sudo *et al., Electron Micrographs of Clay Materials; Developments in Sedimentology* 31 (1981), Elsevier Scientific Publishing Co., New York

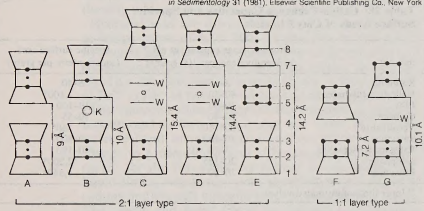


Figure 76: Diagrammatic representation of the layer structures, comparing the relative thickness of the unit structures. (A) Pyrophyllite-talc. (B) Mica. (C) Smectite. (D) Vermiculite. (E) Chlorite. (F) Kaolinite-serpentine. (G) 10 Å halloysite.

The most striking examples of interstratified structures are those having a regular *ABAB* . . . -type structure, where *A* and *B* represent two component layers. There are several minerals that are known to have structures of this type—*i.e.,* rectorite (dioctahedral mica/montmorillonite), tosudite (dioctahedral chlorite/smectite), corrensite (trioctahedral vermiculite/chlorite), hydrobiotite (trioctahedral mica/vermiculite), aliettite (talc/saponite), and kulkeite (talc/chlorite). Other than the *ABAB* . . . type with equal numbers of the two component layers in a structure, many modes of layer-stacking sequences ranging from nearly regular to completely random are possible. The following interstratifications of two components are found in these modes in addition to those given above: illite/smectite, glauconite/smectite, dioctahedral mica/chlorite, dioctahedral mica/vermiculite, and kaolinite/smectite.

Layer-stacking sequences

As the mixing ratio (proportion of the numbers of layers) for the two component layers varies, the number of possible layer-stacking modes increases greatly. For interstratified structures of three component layers, structures consisting of illite/chlorite/smectite and illite/vermiculite/smectite have been reported. Because certain interstratified structures are known to be stable under relatively limited conditions, their occurrence may be used as a geothermometer or other geoindicator.

Sepiolite and palygorskite. Sepiolite and palygorskite are papyrus-like or fibrous (Figure 77) hydrated magnesium silicate minerals and are included in the phyllosilicate group because they contain a continuous two-dimensional tetrahedral sheet of composition Si_2O_5. They differ, however, from the other layer silicates because they lack continuous octahedral sheets. The structures of sepiolite and palygorskite are alike and can be regarded as consisting of narrow strips or ribbons of 2:1 layers that are linked stepwise at the corners (Figure 78). One ribbon is linked to the next by inversion of the direction of the apical oxygen atoms of SiO_4 tetrahedrons; in other words, an elongated rectangular box consisting of continuous 2:1 layers is attached to the nearest boxes at their elongated corner edges. Therefore, channels or tunnels due to the absence of the silicate layers occur on the elongated sides of the boxes. The elongation of the structural element is related to the fibrous morphology of the minerals and is parallel to the *a* axis. Since the octahedral sheet is discontinuous, some octahedral magnesium ions are exposed at the edges and hold bound water molecules (OH_2). In addition to the bound water, variable amounts of zeolitic (*i.e.,* free) water (H_2O) are contained in the rectangular channels. The major difference between the structures of sepiolite and palygorskite is the width of the ribbons, which is greater in sepiolite than in palygorskite. The width determines the number of octahedral cation positions per formula unit. Thus, sepiolite and palygorskite have the ideal compositions $Mg_8Si_{12}O_{30}(OH)_4(OH_2)_4(H_2O)_8$ and $(Mg, Al, \square)_5Si_8O_{20}(OH)_2(OH_2)_4(H_2O)_4$, respectively.

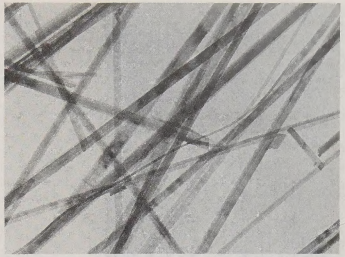


Figure 77: Electron micrograph displaying the elongated, lath-shaped units of sepiolite (magnified about 22,500×).
Japan Electron Optics Laboratory Co., Ltd.; specimen offered by the courtesy of Prof. T. Sudo, Tokyo University of Education

Imogolite and allophane. Imogolite is an aluminosilicate with an approximate composition of $SiO_2 \cdot Al_2O_3 \cdot 2.5H_2O$. This mineral was discovered in 1962 in a soil derived from glassy volcanic ash known as "imogo." Electron-optical observations indicate that imogolite has a unique mor-

From T. Sudo *et al., Electron Micrographs of Clay Materials; Developments in Sedimentology* 31 (1981), Elsevier Scientific Publishing Co., New York

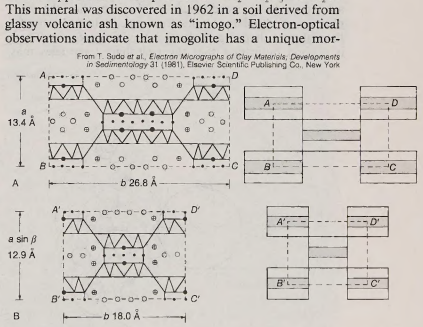


Figure 78: Projections of the (A) sepiolite and (B) palygorskite structures.

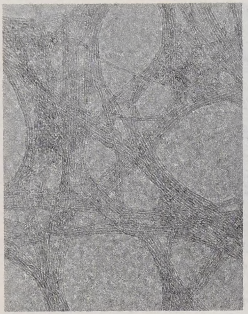


Figure 79: Electron micrograph illustrating the thin, tubular, threadlike units of imogolite (magnified about 390,000×).

Japan Electron Optics Laboratory Co., Ltd.; specimen offered by the courtesy of Dr. N. Yoshinaga, Ehime University

Tubes of imogolite

phological feature of smooth and curved threadlike tubes varying in diameter from 10 to 30 nanometres (3.9×10^{-7} to 1.2×10^{-6} inches) and extending several micrometres in length (Figure 79). The structure of imogolite that most closely fits the observed data is given in Figure 80. The structure is cylindrical and consists of a modified gibbsite sheet in which the hydroxyls of one side of a gibbsite octahedral sheet lose protons and bond to silicon atoms that are located at vacant octahedral cation sites of gibbsite. Thus, three oxygen atoms and one hydroxyl as the fourth anion around one silicon atom make up an isolated SiO_4 tetrahedron as in orthosilicates, and such tetrahedrons make a planar array on the side of a gibbsite sheet. Because silicon-oxygen bonds are shorter than aluminum-oxygen bonds, this effect causes that sheet to curve. As a result, the curved sheet ideally forms a tubelike structure with inner and outer diameters of about 6.4 Å and 21.4 Å, respectively, and with all hydroxyls exposed at the surface. The number of modified gibbsite units therefore determines the diameter of the threadlike tubes.

Allophane can be regarded as a group of naturally occurring hydrous aluminosilicate minerals that are not totally amorphous but are short-range (partially) ordered. Allophane structures are characterized by the dominance of Si-O-Al bonds—*i.e.,* the majority of aluminum atoms are tetrahedrally coordinated. Unlike imogolite, the morphology of allophane varies from fine, rounded particles through ring-shaped particles to irregular aggregates. There is a good indication that the ring-shaped particles may be hollow spherules or polyhedrons. Sizes of the small individual allophane particles are on the order of 30–50 Å in diameter. In spite of their indefinable structure, their chemical compositions surprisingly fall in a relatively narrow range, as the SiO_2:Al_2O_3 ratios are mostly between 1.0 and 2.0. In general, the SiO_2:Al_2O_3 ratio of allophane is higher than that of imogolite. (Hi.K.)

CHEMICAL AND PHYSICAL PROPERTIES

Ion exchange. Depending on deficiency in the positive or negative charge balance (locally or overall) of mineral structures, clay minerals are able to adsorb certain cations and anions and retain them around the outside of the structural unit in an exchangeable state, generally without affecting the basic silicate structure. These adsorbed ions are easily exchanged by other ions. The exchange reaction differs from simple sorption because it has a quantitative relationship between reacting ions. The range of the cation-exchange capacities of the clay minerals is given in Table 28.

Exchange capacities vary with particle size, perfection of crystallinity, and nature of the adsorbed ion; hence, a range of values exists for a given mineral rather than a single specific capacity. With certain clay minerals—such as imogolite, allophane, and to some extent kaolinite—that have hydroxyls at the surfaces of their structures, exchange capacities also vary with the pH (index of acidity or alkalinity) of the medium, which greatly affects dissociation of the hydroxyls.

Table 28: Cation-Exchange Capacities and Specific Surface Areas of Clay Minerals

mineral	cation-exchange capacity at pH 7 (milliequivalents per 100 grams)	specific surface area (square metre per gram)
Kaolinite	3–15	5–40
Halloysite (hydrated)	40–50	1,100*
Illite	10–40	10–100
Chlorite	10–40	10–55
Vermiculite	100–150	760*
Smectite	80–120	40–800
Palygorskite-sepiolite	3–20	40–180
Allophane	30–135	2,200*
Imogolite	20–30	1,540*

*Upper limit of estimated values.

Under a given set of conditions, the various cations are not equally replaceable and do not have the same replacing power. Calcium, for example, will replace sodium more easily than sodium will replace calcium. Sizes of potassium and ammonium ions are similar, and the ions are fitted in the hexagonal cavities of the silicate layer. Vermiculite and vermiculitic minerals preferably and irreversibly adsorb these cations and fix them between the layers. Heavy metal ions such as copper, zinc, and lead are strongly attracted to the negatively charged sites on the surfaces of the 1:1 layer minerals, allophane and imogolite,

From P. Cradwick *et al.*, "Imogolite, a Hydrated Aluminium Silicate of Tubular Structure," *Nature*, 240 (1972)

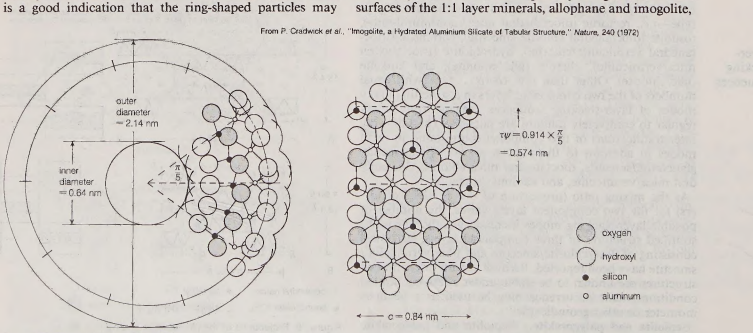


Figure 80: The structure of imogolite.

which are caused by the dissociation of surface hydroxyls of these minerals.

The ion-exchange properties of the clay minerals are extremely important because they determine the physical characteristics and economic use of the minerals.

Clay-water relations. Clay materials contain water in several forms. The water may be held in pores and may be removed by drying under ambient conditions. Water also may be adsorbed on the surface of clay mineral structures and in smectites, vermiculites, hydrated halloysite, sepiolite, and palygorskite; this water may occur in interlayer positions or within structural channels. Finally, the clay mineral structures contain hydroxyls that are lost as water at elevated temperatures.

Zeolitic and bound water adsorption

The water adsorbed between layers or in structural channels may further be divided into zeolitic and bound waters. The latter is bound to exchangeable cations or directly to the clay mineral surfaces. Both forms of water may be removed by heating to temperatures on the order of 100°–200° C and in most cases, except for hydrated halloysite, are regained readily at ordinary temperatures. It is generally agreed that the bound water has a structure other than that of liquid water; its structure is most likely that of ice. As the thickness of the adsorbed water increases outward from the surface and extends beyond the bound water, the nature of the water changes either abruptly or gradually to that of liquid water. Ions and molecules adsorbed on the clay mineral surface exert a major influence on the thickness of the adsorbed water layers and on the nature of this water. The nonliquid water may extend out from the clay mineral surfaces as much as 60–100 A.

Hydroxyl ions are driven off by heating clay minerals to temperatures of 400°–700° C. The rate of loss of the hydroxyls and the energy required for their removal are specific properties characteristic of the various clay minerals. This dehydroxylation process results in the oxidation of Fe^{2+} to Fe^{3+} in ferrous-iron-bearing clay minerals.

The water-retention capacity of clay minerals is generally proportional to their surface area (see Table 28). As the water content increases, clays become plastic and then change to a near-liquid state. The amounts of water required for the two states are defined by the plastic and liquid limits, which vary with the kind of exchangeable cations and the salt concentration in the adsorbed water. The plastic and liquid limits for different clay minerals are given in Table 29. The plasticity index (PI), the difference between the two limits, gives a measure for the rheological (flowage) properties of clays. A good example is a comparison of the PI of montmorillonite with that of allophane or palygorskite. The former is considerably greater than either of the latter, indicating that montmorillonite has a prominent plastic nature. Such rheological properties of clay minerals have great impact on building foundations, highway construction, chemical engineering, and soil structure in agricultural practices.

Interactions with inorganic and organic compounds. Smectite, vermiculite, and other expansible clay minerals can accommodate relatively large, inorganic cations between the layers. Because of this multivalency, the interlayer space is only partially occupied by such inorganic cations that are distributed in the space like islands. Hydroxy polymers of aluminum, iron, chromium, zinc, and titanium are known examples of the interlayering materials. Most of these are thermally stable and hold as pillars to allow a porous structure in the interlayer space. The resulting complexes, often called pillared clays, exhibit attractive properties as catalysts—namely, large surface area, high porosity, regulated pore size, and high solid acidity.

Pillared clays

Cationic organic molecules, such as certain aliphatic and aromatic amines, pyridines, and methylene blue, may replace inorganic exchangeable cations present in the interlayer of expansible minerals. Polar organic molecules may replace adsorbed water on external surfaces and in interlayer positions. Ethylene glycol and glycerol are known to form stable specific complexes with smectites and vermiculites. The formation of such complexes is frequently utilized for identifying these minerals. As organic molecules coat the surface of a clay mineral, the surface of its constituent particles changes from hydrophilic to hydrophobic, thereby losing its tendency to bind water. Consequently, the affinity of the material for oil increases, so that it can react with additional organic molecules. As a result, the surface of such clay materials can accumulate organic materials. Some of the clay minerals can serve as catalysts for reactions in which one organic substance is transformed to another on the mineral's surface. Some of these organic reactions develop particular colours that may be of diagnostic value in identifying specific clay minerals. Organically clad clay minerals are used extensively in paints, inks, and plastics.

Physical properties. Clay mineral particles are commonly too small for measuring precise optical properties. Reported refractive indices of clay minerals generally fall within a relatively narrow range from 1.47 to 1.68. In general, iron-rich mineral species show high refractive indices, whereas the water-rich porous species have lower ones. Specific gravities of most clay minerals are within the range from 2 to 3.3. Their hardness generally falls below $2\frac{1}{2}$, except for antigorite, whose hardness is reported to be $2\frac{1}{2}$–$3\frac{1}{2}$.

Specific gravities

Size and shape. These two properties of clay minerals have been determined by electron micrographs. Well-crystallized kaolinite occurs as well-formed, six-sided flakes, frequently with a prominent elongation in one direction. Halloysite commonly occurs as tubular units with an outside diameter ranging from 0.04 to 0.15 micrometre.

Electron micrographs of smectite often show broad undulating mosaic sheets. In some cases the flake-shaped units are discernible, but frequently they are too small or too thin to be seen individually without special attention.

Illite occurs in poorly defined flakes commonly grouped together in irregular aggregates. Although their sizes vary more widely, vermiculite, chlorite, pyrophyllite, talc, and serpentine minerals except for chrysotile are similar in character to the illites. Chrysotile occurs in slender tube-shaped fibres having an outer diameter of 100–300 Å. Their lengths commonly reach several micrometres. Electron micrographs show that palygorskite occurs as elongated laths, singly or in bundles. Frequently the individual laths are many micrometres in length and 50 to 100 Å in width. Sepiolite occurs in similar lath-shaped units (see Figure 77). As mentioned above, allophane occurs in very small spherical particles (30–50 Å in diameter), individually or in aggregated forms, whereas imogolite occurs in long (several micrometres in length) threadlike tubes (see Figure 79).

High-temperature reactions. When heated at temperatures beyond dehydroxylation, the clay mineral structure may be destroyed or simply modified, depending on the composition and structure of the substance. In the presence of fluxes, such as iron or potassium, fusion may rapidly follow dehydroxylation. In the absence of such components, particularly for aluminous dioctahedral minerals, a succession of new phases may be formed at increasing temperatures prior to fusion. Information concerning high-temperature reactions is important for ceramic science and industry.

Solubility. The solubility of the clay minerals in acids varies with the nature of the acid and its concentration, the acid-to-clay ratio, the temperature, the duration of treatment, and the chemical composition of the clay min-

Table 29: Plastic and Liquid Limits of Clay Minerals
(water content in percent)

	plastic limit	liquid limit
Kaolinite-Na	26	52
Kaolinite-Ca	36	73
Illite-Na	34	61
Illite-Ca	40	90
Montmorillonite-Na	97	700
Montmorillonite-Ca	63	177
Palygorskite-sepiolite	145	171
Allophane-undried	136	231
Allophane-dried	78	85

Source: Adapted from Raymond N. Yong and Benno P. Warkentin, *Soil Properties and Behaviour* (1975).

eral attacked. In general, ferromagnesian clay minerals are more soluble in acids than their aluminian counterparts. Incongruent dissolutions may result from reactions in a low-acid-concentration medium where the acid first attacks the adsorbed or interlayer cations and then the components of the octahedral sheet of the clay mineral structure. When an acid of higher concentration is used, such stepwise reactions may not be recognizable, and the dissolution appears to be congruent. One of the important factors controlling the rate of dissolution is the concentration in the aquatic medium of the elements extracted from the clay mineral. Higher concentration of an element in the solution hinders to a greater degree the extractions of the element.

In alkaline solutions, a cation-exchange reaction first takes place, and then the silica part of the structure is attacked. The reaction depends on the same variables as those stated for acid reactions.

OCCURRENCE

Soils. All types of clay minerals have been reported in soils. Allophane, imogolite, hydrated halloysite, and halloysite are dominant components in ando soils, which are the soils developed on volcanic ash. Smectite is usually the sole dominant component in vertisols, which are clayey soils. Smectite and illite, with occasional small amounts of kaolinite, occur in mollisols, which are prairie chernozem soils. Illite, vermiculite, smectite, chlorite, and interstratified clay minerals are found in podzolic soils. Sepiolite and palygorskite have been reported in some aridisols (desert soils), and kaolinite is the dominant component in oxisols (lateritic soils). Clay minerals other than those mentioned above usually occur in various soils as minor components inherited from the parent materials of those soils.

Agricultural use

Soils composed of illite and chlorite are better suited for agricultural use than kaolinitic soils because of their relatively high ion-exchange properties and hence their capacity to hold plant nutrients. Moderate amounts of smectite, allophane, and imogolite in soils are advantageous for the same reason, but when present in large amounts these clay minerals are detrimental because they are impervious and have too great a water-holding capacity.

Recent sediments. Sediment accumulating under nonmarine conditions may have any clay mineral composition. In the Mississippi River system, for example, smectite, illite, and kaolinite are the major components in the upper Mississippi and Arkansas rivers, whereas chlorite, kaolinite, and illite are the major components in the Ohio and Tennessee rivers. Hence, in the sediments at the Gulf of Mexico, as a weighted average, smectite, illite, and kaolinite are found to be the major components in the clay mineral composition. Although kaolinite, illite, chlorite, and smectite are the principal clay mineral components of deep-sea sediments, their compositions vary from place to place. In general, illite is the dominant clay mineral in the North Atlantic Ocean (greater than 50 percent), while smectite is the major component in the South Pacific and Indian oceans. In some limited regions, these compositions are significantly altered by other factors such as airborne effects, in which sediments are transported by winds and deposited when the carrying force subsides. The high kaolinite concentration off the west coast of Africa near the Equator reflects this effect.

Under highly saline conditions in desert areas, as in soils, palygorskite and sepiolite also form in lakes and estuaries (perimarine environments).

Ancient sediments. Analyses of numerous ancient sediments in many parts of the world indicate that smectite is much less abundant in sediments formed prior to the Mesozoic Era (from 245 to 66.4 million years ago) with the exception of those of the Permian Period (from 286 to 245 million years ago) and the Carboniferous Period (360 to 286 million years ago), in which it is relatively abundant.

The available data also suggest that kaolinite is less abundant in very ancient sediments than in those deposited after the Devonian Period (408 to 360 million years ago). Stated another way, the very old argillaceous (clay-rich) sediments called physilites are composed largely of illite and chlorite. Palygorskite and sepiolite have not been reported in sediments older than Tertiary age—*i.e.*, those more than about 66 million years old.

Kaolinite and illite have been reported in various coals. Bentonite generally is defined as a clay composed largely of smectite that occurs in sediments of pyroclastic materials as the result of devitrification of volcanic ash in situ.

Sediments affected by diagenesis. As temperature and pressure increase with the progression of diagenesis, clay minerals in sediments under these circumstances change to those stable under given conditions. Therefore, certain sensitive clay minerals may serve as indicators for various stages of diagenesis. Typical examples are the crystallinity of illite, the polytypes of illite and chlorite, and the conversion of smectite to illite. Data indicate that smectite was transformed into illite through interstratified illite-smectite mineral phases as diagenetic processes advanced. Much detailed work has been devoted to the study of the conversion of smectite to illite in lower Cenozoic-Mesozoic sediments because such conversion appears to be closely related to oil-producing processes.

Hydrothermal deposits. All the clay minerals, except palygorskite and sepiolite, have been found as alteration products associated with hot springs and geysers and as aureoles around metalliferous deposits. In many cases, there is a zonal arrangement of the clay minerals around the source of the alteration, a process which involves changes in the composition of rocks caused by hydrothermal solutions. The zonal arrangement varies with the type of parent rock and the nature of the hydrothermal solution. An extended kaolinite zone occurs around the tin-tungsten mine in Cornwall-Devon, Eng. Mica (sericite), chlorite, tosudite, smectite, and mica-smectite interstratifications are contained in an extensive clay zone formed in a close association with kuroko (black ore) deposits. Smectites are known to occur as alteration products of tuff and rhyolite. Pottery stones consisting of kaolinite, illite, and pyrophyllite occur as alteration products of acidic volcanic rocks, shales, and mudstone.

ORIGIN

Synthetic formation. All the clay minerals, with the possible exception of halloysite, have been synthesized from mixtures of oxides or hydroxides and water at moderately low temperatures and pressures. Kaolinite tends to form in alumina-silica systems without alkalies or alkaline earths. Illite is formed when potassium is added to such systems; and either smectite or chlorite results upon the addition of magnesium, depending on its concentration. The clay minerals can be synthesized at ordinary temperatures and pressures if the reactants are mixed together very slowly and in greatly diluted form.

Clay minerals of certain types also have been synthesized by introducing partial structural changes to clay minerals through the use of chemical treatments. Vermiculite can be formed by a prolonged reaction in which the potassium of mica is exchanged with any hydrated alkali or alkaline earth cation. Chloritic minerals can be synthesized by precipitating hydroxide sheets between the layers of vermiculite or montmorillonite. The reverse reactions of these changes are also known. A mechanism of mineral formation involving a change from one mineral to another is called transformation and can be distinguished from neoformation, which implies a mechanism for the formation of minerals from solution.

Transformation and neoformation

Formation in nature. In nature both mineral formation mechanisms, neoformation and transformation, are induced by weathering and hydrothermal and diagenetic actions.

The formation of the clay minerals by weathering processes is determined by the nature of the parent rock, climate, topography, vegetation, and the time period during which these factors operated. Climate, topography, and vegetation influence weathering processes by their control of the character and direction of movement of water through the weathering zone (see also GEOMORPHIC PROCESSES: *Weathering*).

In the development of clay minerals by natural hydrothermal processes, the presence of alkalies and alkaline earths influences the resulting products in the same manner as

shown by synthesis experiments. Near-neutral hydrothermal solutions bring about rock alteration, including the formation of illite, chlorite, and smectite, whereas acid hydrothermal solutions result in the formation of kaolinite.

INDUSTRIAL USES

Ancient use in bricks and soaps

Clays are perhaps the oldest materials from which humans have manufactured various artifacts. The making of fired bricks possibly started some 5,000 years ago and was most likely humankind's second earliest industry after agriculture. The use of clays (probably smectite) as soaps and absorbents was reported in *Natural History* by the Roman author Pliny the Elder (*c.* AD 77).

Clays composed of kaolinite are required for the manufacture of porcelain, whiteware, and refractories. Talc, pyrophyllite, feldspar, and quartz are often used in whiteware bodies, along with kaolinite clay, to develop desirable shrinkage and burning properties. Clays composed of a mixture of clay minerals, in which illite is most abundant, are used in the manufacture of brick, tile, stoneware, and glazed products. In addition to its use in the ceramic industry, kaolinite is utilized as an extender in aqueous-based paints and as a filler in natural and synthetic polymers.

Smectitic clays (bentonite) are employed primarily in the preparation of muds for drilling oil wells. This type of clay, which swells to several times its original volume in water, provides colloidal and wall-building properties. Palygorskite and sepiolite clays also are used because of their resistance to flocculation under high salinity conditions. Certain clay minerals, notably palygorskite, sepiolite, and some smectites, possess substantial ability to remove coloured bodies from oil. These so-called fuller's earths are used in processing many mineral and vegetable oils. Because of their large absorbing capacity, fuller's earths are also used commercially for preparing animal litter trays and oil and grease absorbents. Acid treatment of some smectite clays increases their decolorizing ability. Much gasoline is manufactured by using catalysts prepared from a smectite, kaolinite, or halloysite type of clay mineral.

Tons of kaolinite clays are used as paper fillers and paper coating pigments. Palygorskite-sepiolite minerals and acid-treated smectites are used in the preparation of no-carbon-required paper because of the colour they develop during reactions with certain colourless organic compounds.

Clays have a tremendous number of miscellaneous uses, and for each application a distinct type with particular properties is important. (R.E.G./Hi.K.)

Calcite

GENERAL CONSIDERATIONS

The carbonate minerals calcite, aragonite, and dolomite have been calculated to make up approximately 15 percent of the Earth's sediments and sedimentary rocks and about 2 percent of the terrestrial crust (see above Table 15). A large percentage of the calcite, the most abundant of these carbonate minerals, occurs in limestones, which constitute noteworthy proportions of many sequences of marine sediments. Calcite is also the chief component of marls, travertines, calcite veins, most speleothems (cave deposits), many marbles and carbonatites, and some ore-bearing veins.

Calcite is the stable form of $CaCO_3$ at most temperatures and pressures. The orthorhombic polymorph of $CaCO_3$, aragonite, though frequently deposited in nature, is metastable at room temperature and pressure and readily inverts to calcite; the inversion has been shown experimentally to be spontaneous when aragonite is heated to 400° C in dry air and at lower temperatures when it is in contact with water. Hexagonal vaterite, the other natural polymorph of $CaCO_3$, is extremely rare and has been shown in the laboratory to transform into calcite or aragonite or both penecontemporaneously with its formation—*i.e.,* it appears to be metastable under essentially all known natural conditions.

CHEMICAL COMPOSITION

Some natural calcites are essentially pure $CaCO_3$; others contain noteworthy percentages of other cations (*e.g.,* Mg, Mn, Fe, bromine [Br], Sr, and/or Y), substituting for some of their calcium. In general, however, only minor substitution occurs. Only manganese and magnesium are known to substitute extensively for the calcium: manganocalcite and calcian rhodochrosite (*i.e.,* calcium-bearing $MnCO_3$) have been identified, and solid solution has been shown to be possible from pure $CaCO_3$ to 40 percent $MnCO_3$ and from pure $MnCO_3$ to about 25 percent $CaCO_3$. Metastable magnesian calcites containing from approximately 5 to 18 percent $MgCO_3$ occur rather widely as biogenic skeletal material and as cement in some modern marine sediments. Magnesian calcites at the lower end of this range of $MgCO_3$ contents constitute some marine oöids and calcareous tufas.

Substitution for calcium

Between 60 and 70 elements have been recorded in minor or trace amounts in limestone analyses. Some of these elements may occur as substitutions within calcite; others seem more likely to represent minor constituents, such as clay minerals, within the analyzed rocks.

The chemical composition of calcite is responsible for the test that is widely used to identify it, especially in the field. This test is based on the fact that calcite reacts with dilute hydrochloric acid (HCl), and the reaction is manifested by vigorous effervescence. (The dilution of the HCl usually used is about 90:10 [water:concentrated HCl].) The reactions involved are

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2CO_3$$

and

$$H_2CO_3 \rightarrow H_2O + CO_2.$$

The effervescence is due to the spontaneous breakdown of the carbonic acid (H_2CO_3) to produce carbon dioxide gas, CO_2 (see above *The nature of minerals: Physical properties: Solubility in hydrochloric acid*).

CRYSTAL STRUCTURE

The structure of calcite—one of the first mineral structures to be determined by X-ray methods—has been described on three different bases. The two most frequently used bases, illustrated in Figure 81, are the true rhombohedral unit cell, which is the acute rhombohedron, and the cleavage rhombohedron setup. The true unit cell includes 2 $CaCO_3$ with calcium ions at the corners of the rhombohedrons and CO_3 groups, each of which consists of a carbon ion at the centre of a planar group of oxygen atoms whose centres define an equilateral triangle. The configuration can be considered another way: the structure consists of alternating sheets of hexagonally arranged calcium ions and CO_3 complex anions (see Figure 81). This array is

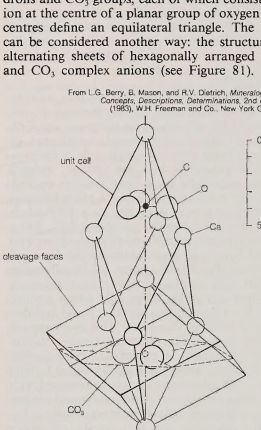


Figure 81: *The crystal structure of calcite.*
This schematic diagram shows both the true unit cell (the acute rhombohedron, which contains 2[$CaCO_3$]) and an alternative cell based on the cleavage rhombohedron.

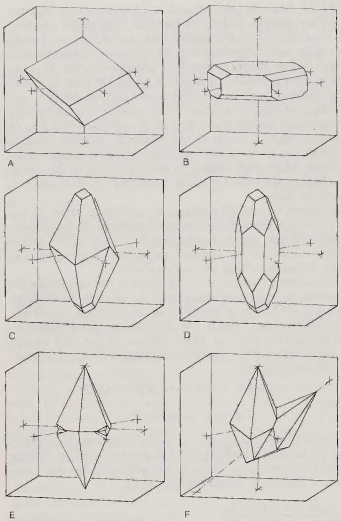


Figure 82: *Calcite crystals.*
Some of the many fairly common crystal habits represented by natural calcite crystals are illustrated here. (A)–(D) are untwinned crystals; (E) and (F) are twinned.
From L.G. Berry, B. Mason, and R.V. Dietrich, *Mineralogy: Concepts, Descriptions, Determinations*, 2nd ed. (1983), W.H. Freeman and Co., New York City

in the hexagonal (trigonal) crystal system. The threefold symmetry is quite obvious in both crystals and cleavage rhombohedrons (Figure 82). The crystals occur most commonly in cavities in rocks—*e.g.*, in vugs (including druses), in vesicles in igneous rocks, and lining partially filled fissures.

PHYSICAL PROPERTIES

Diverse colours of impure calcite

Calcite is colourless or white when pure but may be of almost any colour—reddish, pink, yellow, greenish, bluish, lavender, black, or brown—owing to the presence of diverse impurities. It may be transparent, translucent, or opaque. Its lustre ranges from vitreous to dull; many crystals, especially the colourless ones, are vitreous, whereas granular masses, especially those that are fine-grained, tend to be dull. Calcite is number 3 on the Mohs hardness scale; thus, it can be scratched readily by a knife blade or geologic pick. It has a specific gravity of 2.71. Three perfect cleavages give calcite its six-sided polyhedrons with diamond-shaped faces; the angles defining the faces are 78° and 102° (see Figure 83). Some calcites fluoresce under ultraviolet light; some are also triboluminescent (luminescent when scratched). When light passes through some minerals, it is split into two rays that travel at different speeds and in different directions. This phenomenon is known as birefringence. The difference between the velocities is especially notable in calcite, and consequently crystals of a colourless variety—sometimes called Iceland spar—exhibit double refraction that can be observed with the naked eye. (See also LIGHT: *Polarization and electromagnetic theory: Polarized light: Double refraction.*)

The previously described fact that calcite effervesces vigorously with dilute hydrochloric (muriatic) acid distinguishes calcite from dolomite, which it tends to resemble in both appearance and occurrence. (Dolomite effervesces only when powdered and with only a slow, smoldering action.)

In rocks made up predominantly of calcite, the mineral is typically granular, with grains ranging from those discernible only under a microscope to those that are a few millimetres in greatest dimension. The colour of most of these rocks is gray or tan, but some calcite marbles are white and a few are multicoloured.

ORIGIN AND OCCURRENCE

A large percentage of the calcite in rocks was deposited in sedimentary environments; consequently, calcite is a constituent of several diverse sediments, sedimentary rocks, and their metamorphosed products. A minor amount of the Earth's calcite is of magmatic (*i.e.*, igneous) origin; it is the chief constituent of the rare rock called calcite carbonatite. Calcite also occurs widely in veins: some of the veins are wholly or largely calcite; others contain valuable ore minerals and are usually described as ore veins, even though calcite is the predominant constituent.

Clastic limestones

The sedimentary rocks composed largely of calcite include limestones of chemical and biochemical origin and also limestones usually referred to as clastic because they consist of transported fragments of previously deposited, typically biogenetic materials. Travertine, chalk, and calcarenite, respectively, are examples of these kinds of limestones (Figure 84).

Many limestones have gained their mineralogical makeups and textures during diagenesis. Aragonite, the orthorhombic polymorph of $CaCO_3$, was deposited and subsequently transformed into the calcite of some limestones; magnesian calcites that constitute some organic skeletal parts and cements of marine sediments were the precursors of the calcite of many other limestones. During diagenesis, most of the magnesian calcites were transformed into stable assemblages of rather pure calcite, often along with scattered grains of dolomite.

When sedimentary and diagenetic limestones undergo metamorphism, the calcite is frequently recrystallized and tends to become coarsely crystalline. The resulting rocks are calcite marbles. Some calcite marbles, however, appear to have had dolostone rather than limestone precursors; *i.e.*, the dolostone underwent dedolomitization during metamorphism. The calcite grains in some marbles have cleavage planes that are curved; this is usually interpreted to reflect recrystallization during deformation or plastic flowage associated with dynamic metamorphism.

The calcite of carbonatites is generally thought to have formed from dense H_2O-CO_2 fluids that in many ways are more like the volatile-rich fluids from which pegmatites are believed to have been deposited than the more "normal" magmas from which igneous rocks such as granites and basalt have consolidated. These rocks closely resemble marbles, and some masses of both marble and carbonatite

From R.V. Dietrich and B.J. Skinner, *Rocks and Rock Minerals*, copyright © 1979; reprinted by permission of John Wiley and Sons, Inc.; photograph, B.J. Skinner

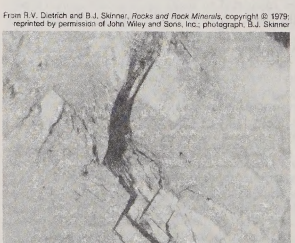


Figure 83: *Calcite cleavage.*
The perfect cleavage of calcite yields rhombohedrons, the faces of which are parallelograms with angles of 102° and 78°. This broken surface is magnified and thus appears as it would through a hand lens.

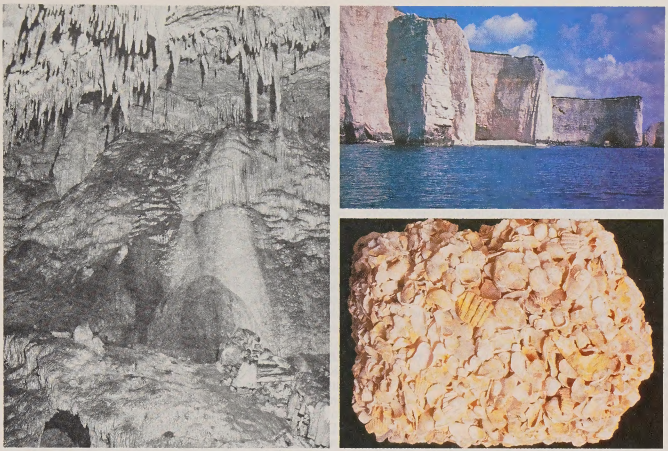


Figure 84: *Examples of some calcite-rich sedimentary rocks.*
(Left) Travertine is the name usually given to the $CaCO_3$ precipitate—either calcite or aragonite—that makes up speleothems (cave formations) such as these that occur in New River cave in southwestern Virginia, U.S. (Top right) Chalk, such as that constituting these rocks along the southern coast of Denmark, is a calcite-rich rock that consists almost entirely of biochemically precipitated microscopic exoskeletons of ancient life forms. (Bottom right) Coquina is a clastic calcareous rock composed largely of broken and transported shell fragments like those currently accumulating along, for example, some of the beaches of the Florida Keys, U.S.

From (left) R.V. Dietrich, *Geology and Virginia*, University of Virginia Press; photograph, J.W. Murray; (right) R.V. Dietrich and B.J. Skinner, *Gems, Granites and Gravels*, Cambridge University Press; photographs, (top) R.V. Dietrich, (bottom) B.J. Skinner

were originally misidentified, one as the other. In most cases, the identities of the accessory minerals serve as ready criteria for differentiating between an igneous and metamorphic origin.

Calcite is deposited by solutions, either ordinary groundwater solutions or hydrothermal solutions associated with magmatic activities. Such calcite constitutes the cement for many clastic sediments—*e.g.*, some sandstones—and also the calcite or aragonite of speleothems and of both calcite and calcitic ore-bearing veins.

Calcite breaks down in most areas where chemical weathering takes place. It is dissolved and its products are carried in surface-water and groundwater solutions. The excavation of caves is a subsurface manifestation of these processes, just as their subsequent filling-in with speleothems is a manifestation of one of the modes whereby calcite is deposited. As might be suspected, most karst topography, which is characterized by sinkholes and underground drainage, occurs in areas underlain by limestone.

USES

Calcite has many uses. Since ancient times, limestone has been burned to quicklime (CaO), slaked to hydrated lime [$Ca(OH)_2$], and mixed with sand to make mortar. Limestone is one of the ingredients used in the manufacture of portland cement and is often employed as a flux in metallurgical processes, such as the smelting of iron ores. Crushed limestone is utilized widely as riprap, as aggregate for both concrete and asphalt mixes, as agricultural lime, and as an inert ingredient of medicines. Marble is used for statuary and carvings, and as polished slabs it is a popular facing stone. The term marble is used differently in the marketplace than in geology; in the marketplace, it is applied to any coarse-grained carbonate rock that will take a good polish rather than to metamorphic carbonate-rich rocks exclusively. Some coarsely crystalline diagenetic limestones are among the most widely used commercial "marbles." Travertine is also a popular facing stone, usually for interior use. Iceland spar has been employed for optical purposes for nearly two centuries. These uses constitute only a few of the many applications of calcite.

Use of marble

Dolomite

GENERAL CONSIDERATIONS

As mentioned in the section on calcite, dolomite along with calcite and aragonite makes up approximately 2 percent of the Earth's crust (see above Table 15). The bulk of the dolomite constitutes dolostone formations that occur as thick units of great areal extent in many sequences of chiefly marine strata. (The rock dolostone is referred to by only the mineral name—*i.e.*, dolomite—by many geologists.) The Dolomite Alps of northern Italy are a well-known example. Other relatively common occurrences of the mineral dolomite are in dolomite marble and dolomite-rich veins. It also occurs in the rare igneous rock known as dolomite carbonatite.

From the standpoint of its origin, the dolomite of dolostones is one of the most interesting of all the major rock-forming minerals. As discussed below, a large percentage of the dolomite in thick marine dolostone units is thought by many geologists and geochemists to have been formed by replacement of $CaCO_3$ sediment rather than by direct precipitation.

CHEMICAL COMPOSITION

The chemical formula of dolomite is $CaMg(CO_3)_2$. Ferrous iron commonly substitutes for some of the magnesium, and a complete series very likely extends between dolomite and ankerite [$\sim CaFe(CO_3)_2$]. Manganese also substitutes for magnesium, but typically only to the extent of a few percent and in most cases only along with iron. Other cations known to substitute—albeit in only relatively minor amounts—within the dolomite structure are barium and lead for calcium and zinc and cobalt for magnesium.

Nearly all the natural elements have been recorded

as present in at least trace quantities in dolostones. It is, however, unclear which ones actually occur in the dolomite; some of them may occur within other mineral constituents of the analyzed rocks. Indeed, only a few of these elements—*e.g.*, strontium, rubidium, boron, and uranium (U)—are known definitely to occur within the dolomite structure.

Distinction between calcite and dolomite

Dolomite effervesces with dilute hydrochloric acid, but slowly rather than vigorously as calcite does; in general, it appears to smolder slowly, and in some cases it does so only after the rock has been powdered or the acid warmed, or both. This difference in the character of the effervescence serves as the test usually used to distinguish dolomite from calcite in the field. In the laboratory, staining techniques, also based on chemical properties or typical compositions, may be used to distinguish between these minerals. The stains generally employed are especially valuable for investigating rocks made up of alternate lamellae of dolostone and limestone composition.

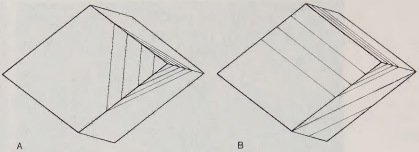


Figure 86: Relations between lamellar twinning and cleavage planes in (A) dolomite and (B) calcite. This difference can be discerned best when thin sections of the minerals are viewed under a microscope.

From L.G. Berry, B. Mason, and R.V. Dietrich, *Mineralogy: Concepts, Descriptions, Determinations*, 2nd ed. (1983), W.H. Freeman and Co., New York City

CRYSTAL STRUCTURE

In a somewhat simplified way, the dolomite structure can be described as resembling the calcite structure but with magnesium ions substituted for calcium ions in every other cation layer. Thus, the dolomite structure can be viewed as ideally comprising a calcium layer, a CO_3 layer, a magnesium layer, another CO_3 layer, and so forth (see Figure 85). However, as described for the potassium feldspars,

From J.K. Warren, *Evaporite Sedimentology* (1989), Prentice Hall, Englewood Cliffs, New Jersey

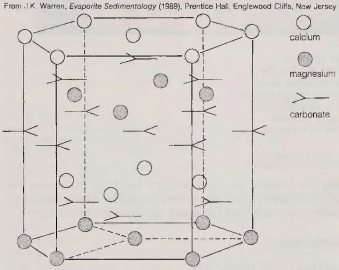


Figure 85: The layered structure of dolomite.

dolomites—unlike calcites—may also exhibit order-disorder relationships. This results because the purity of some of the cation layers may be less than ideal—*i.e.*, some of the "calcium layers" may contain magnesium, and some of the "magnesium layers" may contain some calcium. The term protodolomite is frequently applied to Holocene dolomites (those formed during approximately the last 10,000 years) that have less than ideal dolomite structures. Most dolomites of ancient dolostones, however, appear to be well ordered. Modifications that may reflect diverse calcium-versus-magnesium layering aberrations are treated extensively in professional literature.

PHYSICAL PROPERTIES

Dolomite crystals are colourless, white, buff-coloured, pinkish, or bluish. Granular dolomite in rocks tends to be light to dark gray, tan, or white. Dolomite crystals range from transparent to translucent, but dolomite grains in rocks are typically translucent or nearly opaque. The lustre ranges from subvitreous to dull. Dolomite, like calcite, cleaves into six-sided polyhedrons with diamond-shaped faces. Relations between lamellar twinning and cleavage planes of dolomite, however, differ from those of calcite (see Figure 86), and this difference may be used to distinguish the two minerals in coarse-grained rocks such as marbles. Dolomite has a Mohs hardness of $3\frac{1}{2}$ to 4 and a specific gravity of 2.85 ± 0.01. Some dolomites are triboluminescent.

Sizes of dolomite grains

The dolomite of most dolostones is granular, with the individual grains ranging in size from microscopic up to a few millimetres across. Most dolomite marbles are coarsely granular with individual grains ranging between two and six millimetres (.079 and .24 inch) in greatest dimension. Vein dolomite grains may be up to several centimetres across. Saddle-shaped groups of dolomite crystals, most of which occur on fracture surfaces, measure from 0.5 to 2 centimetres (0.20 to 0.79 inch) across (see Figure 87).

ORIGIN AND OCCURRENCE

Dolomite occurs widely as the major constituent of dolostones and dolomite marbles. As mentioned above, the origin of dolomite-rich rocks in marine sequences remains an unresolved problem of petrogenesis.

Dolomite—actually protodolomite—is known to have formed fairly recently in restricted environments such as on supratidal flats. None, however, is known to have formed recently within more common marine environments that appear to be represented by thick dolostone units deposited in the geologic past. Also, no dolomite has been synthesized in an environment comparable to natural conditions. Thus, the explanation for the formation of dolomite in these marine units remains in question. It is now thought that dolostones may be of various origins. Indeed, several different models have been suggested for dolomite formation, each based on diverse considerations, combined with empirical and/or experimental data.

Except for models invoking formation of dolomite by direct precipitation, a process thought by most geologists to apply to only a small percentage of all dolostones, each model is based on the assumption that the dolomite of dolostones has been formed by conversion of $CaCO_3$ sediment or sedimentary rocks to dolostone. Thus, the models have been formulated to account for this conversion, which is known as dolomitization.

The most widely discussed models for dolomitization, either partial or complete, involve four chief variables: time,

By courtesy of S.C. Chamberlain, Syracuse University

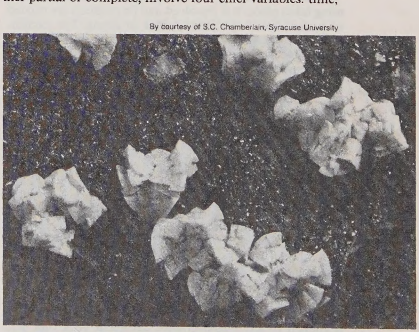


Figure 87: *Saddle-shaped groups of dolomite crystals.* Microscopic investigations have revealed that groups such as these reflect faultlike defects. The crystals shown here are believed to have been deposited by relatively low-temperature solutions.

location with respect to the sediment-seawater interface, composition and derivation of the solutions involved, and fluxing mechanisms. The time ranges from dolomitization that occurs penecontemporaneously with deposition to that which takes place subsequent to relatively deep burial of the precursor sediments. The location ranges from at or very near the sediment-seawater interface to well beneath some overlying sediments that were deposited at a later time. The solutions supply the magnesium needed and must have the appropriate pH and concentrations of other necessary ions; these solutions are generally considered to be seawater (either "normal" seawater or brines concentrated by evaporation), connate water, meteoric water, or some combination of these waters. (Connate refers to water that becomes enclosed within sediments upon their deposition; meteoric water is derived from the atmosphere as rain or snow, which often occurs in pore spaces within rocks.) The fluxing mechanisms are generally attributed to density differences of the solutions involved and the permeability characteristics available for percolation through the precursor sediment. There also are additional direct and indirect controls—*e.g.*, climate, biochemical processes, and HDO:H_2O and/or D_2O:H_2O ratios in the water. (The symbol D represents deuterium, the hydrogen isotope with a nucleus containing one neutron in addition to the single proton of the ordinary hydrogen nucleus.) In any case, it has been shown that some dolostones have gained their current characteristics as a consequence of certain combinations of these conditions and processes.

Conditions of dolomitization

Criteria involving factors such as the identity of associated rocks and the coarseness of the grains of dolostones have been suggested for use in attributing one versus the other hypothesized models to certain occurrences of dolostone. None, however, has been accepted as an absolute criterion by many carbonate petrologists.

The desire for an understanding of dolomitization of sedimentary strata has been based on economic as well as scientific interests. In many places, dolomitization has led to increases in permeability and porosity and thus increased the potential of such rock strata as good oil, gas, and groundwater reservoirs and, in some cases, even as hosts of certain kinds of ore deposits.

The other fairly common dolomite occurrences include the following: Dolostones have been metamorphosed to both dolomite and calcite marbles; dedolomitization processes account for the latter. Some dolomite marbles are nearly pure dolomite. Dolomite carbonatites are of the same general origin as calcite carbonatites (see above *Calcite: Origin and occurrence*). The dolomite present in dolomite veins has also been ascribed diverse origins; some appears to have been deposited by percolating connate or meteoric groundwater, and some seems more likely to have been deposited by hydrothermal solutions charged with magmatic volatiles.

USES

Dolomite is used as a source of magnesium metal and of magnesia (MgO), which is a constituent of refractory bricks. Dolostone is often used instead of limestone as an aggregate for both cement and bitumen mixes and also as a flux in blast furnaces. The use of dolostone as a flux has increased, especially since environmental contamination has become a widely heeded consideration, because the resulting slag can be employed for such things as lightweight aggregate, whereas that formed when limestone is used cannot. Such is the case because dolostone-based slag does not slake (disintegrate in water), but limestone-based slag does.

Use as a flux

Other common rock-forming minerals

The 10 minerals listed above in Table 16 that are not described in the preceding sections are important rock-forming minerals even though they do not make up large percentages of any common rocks. Each of these minerals is a major constituent of some sizable rock masses, occurs widely as an accessory mineral in many common rocks, or assumes both roles. Consequently, they warrant brief description here.

MAGNETITE AND CHROMITE

Magnetite (Fe_3O_4—that is, $Fe^{2+}Fe^{3+}_2O_4$) and chromite ($Fe^{2+}Cr_2O_4$) are both members of the spinel group. The spinels, comprising some 21 species (including the well-known gemstone balas ruby), are cubic (isometric) and commonly occur as octahedrons (Figure 88). Magnetite and chromite are opaque and dark gray to iron-black; magnetite is strongly magnetic. Magnetite and chromite are the major constituents of the rocks called magnetitite and chromitite, respectively. In addition, each is a common accessory mineral in one or more igneous rocks. Magnetite also occurs widely in several metamorphic and sedimentary rocks; one or both of these minerals occur in several placer deposits. Magnetite has been recovered as iron ore; chromite is the only important commercial mineral of chromium.

From R.V. Dietrich and B.J. Skinner, *Rocks and Rock Minerals* (1979), reprinted with permission of John Wiley and Sons, Inc., New York City

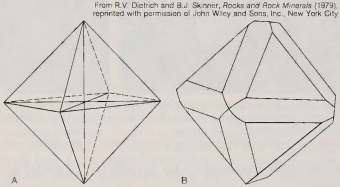


Figure 88: *Typical crystal forms of magnetite.*
(Left) An octahedron and (right) an octahedron modified by dodecahedral faces.

HALITE, GYPSUM, AND ANHYDRITE

Halite (NaCl), gypsum ($CaSO_4 \cdot 2H_2O$), and anhydrite ($CaSO_4$) are the major constituents of the sedimentary rocks rock salt, rock gypsum, and rock anhydrite, respectively. These rocks are usually referred to as evaporites. Halite, the mineral name for common salt, is cubic and is typically colourless or white but may be tinted various colours by impurities. It breaks into cubes because of its three perfect cleavages at right angles to each other and has a characteristic salty taste. Gypsum is monoclinic and commonly occurs as tabular crystals, either simple or twinned, and also forms coarse to fine granular masses. It is typically colourless or white but may be red, orange, brown, or black because of the presence of impurities, and it cleaves into plates that may be bent but are not flexible. Gypsum is so soft (Mohs hardness of 2) that it can be scratched easily with one's fingernail. Anhydrite is orthorhombic and resembles granular dolomite in many rocks, but it does not react with dilute hydrochloric acid. When altered, anhydrite usually takes on a thin coating of white gypsum. Halite has been recovered from rock salt deposits for diverse uses for at least seven millennia. The

Constituents of evaporites



Figure 89: Granitic rock consisting of reddish orange feldspar, nearly white quartz, and green epidote that appears to have been introduced into an original quartz-feldspar granite. This rock, sometimes called unakite, is used widely in jewelry.



Figure 90: (Left) Pyrite (fool's gold) from Spain, exhibiting its typical brassy yellow colour. (Right) Gold specimen from Gross Valley, Calif., U.S., displaying its characteristic golden yellow colour.
National Museum of Natural History, Washington, D.C.; photographs, D. Parsland (NMNH numbers R18657, 121297)

major use of gypsum is for the manufacture of plaster of paris.

EPIDOTE

Epidote is the name given to both a group of minerals and a mineral species. Epidote, the species $[Ca_2(Al, Fe)_3(SiO_4)_3(OH)]$, crystallizes in the monoclinic system. Its presence in rocks is generally recognized on the basis of its yellowish to bilious-green colour (Figure 89). Macroscopically, it is usually distinguished from olivine, which it may closely resemble, on the basis of its association with quartz. Epidote commonly occurs in quartz-bearing metamorphic and igneous rocks, whereas olivine occurs only rarely in rocks that contain quartz. Epidote may be cut as a gem.

HEMATITE

Hematite (α-Fe_2O_3) is hexagonal. Although it is present as silvery-gray, highly lustrous platelike masses in some rocks, it is most widely encountered as the henna-red pigment of many diverse rocks—*e.g.*, red sandstones and many other red beds. Some sedimentary rocks and their metamorphosed products contain such high percentages of hematite that they have been recovered as iron ore. Hematite may also be used as a polishing powder and as a paint pigment.

LIMONITE

Limonite is the catchall name widely applied to hydrous iron oxide minerals. Goethite [α-$Fe^{+}O(OH)$], which is hexagonal, is the most common of these minerals; indeed, in nature most FeO(OH) minerals ultimately become this α-phase. Goethite, much of which has the general colour of iron rust, occurs wherever chemical weathering affects rocks that contain one or more iron-bearing minerals. In some cases, only surficial stains have resulted; in others, masses large enough to constitute iron ore deposits have been formed. Goethite also is common in modern sediments; *e.g.*, it is the typical iron mineral in marine ferromanganese nodules.

PYRITE AND PYRRHOTITE

Common sulfide minerals

Pyrite (FeS_2) and pyrrhotite ($Fe_{1-x}S$) are the most common sulfide minerals. Brassy yellow pyrite (Figure 90), often called "fool's gold," occurs variously as an accessory mineral in many rocks, in veins, and even as a chief component of some fossils. Pyrrhotite, which typically has a bronzelike appearance and is slightly magnetic, is a common accessory mineral in mafic igneous rocks. Both of these minerals, which are associated with each other in some deposits, have yielded large quantities of sulfur recovered for uses such as the production of sulfuric acid.

(R.V.Di.)

THE NATURE OF ROCKS

General considerations

ROCK TYPES

Rocks are, as noted above, aggregates of mineral grains or crystals. They are classified into three major types according to origin: (1) igneous, (2) sedimentary, and (3) metamorphic.

Igneous rocks are those that solidify from a melt (called magma, a molten mixture of rock-forming minerals and usually volatiles such as gases and steam). Since their constituent minerals are crystallized from molten material, igneous rocks are formed at high temperatures. They originate from processes deep within the Earth—typically at depths of about 50 to 200 kilometres (30 to 120 miles)—in the mid- to lower-crust or in the upper mantle. Igneous rocks are subdivided into two categories: intrusive (emplaced in the crust), and extrusive (extruded onto the surface of the land or ocean bottom), in which case the cooling molten material is called lava.

Sedimentary rocks are those that are deposited and lithified (compacted and cemented together) at the Earth's surface, with the assistance of running water, wind, ice, or living organisms. Most are deposited from the land surface to the bottoms of lakes, rivers, and oceans. Sedimentary rocks are generally stratified—*i.e.*, they have layering. Layers may be distinguished by differences in colour, particle size, type of cement, or internal arrangement.

Metamorphic rocks are those formed by changes in pre-existing rocks under the influence of high temperature, pressure, and chemically active solutions. The changes can be chemical (compositional) and physical (textural) in character. Metamorphic rocks are formed by processes deep within the Earth that produce new minerals, textures, and crystal structures. The recrystallization that takes place does so essentially in the solid state, rather than by complete remelting, and can be aided by ductile deformation and the presence of interstitial fluids such as water. Metamorphism often produces apparent layering, or banding, because of the segregation of minerals into separate bands.

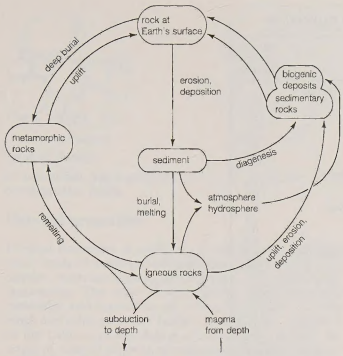


Figure 91: The rock cycle.

ROCK CYCLE

Geologic materials—mineral crystals and their host rock types—are cycled through various forms. The process depends on temperature, pressure, time, and changes in environmental conditions in the Earth's crust and at its surface. The rock cycle illustrated in Figure 91 reflects the basic relationships among igneous, metamorphic, and sedimentary rocks. Erosion includes weathering (the physical and chemical breakdown of minerals) and transportation to a site of deposition. Diagenesis is, as previously explained, the process of forming sedimentary rock by compaction and natural cementation of grains, or crystallization from water or solutions, or recrystallization. The conversion of sediment to rock is termed lithification.

ABUNDANCE OF ROCK TYPES

An estimate of the distribution of rock types in large structural units of the terrestrial crust is given in Table 30. The relative abundance of main rock types and minerals in the crust is shown in Table 31.

Texture

The texture of a rock is the size, shape, and arrangement of the grains (for sedimentary rocks) or crystals (for igneous and metamorphic rocks). Also of importance are the rock's extent of homogeneity (*i.e.*, uniformity of composition throughout) and the degree of isotropy. The latter is the extent to which the bulk structure and composition are the same in all directions in the rock.

Analysis of texture can yield information about the rock's source material, conditions and environment of deposition (for sedimentary rock) or crystallization and recrystallization (for igneous and metamorphic rock, respectively), and subsequent geologic history and change.

The common textural terms used for rock types with respect to the size of the grains or crystals, are given in Table 32. The particle-size categories are derived from the Udden-Wentworth scale developed for sediment. For igneous and metamorphic rocks, the terms are generally used as modifiers—*e.g.*, medium-grained granite. Aphanitic is a descriptive term for small crystals, and phaneritic for larger ones. Very coarse crystals (those larger than 3 centimetres, or 1.2 inches) are termed pegmatitic.

Udden-Wentworth scale

For sedimentary rocks, the broad categories of sediment size are coarse (greater than 2 millimetres, or 0.08 inch), medium (between 2 and $^1/_{16}$ millimetres), and fine (under $^1/_{16}$ millimetre). The latter includes silt and clay, which both have a size indistinguishable by the human eye and are also termed dust. Most shales (the lithified version of clay) contain some silt. Pyroclastic rocks are those formed from clastic (from the Greek word for broken) material ejected from volcanoes. Blocks are fragments broken from solid rock, while bombs are molten when ejected.

The term rock refers to the bulk volume of the material, including the grains or crystals as well as the contained void space. The volumetric portion of bulk rock that is not occupied by grains, crystals, or natural cementing material is termed porosity. That is to say, porosity is the ratio of void volume to the bulk volume (grains plus void space). This void space consists of pore space between grains or crystals, in addition to crack space. In sedimentary rocks, the amount of pore space depends on the degree of compaction of the sediment (with compaction generally increasing with depth of burial), on the packing arrangement and shape of grains, on the amount of cementation, and on the degree of sorting. Typical cements are siliceous, calcareous or carbonate, or iron-bearing minerals.

Table 30: Distribution of Rock Types in Large Structural Units of the Earth's Crust

crustal layers	average thickness (in kilometres)	volume (in cubic kilometres)	mass (10^{24} grams)	rock types and abundances (percent volume of layer)
Continental platform				
Sedimentary	1.8	135	0.35	sands, 23.6; clays, 49.5; carbonates, 21; evaporites, 2; basalts, 3.9
Continental geosynclinal folded belts				
Sedimentary	10.0	365	0.94	sands, 18.7; clays and shales, 39.4; carbonates, 16.3; evaporites, 0.3; basalts, 12.6; andesites, 10.2; rhyolites, 2.5
Subcontinental, shelf and slope				
Sedimentary	2.9	190	0.48	similar to above groups
Continental and subcontinental				
Granitic		3,590	9.81	granites, 18.1; granodiorites, 19.9: syenites, 0.3; gabbro, 3.7; peridotites, 0.1; gneisses, 37.6; schists, 9.0; marble, 1.5; amphibolite, 9.8
(continental)	20.1			
(subcontinental)	9.1			
Basaltic		3,760	10.91	acid igneous and metamorphic rocks, 50; basic igneous and metamorphic rocks, 50
(continental)	20.1			
(subcontinental)	11.7			
Oceanic				
Layer 1 (sedimentary)	0.4	120	0.19	(percent by area) terrigenous, 7.3; calcareous, 41.5; siliceous, 17; red clays, 31.2
Layer 2	0.6	175	0.44	(percent by volume) sediments, 50
	0.6	175	0.52	(percent by volume) basalts, 50
Layer 3	5.7	1,700	4.92	(percent by volume) oceanic tholeiitic basalts, 99; alkaline differentiates, 1

Source: After data from A.B. Ronov and A.A. Yaroshevsky, 1969, in Peter J. Wyllie, *The Dynamic Earth*, John Wiley and Sons (1971).

Table 31: Abundances of Main Rock Types and Minerals in the Earth's Crust

rocks	percent volume of crust	minerals	percent volume of crust
Sedimentary		**Constituents of sedimentary rocks**	
Sands	1.7	Quartz	12
Clays and shales	4.2	Alkali feldspar	12
Carbonates (including salt)	2.0	Plagioclase feldspar	39
	7.9	Micas	5
Igneous		Amphiboles	5
Granite	10.4		73
Granodiorite, diorite	11.2	**Constituents of igneous rocks**	
Syenite	0.4	Pyroxene	11.0
Basalt, gabbro, amphibolite, eclogite	42.5	Olivine	3.0
Dunite, peridotite	0.2	Clay minerals (and chlorite)	4.6
	64.7	Calcite	1.5
Metamorphic		Dolomite	0.5
Gneiss	21.4	(Titano) magnetite	1.5
Schist	5.1	Others (garnet, kyanite, apatite, etc.)	4.9
Marble	0.9		27.0
	27.4	**Totals**	
Totals		Quartz and feldspar	63
Sedimentary	7.9	Pyroxene and olivine	14
Igneous	64.7	Hydrated silicates	14.6
Metamorphic	27.4	Carbonates	2.0
	100.0	Others	6.4
			100.0

Source: After data from A.B. Ronov and A.A. Yaroshevsky, 1969, in Peter J. Wyllie, *The Dynamic Earth*, John Wiley and Sons, (1971).

Sorting

Sorting is the tendency of sedimentary rocks to have grains that are similarly sized—*i.e.*, to have a narrow range of sizes (see Figure 92). Poorly sorted sediment displays a wide range of grain sizes and hence has decreased porosity. Well-sorted indicates a grain size distribution that is fairly uniform. Depending on the type of close-packing of the grains, porosity can be substantial. It should be noted that in engineering usage—*e.g.*, geotechnical or civil engineering—the terminology is phrased oppositely and is referred to as grading. A well-graded sediment is a (geologically) poorly sorted one, and a poorly graded sediment is a well-sorted one.

Total porosity encompasses all the void space, including those pores that are interconnected to the surface of the sample as well as those that are sealed off by natural cement or other obstructions. Thus the total porosity (φ_T) is

$$\varphi_T = 100\left(1 - \frac{\text{Vol}_G}{\text{Vol}_B}\right)\%,$$

where Vol_G is the volume of grains (and cement, if any) and Vol_B is the total bulk volume. Alternatively, one can calculate φ_T from the measured densities of the bulk rock and of the (mono)mineralic constituent. Thus,

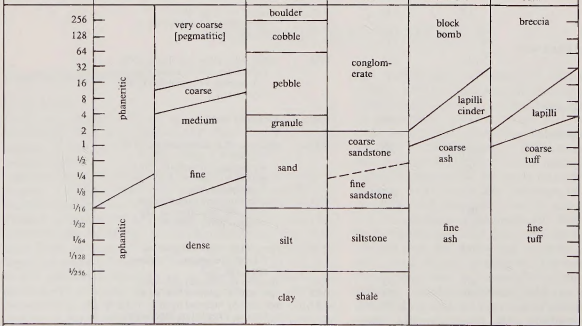
$$\varphi_T = 100\left(1 - \frac{\rho_B}{\rho_G}\right)\%,$$

where ρ_B is the density of the bulk rock and ρ_G is the density of the grains (*i.e.*, the mineral, if the composition is monomineralogic and homogeneous). For example, if a sandstone has a ρ_B of 2.38 grams per cubic centimetre (g/cm^3) and is composed of quartz (SiO_2) grains having ρ_G of 2.65 g/cm^3, the total porosity is

$$\varphi_T = 100\left(1 - \frac{2.38}{2.65}\right) = 10.2\%.$$

Apparent (effective, or net) porosity is the proportion of void space that excludes the sealed-off pores. It thus measures the pore volume that is effectively interconnected and accessible to the surface of the sample, which is important when considering the storage and movement

Table 32: Common Textural Terms for Rocks*



*Diagonal lines in the table reflect the variability in size limits of certain grades resulting from the use of different values by different authors.

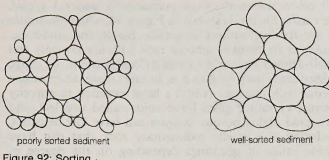


Figure 92: Sorting.

of subsurface fluids such as petroleum, groundwater, or contaminated fluids.

Physical properties

Physical properties of rocks are of interest and utility in many fields of work, including geology, petrophysics, geophysics, materials science, geochemistry, and geotechnical engineering. The scale of investigation ranges from the molecular and crystalline up to terrestrial studies of the Earth and other planetary bodies. Geologists are interested in the radioactive age dating of rocks to reconstruct the origin of mineral deposits; seismologists formulate prospective earthquake predictions using premonitory physical or chemical changes; crystallographers study the synthesis of minerals with special optical or physical properties; exploration geophysicists investigate the variation of physical properties of subsurface rocks to make possible detection of natural resources such as oil and gas, geothermal energy, and ores of metals; geotechnical engineers examine the nature and behaviour of the materials on, in, or of which such structures as buildings, dams, tunnels, bridges, and underground storage vaults are to be constructed; solid-state physicists study the magnetic, electrical, and mechanical properties of materials for electronic devices, computer components, or high-performance ceramics; and petroleum reservoir engineers analyze the response measured on well logs or in the processes of deep drilling at elevated temperature and pressure.

Mineral properties

Since rocks are aggregates of mineral grains or crystals, their properties are determined in large part by the properties of their various constituent minerals. In a rock these general properties are determined by averaging the relative properties and sometimes orientations of the various grains or crystals. As a result, some properties that are anisotropic (*i.e.*, differ with direction) on a submicroscopic or crystalline scale are fairly isotropic for a large bulk volume of the rock. Many properties are also dependent on grain or crystal size, shape, and packing arrangement, the amount and distribution of void space, the presence of natural cements in sedimentary rocks, the temperature and pressure, and the type and amount of contained fluids (*e.g.*, water, petroleum, gases). Because many rocks exhibit a considerable range in these factors, the assignment of representative values for a particular property is often done using a statistical variation.

Some properties can vary considerably, depending on whether measured in situ (in place in the subsurface) or in the laboratory under simulated conditions. Electrical resistivity, for example, is highly dependent on the fluid content of the rock in situ and the temperature condition at the particular depth.

DENSITY

Density varies significantly among different rock types because of differences in mineralogy and porosity. Knowledge of the distribution of underground rock densities can assist in interpreting subsurface geologic structure and rock type.

In strict usage, density is defined as the mass of a substance per unit volume; however, in common usage, it is taken to be the weight in air of a unit volume of a sample at a specific temperature. Weight is the force that gravitation exerts on a body (and thus varies with location), whereas mass (a measure of the matter in a body) is a fundamental property and is constant regardless of location. In routine density measurements of rocks, the sample weights are considered to be equivalent to their masses, because the discrepancy between weight and mass would result in less error on the computed density than the experimental errors introduced in the measurement of volume. Thus, density is often determined using weight rather than mass. Density should properly be reported in kilograms per cubic metre (kg/m^3), but is still often given in grams per cubic centimetre (g/cm^3).

Table 33: Dry Bulk Densities for Various Rock Types

rock type	number of samples	mean (g/cm^3)	standard deviation	mode (g/cm^3)	median (g/cm^3)
All rocks	1647	2.73	0.26	2.65	2.86
Andesite	197	2.65	0.13	2.58	2.66
Basalt	323	2.74	0.47	2.88	2.87
Diorite	68	2.86	0.12	2.89	2.87
Dolerite (diabase)	224	2.89	0.13	2.96	2.90
Gabbro	98	2.95	0.14	2.99	2.97
Granite	334	2.66	0.06	2.66	2.66
Quartz porphyry	76	2.62	0.06	2.60	2.62
Rhyolite	94	2.51	0.13	2.60	2.49
Syenite	93	2.70	0.10	2.67	2.68
Trachyte	71	2.57	0.10	2.62	2.57
Sandstone	107	2.22	0.23	2.22	2.22

Source: After data from H.S. Washington (1917) and R.J. Piersol, L.E. Workman, and M.C. Watson (1940) as compiled by Gary R. Olhoeft and Gordon R. Johnson in Robert S. Carmichael, ed., *Handbook of Physical Properties of Rocks*, vol. III, CRC Press, Inc. (1984).

Specific gravity

Another property closely related to density is specific gravity. It is defined, as noted above, as the ratio of the weight or mass in air of a unit volume of material at a stated temperature to the weight or mass in air of a unit volume of distilled water at the same temperature. Specific gravity is dimensionless (*i.e.*, has no units).

The bulk density of a rock is $\rho_B = W_G/V_B$, where W_G is the weight of grains (sedimentary rocks) or crystals (igneous and metamorphic rocks) and natural cements, if any, and V_B is the total volume of the grains or crystals plus the void (pore) space. The density can be dry if the pore space is empty, or it can be saturated if the pores are filled with fluid (*e.g.*, water), which is more typical of the subsurface (in situ) situation. If there is pore fluid present,

$$\text{(saturated) } \rho_B = \frac{W_G + W_{fl}}{V_B},$$

where W_{fl} is the weight of pore fluid. In terms of total porosity, saturated density is

$$\text{(saturated) } \rho_B = \rho_G(1 - \varphi_T) + \rho_{fl}\varphi_T,$$

and thus

$$\varphi_T = \frac{\rho_G - \rho_B}{\rho_G - \rho_{fl}},$$

Table 34: Typical Density Ranges for Some Other Rock Types

rock type	density (g/cm^3)
Amphibolite	2.79–3.14
Andesite glass	2.40–2.57
Anhydrite	2.82–2.93
Anorthosite	2.64–2.92
Basalt glass	2.70–2.85
Chalk	2.23
Dolomite	2.72–2.84
Dunite	2.98–3.76
Eclogite	3.32–3.45
Gneiss	2.59–2.84
Granodiorite	2.67–2.78
Limestone	1.55–2.75
Marble	2.67–2.75
Norite	2.72–3.02
Peridotite	3.15–3.28
Quartzite	2.65
Rock salt	2.10–2.20
Schist	2.73–3.19
Shale	2.06–2.67
Slate	2.72–2.84

Source: After data from R.A. Daly, G.E. Manger, and S.P. Clark, Jr. (1966); A.F. Birch (1966); F. Press (1966); and R.N. Schock, B.P. Bonner, and H. Louis (1974) in Robert S. Carmichael, ed., *Handbook of Physical Properties of Rocks*, vol. III, CRC Press, Inc. (1984).

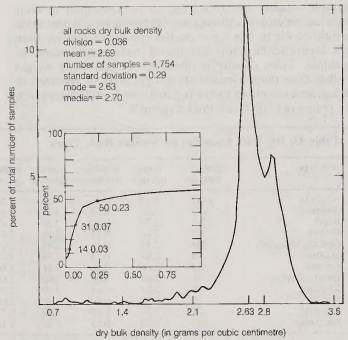


Figure 93: Dry bulk densities (distribution with density) for all rocks given in Table 33.

From G. Johnson and G. Olhoeft in R.S. Carmichael (ed.), *Handbook of Physical Properties of Rocks*, vol. III (1984), CRC Press, Inc., Boca Raton, Florida

where ρ_f is the density of the pore fluid. Density measurements for a given specimen involve the determination of any two of the following quantities: pore volume, bulk volume, or grain volume, along with the weight.

A useful way to assess the density of rocks is to make a histogram plot of the statistical range of a set of data. The representative value and its variation can be expressed as follows: (1) mean, the average value, (2) mode, the most common value (*i.e.*, the peak of the distribution curve), (3) median, the value of the middle sample of the data set (*i.e.*, the value at which half of the samples are below and half are above), and (4) standard deviation, a statistical measure of the spread of the data (plus and minus one standard deviation from the mean value includes about two-thirds of the data).

Dry bulk densities

A compilation of dry bulk densities for various rock types found in the upper crust of the Earth is listed in Table 33. A histogram plot of these data, giving the percent of the samples as a function of density is shown in Figure 93. The parameters given include (1) sample division, the range of density in one data column—*e.g.*, 0.036 g/cm³ for Figure 93, (2) number of samples, and (3) standard deviation. The small inset plot is the percentage of samples (on the vertical axis) that lie within the interval of the "mode − x" to the "mode + x," where x is the horizontal axis.

In Figure 93, the most common (modal) value of the distribution falls at 2.63 g/cm³, roughly the density of quartz, an abundant rock-forming mineral. Few density values for these upper crustal rocks lie above 3.3 g/cm³. A few fall well below the mode, even occasionally under 1 g/cm³. The reason for this is shown in Figure 94, which illustrates the density distributions for granite, basalt, and sandstone. Granite is an intrusive igneous rock with low porosity and a well-defined chemical (mineral) composition; its range of densities is narrow. Basalt is, in most cases, an extrusive igneous rock that can exhibit a large variation in porosity (because entrained gases leave voids called vesicles), and thus some highly porous samples can have low densities. Sandstone is a clastic sedimentary rock that can have a wide range of porosities depending on the degree of sorting, compaction, packing arrangement of grains, and cementation. The bulk density varies accordingly.

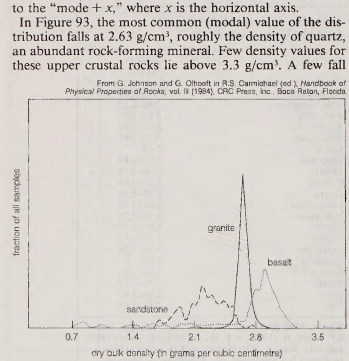


Figure 94: Dry density distribution of three different rock types: basalt, granite, and sandstone.

Other distribution plots of dry bulk densities are given in Figures 95 and 96, with a sample division of 0.036 g/cm³ for Figures 95 and 96A and of 0.828 percent for Figure 96B. Table 34 lists typical ranges of dry bulk densities for a variety of other rock types as prepared by the American geologists Gordon R. Johnson and Gary R. Olhoeft.

The density of clastic sedimentary rocks increases as the rocks are progressively buried. This is because of the increase of overburden pressure, which causes compaction, and the progressive cementation with age. Both compaction and cementation decrease the porosity.

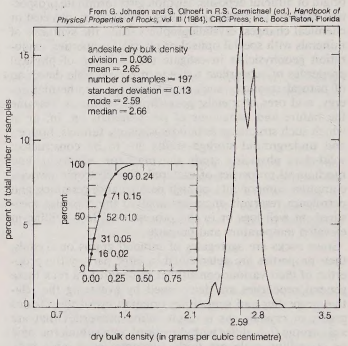


Figure 95: Density distribution for andesite.

Representative densities for common rock-forming minerals (*i.e.*, ρ_G) and rocks (*i.e.*, ρ_B) are listed in Table 35. The bulk densities for sedimentary rocks, which typically have variable porosity, are given as ranges of both dry ρ_B and (water-) saturated ρ_B. The pore-filling fluid is usually briny water, often indicative of the presence of seawater when the rock was being deposited or lithified. It should be noted that the bulk density is less than the grain density of the constituent mineral (or mineral assemblage), depending on the porosity. For example, sandstone (characteristically quartzose) has a typical dry bulk density of 2.0–2.6 g/cm³, with a porosity that can vary from low to more than 30 percent. The density of quartz itself is 2.65 g/cm³. If porosity were zero, the bulk density would equal the grain density.

Saturated bulk density is higher than dry bulk density, owing to the added presence of pore-filling fluid. Table 35 also lists representative values for density of seawater, oil, and methane gas at a subsurface condition—pressure of 200 bars (one bar = 0.987 atmosphere, or 29.53 inches of mercury) and a temperature of about 80° C (176° F).

MECHANICAL PROPERTIES

Stress and strain

When a stress σ (force per unit area) is applied to a material such as rock, the material experiences a change in dimension, volume, or shape. This change, or deformation, is called strain (ε). Stresses can be axial—*e.g.*, directional tension or simple compression—or shear (tangential), or all-sided (*e.g.*, hydrostatic compression). The terms stress

Table 35: Typical Densities

material		ρ (g/cm^3)	
minerals (approximately pure, no porosity)		ρ_G	
Halite ($NaCl$)		2.16	
Gypsum ($CaSO_4 \cdot 2H_2O$)		2.32	
Orthoclase feldspar ($KAlSi_3O_8$)		2.56	
Quartz (SiO_2)		2.65	
Calcite ($CaCO_3$)		2.71	
Anhydrite ($CaSO_4$)		2.9	
Olivine ($Mg, Fe)_2SiO_4$		3.3–3.6	
Hematite (Fe_2O_3)		5.26	
rocks (surface T and P)	typical porosity	dry ρ_B	saturated ρ_B
Loess		1.1	1.4–1.6
Silt		1.36	1.4–1.8
Rock salt		2.2	—
Shale	≥ 8%	1.9–2.4	2.1–2.5
Sandstone	~15%, variable	2.0–2.6	2.2–2.6
Limestone	~5%	1.9–2.6	2.1–2.7
Dolomite		2.5–2.8	2.6–2.8
Granite-diorite		2.6–2.9	
Gabbro-diabase		2.8–3.1	
Dunite-peridotite		3.1–3.4	
Granite; sial crust		2.67	
Basalt; sima crust		2.87	
Top of mantle		3.32	
other		ρ	
Water (0° C)		0.99987	
20° C		0.99823	
100° C		0.95841	
Seawater (0° C)		1.025	
Ice		0.92	
Oil		~0.8–0.9	
Methane gas (at 200 bars, T~80° C)		~0.12	

Rock mechanics

The study of deformation resulting from the strain of rocks in response to stresses is called rock mechanics. When the scale of the deformation is extended to large geologic structures in the crust of the Earth, the field of study is known as geotectonics.

The mechanisms and character of the deformation of rocks and Earth materials can be investigated through laboratory experiments, development of theoretical models based on the properties of materials, and study of deformed rocks and structures in the field. In the laboratory, one can simulate—either directly or by appropriate scaling of experimental parameters—several conditions. Two types of pressure may be simulated: confining (hydrostatic), due to burial under rock overburden, and internal (pore), due to pressure exerted by pore fluids contained in void space in the rock. Directed applied stress, such as compression, tension, and shear, is studied, as are the effects of increased temperature introduced with depth in the Earth's crust. The effects of the duration of time and the rate of applying stress (*i.e.*, loading) as a function of time are examined. Also, the role of fluids, particularly if they are chemically active, is investigated.

A simple apparatus for deforming rocks is shown schematically in Figure 97. This is for biaxial stress application: a directed (uniaxial) compression is applied while a confining pressure is exerted (by pressurized fluid) around the cylindrical specimen. This simulates deformation at depth within the Earth. An independent internal pore-fluid pressure also can be exerted. The rock specimen can be jacketed with a thin, impermeable sleeve (*e.g.*, rubber or copper) to separate the external pressure medium from the internal pore fluids (if any). The specimen is typically a few centimetres in dimension.

and pressure are sometimes used interchangeably, but often stress refers to directional stress or shear stress and pressure (P) refers to hydrostatic compression. For small stresses, the strain is elastic (recoverable when the stress is removed and linearly proportional to the applied stress). For larger stresses and other conditions, the strain can be inelastic, or permanent.

Elastic constants

In elastic deformation, there are various constants that relate the magnitude of the strain response to the applied stress. These elastic constants include the following:

(1) Young's modulus (E) is the ratio of the applied stress to the fractional extension (or shortening) of the sample length parallel to the tension (or compression). The strain is the linear change in dimension divided by the original length.

(2) Shear modulus (μ) is the ratio of the applied stress to the distortion (rotation) of a plane originally perpendicular to the applied shear stress; it is also termed the modulus of rigidity.

(3) Bulk modulus (k) is the ratio of the confining pressure to the fractional reduction of volume in response to the applied hydrostatic pressure. The volume strain is the change in volume of the sample divided by the original volume. Bulk modulus is also termed the modulus of incompressibility.

(4) Poisson's ratio (σ_p) is the ratio of lateral strain (perpendicular to an applied stress) to the longitudinal strain (parallel to applied stress).

For elastic and isotropic materials, the elastic constants are interrelated. For example,

$$\sigma_p = \frac{E}{2\mu} - 1;$$

$$E = 3k(1 - 2\sigma_p);$$

and

$$\mu = \frac{3}{2}k\left(\frac{1 - 2\sigma_p}{1 + \sigma_p}\right).$$

The following are the common units of stress:

1 bar = 10^6 dynes per square centimetre
= 10^5 newtons per square metre, or pascals (Pa)
= 0.1 megapascal (*i.e.*, 0.1×10^6 Pa).

Thus 10 kilobars = 1 gigapascal (*i.e.*, 10^9 Pa).

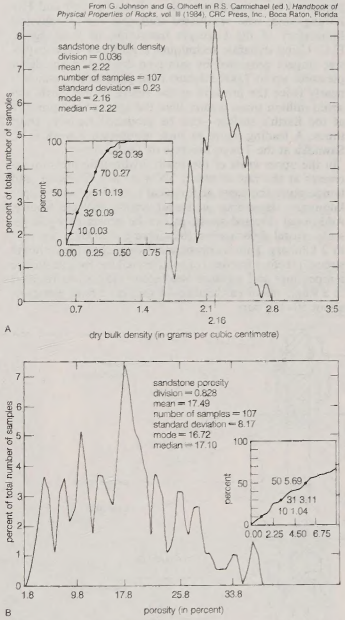


Figure 96: *Histograms for sandstone.*
(A) Density distribution. (B) Porosity distribution for (A).

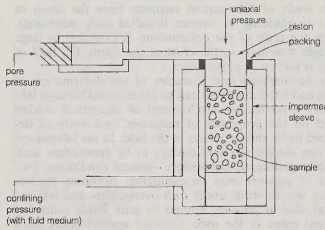


Figure 97: Simple experimental apparatus for use in rock mechanics studies.

Another apparatus for exerting high pressure on a sample is shown in Figure 98. It was designed in 1968 by Akira Sawaoka, Naoto Kawai, and Robert Carmichael to give hydrostatic confining pressures up to 12 kilobars (1.2 gigapascal), additional directed stress, and temperatures up to a few hundred degrees Celsius. The specimen is positioned on the baseplate; the pressure is applied by driving in pistons with a hydraulic press. The end caps can be locked down to hold the pressure for time experiments and to make the device portable.

Apparatuses have been developed, typically using multi-anvil designs, which extend the range of static experimental conditions—at least for small specimens and limited times—to pressures as high as about 1,700 kilobars and temperatures of about 2,000° C. Such work has been pioneered by researchers such as Peter M. Bell and Ho-Kwang Mao, who conducted studies at the Geophysical Laboratory of the Carnegie Institution in Washington, D.C. Using dynamic techniques (*i.e.*, shock from explosive impact generated by gun-type designs), even higher pressures up to 7,000 kilobars (700 gigapascal)—which is nearly twice the pressure at the centre of the Earth and seven million times greater than the atmospheric pressure at the Earth's surface—can be produced for very short times. A leading figure in such ultrapressure work is A. Sawaoka at the Tokyo Institute of Technology.

Ultra-pressure work

In the upper crust of the Earth, hydrostatic pressure increases at the rate of about 320 bars per kilometre, and temperature increases at a typical rate of 20°–40° C per kilometre, depending on recent crustal geologic history. Additional directed stress, as can be generated by large-scale crustal deformation (tectonism), can range up to 1 to 2 kilobars. This is approximately equal to the ultimate strength (before fracture) of solid crystalline rock at surface temperature and pressure (see below). The stress released in a single major earthquake—a shift on a fault plane—is about 50–150 bars.

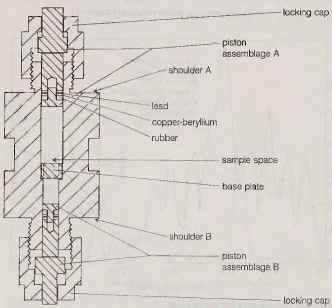


Figure 98: Cross section of a high-pressure "bomb" (see text).

In studying the deformation of rocks one can start with the assumption of ideal behaviour: elastic strain and homogeneous and isotropic stress and strain. In reality, on a microscopic scale there are grains and pores in sediments and a fabric of crystals in igneous and metamorphic rocks. On a large scale, rock bodies exhibit physical and chemical variations and structural features. Furthermore, conditions such as extended length of time, confining pressure, and subsurface fluids affect the rates of change of deformation. Figure 99 shows the generalized transition from brittle fracture through faulting to plastic-flow deformation in response to applied compressional stress and the progressive increase of confining pressure.

The deformation of materials is characterized by stress-strain relations. For elastic-behaviour materials, the strain is proportional to the load (*i.e.*, the applied stress). The strain is immediate with stress and is reversible (recoverable) up to the yield point stress, beyond which permanent strain results. For viscous material, there is laminar (slow, smooth, parallel) flow; one must exert a force to maintain motion because of internal frictional resistance to flow, called the viscosity. Viscosity varies with the applied stress, strain rate, and temperature. In plastic behaviour, the material strains continuously (but still has strength) after the yield point stress is reached; however, beyond this point there is some permanent deformation. In elasticoviscous deformation, there is combined elastic and viscous behaviour. The material yields continuously (viscously) for a constant applied load. An example of such behaviour is creep, a slow, permanent, and continuous deformation occurring under constant load over a long time in such materials as crystals, ice, soil and sediment, and rocks at depth. In firmoviscous behaviour, the material is essentially solid but the strain is not immediate with application of stress; rather, it is taken up and released exponentially. A plasticoviscous material exhibits elastic behaviour for initial stress (as in plastic behaviour), but after the yield point stress is reached, it flows like a viscous fluid.

Creep

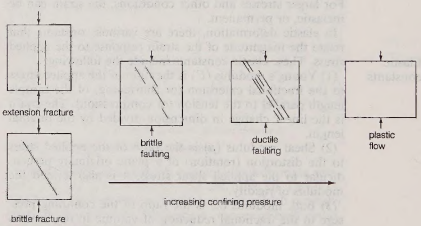


Figure 99: Deformation as affected by increased confining pressure.

Some representative values of elastic constants and properties are listed in Table 36. The coefficient of viscosity (η) is the ratio of applied stress to the rate of straining (change of strain with time). It is measured in units of poise; one poise equals one dyne-second per square centimetre.

Rheology is the study of the flow deformation of materials. The concept of rheidity refers to the capacity of a material to flow, arbitrarily defined as the time required with a shear stress applied for the viscous strain to be 1,000 times greater than the elastic strain. It is thus a measure of the threshold of fluidlike behaviour. Although such behaviour depends on temperature, relative comparisons can be made. Some representative values of rheidity times are given in Table 37.

Typical stress-strain (deformation) curves for rock materials are shown in Figure 100. The stress σ, compression in the figure, is force per unit area. The strain ε is fractional shortening of the specimen parallel to the applied compression; it is given here in percent. The brittle material behaves elastically nearly until the point of fracture (denoted X), whereas the ductile (plastically deformable) material is elastic up to the yield point but then has a

Table 36: Some Typical Values of Elastic Constants and Properties

material	elastic constants (at room temperature and pressure) Young's modulus E (in 10^6 bars)	shear modulus μ (in 10^6 bars)
Ice	0.1	0.03
Shale	0.2–0.3	0.15
Limestone	0.4–0.7	0.22–0.26
Granite	0.3–0.6	0.2
Basalt	0.7–0.9	0.3
Steel	2.1	0.83
material	**temperature (°C)**	**coefficient of viscosity η (poises)**
Lava (Mount Vesuvius)	1,100	28,300
	1,400	250
Lava (Oshima, Japan)	1,038	230,000
	1,125	5,600
Andesite lava	1,400	150–1,500
material	**compressive strength (at room temperature and pressure, in kilobars)**	
Shale	0.8–1.8	
Sandstone	0.5–2	
Limestone	1–2	
Granite	1.7–2.5	
Basalt	1–3.4	

range of plastic deformation before fracturing. The ability to undergo large permanent deformation before fracture is called ductility. For plastic deformation, the flow mechanisms are intracrystalline (slip and twinning within crystal grains), intercrystalline motion by crushing and fracture (cataclasis), and recrystallization by solutioning or solid diffusion.

If the applied stress is removed while a ductile material is in the plastic range, part of the strain is recoverable (elastically), but there is permanent deformation. The ultimate strength is the highest point (stress) on a stress-strain curve, often occurring at fracture (which is the complete loss of cohesion). The strength of a material is its resistance to failure (destruction of structure) by flow or fracture; it is a measure of the stress required to deform a body. Typical compressive strengths (the stress required to cause failure under compression) are given in Table 36.

Ultimate strength

Table 37: Rheidity Threshold of Fluidlike Deformation

material	approximate time
Ice (*e.g.*, glacier)	2 weeks
Gypsum	1 year
Rock salt (*e.g.*, salt dome)	10–20 years
Serpentine (a mafic silicate mineral)	10,000 years

The behaviour and mechanical properties of rocks depend on a number of environmental conditions. (1) Confining pressure increases the elasticity, strength (*e.g.*, yield point and ultimate fracture stress), and ductility. (2) Internal pore-fluid pressure reduces the effective stress acting on the sample, thus reducing the strength and ductility. The effective, or net, confining pressure is the external hydrostatic pressure minus the internal pore-fluid pressure. (3) Temperature lowers the strength, enhances ductility, and may enhance recrystallization. (4) Fluid solutions can enhance deformation, creep, and recrystallization. (5) Time is an influential factor as well. (6) The rate of loading (*i.e.*, the rate at which stress is applied) influences mechanical properties. (7) Compaction, as would occur with burial to depth, reduces the volume of pore space for sedimentary rocks and the crack porosity for crystalline rocks.

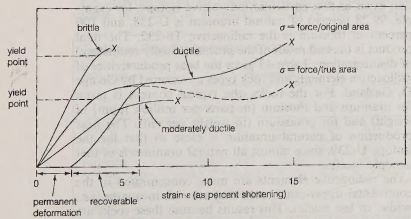


Figure 100: Typical stress-strain curves for rock materials. Each *X* represents the point of fracture for the corresponding material.

Rocks, which are typically brittle at the Earth's surface, can undergo ductile deformation when buried and subjected to increased confining pressure and temperature for long periods of time. If stress exceeds their strength or if they are not sufficiently ductile, they will fail by fracture—as a crystal, within a bed or rock, on an earthquake fault zone, and so on—whereas with ductility they can flow and fold.

Some strengths for various rock types under different temperatures and confining pressures are listed in Table 38. The plastic yield strength here is the stress at a 2 percent strain; the ultimate strength, as stated above, is the highest point (stress) on the stress-strain curve.

An increase in confining pressure causes brittle fracture to become shear slippage and eventually causes flow (ductile) behaviour. This transition is also aided by higher temperature, decreased internal pore-fluid pressure, and slower strain rate.

Table 38: Rock Strengths, with Varying Temperature and Pressure

rock type	temperature (°C)	confining pressure (kilobars)	plastic yield strength (kilobars)	ultimate strength (kilobars)
Granite	500	5	10	11.5
	800	5	5	6
Gabbro	500	5	4	8
Peridotite	500	5	8	9
	800	5	5.5	8
Basalt	500	5	8	10
	800	5	2	2.5
Marble	24	2	2.5	5.5
	500	3	1	2
Limestone	24	2	4.5	5.5
	500	3	2.5	3
Dolomite	24	2	6	7
	500	5	4	6.5
Shale	24	2	1.5	2.5
Rock salt	24	1	0.5	1

Table 39 gives the values of some elastic constants—bulk modulus (k), Young's modulus (E), shear modulus (μ), and Poisson's ratio (σ_p)—at room pressure (1 bar) and high confining pressure (3,000 bars). The values for clastic sedimentary rocks would be particularly variable.

Table 39: Variation of Some Elastic Constants (in 10^6 bars) with Rock Type and Confining Pressure

rock type	at pressure = 1 bar k	E	μ	σ_p	at pressure = 3,000 bars k	E	μ	σ_p
Granite	0.1	0.3	0.2	0.05	0.5	0.6	0.4	0.25
Gabbro	0.3	0.9	0.6	0.1	0.9	0.8	0.5	0.2
Dunite	1.1	1.5	0.5	0.3	1.2	1.7	0.7	0.27
Obsidian	0.4	0.7	0.3	0.08				
Basalt	0.5	0.8	0.3	0.23	0.8	1.2	0.4	0.25
Gneiss	0.1	0.2	0.1	0.05	0.5	0.7	0.3	
Marble	0.1	0.4	0.2	0.1	0.8	0.7	0.3	0.3
Quartzite					0.5	1.0	0.4	0.07
Sandstone	0.07	0.2	0.08	0.1				
Shale	0.04	0.1	0.05	0.04				
Limestone	0.8	0.6	0.2	0.3				

THERMAL PROPERTIES

Flux

Heat flow (or flux), q, in the Earth's crust or in rock as a building material, is the product of the temperature gradient (change in temperature per unit distance) and the material's thermal conductivity (k, the heat flow across a surface per unit area per unit time when a temperature difference exists in unit length perpendicular to the surface). Thus,

$$q = \frac{dT}{dz} \times k.$$

The units of the terms in this equation are given below, expressed first in the centimetre-gram-second (cgs) system and then in the International System of Units (SI) system, with the conversion factor from the first to the second given between them.

q, heat flow:
calories per square centimetre per second (cal/cm² · sec) $\times \frac{1}{23.9} \times 10^{-6} =$ watts per square metre (W/m²)

$\frac{dT}{dz}$, temperature gradient:
degrees Celsius per kilometre (°C/km, practical unit for Earth) $\times 10^{-3} =$ degrees Celsius per metre (°C/m)

k, thermal conductivity:
calories per square centimetre per second per degree Celsius (cal/cm² · sec · °C) $\times \frac{1}{23.9} \times 10^{-3} =$ watts per metre per degree Celsius (W/m · °C)

Thermal conductivity. Thermal conductivity can be determined in the laboratory or in situ, as in a borehole or deep well, by turning on a heating element and measuring the rise in temperature with time. It depends on several factors: (1) chemical composition of the rock (*i.e.*, mineral content), (2) fluid content (type and degree of saturation of the pore space); the presence of water increases the thermal conductivity (*i.e.*, enhances the flow of heat), (3) pressure (a high pressure increases the thermal conductivity by closing cracks which inhibit heat flow), (4) temperature, and (5) isotropy and homogeneity of the rock.

Typical values of thermal conductivities of rock materials are given in Table 40. For crystalline silicate rocks—the dominant rocks of the "basement" crustal rocks—the lower values are typical of ones rich in magnesium and iron (*e.g.*, basalt and gabbro) and the higher values are typical of those rich in silica (quartz) and alumina (*e.g.*, granite). These values result because the thermal conductivity of quartz is relatively high, while that for feldspars is low.

Thermal expansion. The change in dimension—linear or volumetric—of a rock specimen with temperature is expressed in terms of a coefficient of thermal expansion. This is given as the ratio of dimension change (*e.g.*, change in volume) to the original dimension (volume, V) per unit of temperature (T) change:

$$\frac{1}{V}\frac{\Delta V}{\Delta T}.$$

Most rocks have a volume-expansion coefficient in the range of 15–33 × 10⁻⁶ per degree Celsius under ordinary conditions. Quartz-rich rocks have relatively high values because of the higher volume expansion coefficient of quartz. Thermal-expansion coefficients increase with temperature. Table 41 lists some linear-expansion coefficients,

$$\frac{1}{L}\frac{\Delta L}{\Delta T},$$

where L represents length. All data are based on at least three samples.

Table 40: Typical Values of Thermal Conductivity
(in 10^{-3} cal/cm · sec · °C)

material	at 20° C	at 200° C
Typical rocks	4–10	
Granite	7.8	6.6
Gneiss		
(perpendicular to banding)	5.9	5.5 } 100° C
(parallel to banding)	8.2	7.4 } 100° C
Gabbro	5.1	5.0
Basalt	4.0	4.0
Dunite	12.0	8.1
Marble	7.3	5.2
Quartzite	15.0	9.0
Limestone	6.0	
Ore sandstone		
(dry)	4.4	
(saturated)	5.4	
Shale	3–4	
Rock salt	12.8	
Sand		
(dry)	0.65	
(30% water)	3.94	
Water	1.34 (0° C)	1.6 (80° C)
Ice	5.3 (0° C)	9.6 (−130° C)
Magnetite	12.6	
Quartz	20.0	
Feldspars	5.0	

Table 41: Thermal Expansion of Rocks

rock type	linear-expansion coefficient (in 10^{-6} per °C)
Granite and rhyolite	8 ± 3
Andesite and diorite	7 ± 2
Basalt, gabbro, and diabase	5.4 ± 1
Sandstone	10 ± 2
Limestone	8 ± 4
Marble	7 ± 2
Slate	9 ± 1

Radioactive heat generation. The spontaneous decay (partial disintegration) of the nuclei of radioactive elements provides decay particles and energy. The energy, composed of emission kinetic energy and radiation, is converted to heat; it has been an important factor in affecting the temperature gradient and thermal evolution of the Earth. Deep-seated elevated temperatures provide the heat that causes rock to deform plastically and to move, thus generating to a large extent the processes of plate tectonics—plate motions, seafloor spreading, continental drift, and subduction—and most earthquakes and volcanism.

Some elements, or their isotopes (nuclear species with the same atomic number but different mass numbers), decay with time. These include elements with an atomic number greater than 83—of which the most important are uranium-235, uranium-238, and thorium-232—and a few with a lower atomic number, such as potassium-40.

Table 42: Some Radioactive Decay Series

element	radioactive isotope	final product	isotopic abundance (%)	half-life, $t_{1/2}$ (in 10^9 years)
Uranium	U-235	Pb-207	0.72	0.7
	U-238	Pb-206	99.28	4.5
Thorium	Th-232	Pb-208	100.0	14.0
Potassium	K-40	(89%) Ca-40 (11%) Argon-40	0.01	1.4* 11.9*
Rubidium	Rb-87	Sr-87	27.8	48.8

*$t_{1/2}$ for K-40 as a whole is 1.25×10^9 years.

The heat generated within rocks depends on the types and abundances of the radioactive elements and their host minerals. Such heat production, A, is given in calories per cubic centimetre per second, or 1 calorie per gram per year = 4.186×10^7 ergs per gram per year = 1.327 ergs per gram per second. The rate of radioactive decay, statistically an exponential process, is given by the half-life, $t_{1/2}$. The half-life is the time required for half the original radioactive atoms to decay for a particular isotope. Half-life

Some radioactive decay series are listed in Table 42. The isotopic abundance is the percent of the natural element that exists as that particular radioactive isotope; for example, 99.28 percent of natural uranium is U-238, and 100 percent of thorium is the radioactive Th-232. The final product is the end result of the process (usually multistage) of disintegration. Table 43 gives the heat productivities of radioactive elements and rock types as reported by George D. Garland. For the rocks, the typical content is given for uranium and thorium (in parts per million [ppm] of weight) and for potassium (in weight percent). The heat production of natural uranium is close to that for the isotope U-238, since almost all natural uranium is of that isotopic species.

The radioactive elements are more concentrated in the continental upper-crust rocks that are rich in quartz (*i.e.*, acidic, or less mafic). This results because these rocks are differentiated by partial melting of the upper-mantle and oceanic-crust rock. The radioactive elements tend to be preferentially driven off from these rocks for geochemical

reasons. A compilation of heat productivities of various rock types is given in Table 44.

ELECTRICAL PROPERTIES

The electrical nature of a material is characterized by its conductivity (or, inversely, its resistivity) and its dielectric constant, and coefficients that indicate the rates of change of these with temperature, frequency at which measurement is made, and so on. For rocks with a range of chemical composition as well as variable physical properties of porosity and fluid content, the values of electrical properties can vary widely.

Resistivity and conductivity

Resistance (R) is defined as being one ohm when a potential difference (voltage; V) across a specimen of one volt magnitude produces a current (i) of one ampere; that is, $V = Ri$. The electrical resistivity (ρ) is an intrinsic property of the material. In other words, it is inherent and not dependent on sample size or current path. It is related to resistance by $R = \rho L/A$ where L is the length of specimen, A is the cross-sectional area of specimen, and units of ρ are ohm-centimetre; 1 ohm-centimetre equals 0.01 ohm-metre. The conductivity (σ) is equal to $1/\rho$ ohm^{-1} · centimetre^{-1} (or termed mhos/cm). In SI units, it is given in mhos/metre, or siemens/metre.

Table 43: Heat Productivities

isotope	heat productivity, A (cal/g · year)
U-235	4.29
U-238	0.71
Natural uranium	0.73
Th-232	0.20
K-40	0.22
Natural potassium	27×10^{-6}
Rb-87	130×10^{-6}
Natural rubidium	36×10^{-6}

major rock province	abundances			heat productivity, A (in 10^{-13} [cal/cm^3 · s])
	U ppm	Th ppm	K %	
Oceanic crust	0.42	1.68	0.69	0.71
Continental shield crust (old)	1.00	4.00	1.63	1.67
Continental upper crust (young)	1.32	5.28	2.15	2.20

Some representative values of electrical resistivity for rocks and other materials are listed in Table 45. Materials that are generally considered as "good" conductors have a resistivity of 10^{-5}–10 ohm-centimetre (10^{-7}–10^{-1} ohm-metre) and a conductivity of 10–10^7 mhos/metre. Those that are classified as intermediate conductors have a resistivity of 100–10^6 ohm-centimetre (1–10^7 ohm-metre) and a conductivity of 10^{-7}–1 mhos/metre. "Poor" conductors, also known as insulators, have a resistivity of 10^{10}–10^{17} ohm-centimetre (10^8–10^{15} ohm-metre) and a conductivity of 10^{-15}–10^{-8}. Seawater is a much better conductor (*i.e.*, it has lower resistivity) than fresh water owing to its higher content of dissolved salts; dry rock is very resistive. In the subsurface, pores are typically filled to some degree by fluids. The resistivity of materials has a wide range—copper is, for example, different from quartz by 22 orders of magnitude.

For high-frequency alternating currents, the electrical response of a rock is governed in part by the dielectric constant, ε. This is the capacity of the rock to store electric charge; it is a measure of polarizability in an electric field. In cgs units, the dielectric constant is 1.0 in a vacuum. In SI units, it is given in farads per metre or in terms of the ratio of specific capacity of the material to specific capacity of vacuum (which is 8.85×10^{-12} farads per metre). The dielectric constant is a function of temperature, and of frequency, for those frequencies well above 100 hertz (cycles per second).

Dielectric constant

Electrical conduction occurs in rocks by (1) fluid conduction—*i.e.*, electrolytic conduction by ionic transfer in briny pore water—and (2) metallic and semiconductor (*e.g.*, some sulfide ores) electron conduction. If the rock has any porosity and contained fluid, the fluid typically dominates the conductivity response. The rock conductivity depends on the conductivity of the fluid (and its chemical composition), degree of fluid saturation, porosity and permeability, and temperature. If rocks lose water, as with compaction of clastic sedimentary rocks at depth, their resistivity typically increases. Ranges of electrical resistivities for various rock types are given in Figure 101, and the variation of electrical resistivity for granodiorite, as the frequency and temperature are changed, is shown in Figure 102.

Table 45: Typical Resistivities

material	resistivity (ohm-centimetre)
Seawater (18° C)	21
Uncontaminated surface water	2×10^4
Distilled water	0.2–1×10^6
Water (4° C)	9×10^6
Ice	3×10^8
Rocks (in situ)	
Sedimentary	
Clay, soft shale	10^2–5×10^3
Hard shale	7–50×10^3
Sand	5–40×10^3
Sandstone	10^4–10^8
Glacial moraine	1–500×10^3
Porous limestone	1–30×10^4
Dense limestone	$>10^8$
Rock salt	10^6–10^9
Igneous	5×10^4–10^8
Metamorphic	5×10^4–5×10^8
Rocks (laboratory)	
Dry granite	10^{12}
Minerals	
Copper (18° C)	1.7×10^{-6}
Graphite	5–500×10^{-4}
Pyrrhotite ($Fe_{1-x}S$)	0.1–0.6
Magnetite crystals (Fe_3O_4)	0.6–0.8
Pyrite (FeS_2) ore	1–10^5
Magnetite ore	10^2–5×10^5
Chromite ore	$>10^6$
Quartz (18° C)	10^{14}–10^{16}

MAGNETIC PROPERTIES

The magnetic properties of rocks arise from the magnetic properties of the constituent mineral grains and crystals. Typically, only a small fraction of the rock consists of magnetic minerals. It is this small portion of grains that determines the magnetic properties and magnetization of the rock as a whole, with two results: (1) the magnetic properties of a given rock may vary widely within a given rock body or structure, depending on chemical inhomo-

Magnetic minerals

Table 44: Heat Productivities of Various Rocks

rock type	abundances				heat production			total A (in 10^{-6} cal/g · year)
	U ppm	Th ppm	Rb ppm	K %	from U	from Th	from K	
Granite	3.4	50	220	4.45	2.52	9.95	1.16	13.63
Andesite	1.9	6.4	67	2.35	1.41	1.27	0.61	3.29
Oceanic basalt	0.5	0.9	9	0.43	0.37	0.18	0.11	0.66
Peridotite	0.005	0.01	0.063	0.001	0.0037	0.002	0.0003	0.006
Average upper-continental crust	2.5	10.5	110	2.7	1.85	2.09	0.7	4.64
Average continental crust	1.0	2.5	50	1.25	0.74	0.5	0.33	1.56

Source: Modified from compilation by William Van Schmus in Robert S. Carmichael, ed., *Handbook of Physical Properties of Rocks*, vol. III, CRC Press, Inc. (1984).

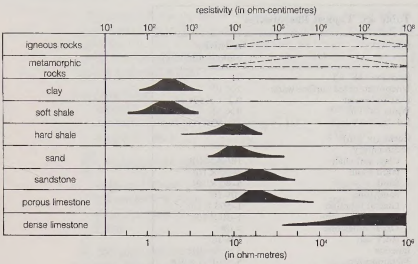


Figure 101: Electrical resistivities of some rock types.
From D. Griffiths and R. King, *Applied Geophysics for Geologists and Engineers*, 2nd ed., (1981) Pergamon Press, Elmsford, New York

geneities, depositional or crystallization conditions, and what happens to the rock after formation; and (2) rocks that share the same lithology (type and name) need not necessarily share the same magnetic characteristics. Lithologic classifications are usually based on the abundance of dominant silicate minerals, but the magnetization is determined by the minor fraction of such magnetic mineral grains as iron oxides. The major rock-forming magnetic minerals are iron oxides and sulfides.

Although the magnetic properties of rocks sharing the same classification may vary from rock to rock, general magnetic properties do nonetheless usually depend on rock type and overall composition. The magnetic properties of a particular rock can be quite well understood provided one has specific information about the magnetic properties of crystalline materials and minerals, as well as about how those properties are affected by such factors as temperature, pressure, chemical composition, and the size of the grains. Understanding is further enhanced by information about how the properties of typical rocks are dependent on the geologic environment and how they vary with different conditions.

An understanding of rock magnetization is important in at least three different areas: prospecting, geology, and materials science. In magnetic prospecting, one is interested in mapping the depth, size, type, and inferred composition of buried rocks. The prospecting, which may be done from ground surface, ship, or aircraft, provides an important first step in exploring buried geologic structures and may, for example, help identify favourable locations for oil, natural gas, and economic mineral deposits.

Rock magnetization has traditionally played an important role in geology. Paleomagnetic work seeks to determine the remanent magnetization (see below) and thereby ascertain the character of the Earth's field when certain rocks were formed. The results of such research have important ramifications in stratigraphic correlation, age dating, and reconstructing past movements of the Earth's crust. Indeed, magnetic surveys of the oceanic crust provided for the first time the quantitative evidence needed to cogently demonstrate that segments of the crust had undergone large-scale lateral displacements over geologic time, thereby corroborating the concepts of continental drift and seafloor spreading, both of which are fundamental to the theory of plate tectonics (see PLATE TECTONICS).

From R.S. Carmichael (ed.), *Handbook of Physical Properties of Rocks*, vol. II (1982), CRC Press, Inc., Boca Raton, Florida

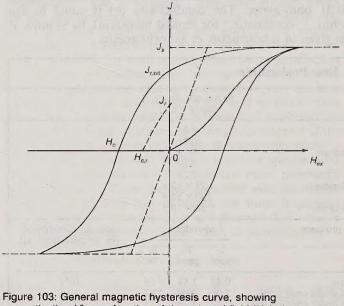


Figure 103: General magnetic hysteresis curve, showing magnetization (J) as a function of the external field (H_{ext}). J_s is the saturation (or "spontaneous") magnetization; $J_{r,sat}$ is the remanent magnetization that remains after a saturating applied field is removed; J_r is the residual magnetization left by some magnetization process other than IRM saturation; H_c is the coercive field; and $H_{c,r}$ is the field necessary to reduce J_r to zero.

The understanding of magnetization is increasingly important in materials science as well. The design and manufacture of efficient memory cores, magnetic tapes, and permanent magnets increasingly rely on the ability to create materials having desired magnetic properties.

Basic types of magnetization

There are six basic types of magnetization: (1) diamagnetism, (2) paramagnetism, (3) ferromagnetism, (4) antiferromagnetism, (5) ferrimagnetism, and (6) superparamagnetism.

Diamagnetism arises from the orbiting electrons surrounding each atomic nucleus. When an external magnetic field is applied, the orbits are shifted in such a way that the atoms set up their own magnetic field in opposition to the applied field. In other words, the induced diamagnetic field opposes the external field. Diamagnetism is present in all materials, is weak, and exists only in the presence of an applied field. The propensity of a substance for being magnetized in an external field is called its susceptibility (k) and it is defined as J/H, where J is the magnetization (intensity) per unit volume and H is the strength of the applied field. Since the induced field always opposes the applied field, the sign of diamagnetic susceptibility is negative. The susceptibility of a diamagnetic substance is on the order of -10^{-6} electromagnetic units per cubic centimetre (emu/cm^3). It is sometimes denoted κ for susceptibility per unit mass of material.

Paramagnetism results from the electron spin of unpaired electrons. An electron has a magnetic dipole moment—which is to say that it behaves like a tiny bar magnet—and so when a group of electrons is placed in a magnetic

From G. Keller, in R.S. Carmichael (ed.), *Handbook of Physical Properties of Rocks*, vol. I (1982), CRC Press, Inc., Boca Raton, Florida

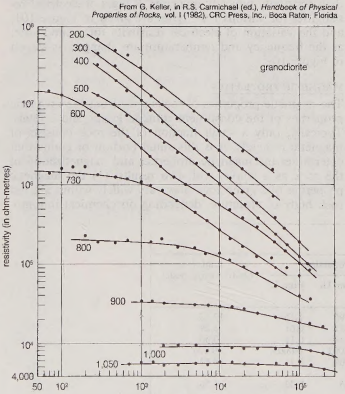


Figure 102: Resistivity of granodiorite as a function of frequency and temperature (in °C).

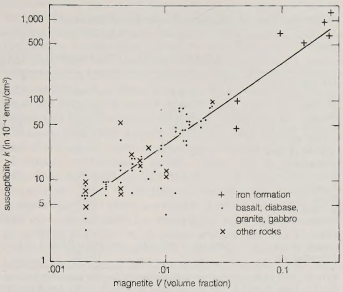


Figure 104: Relation of susceptibility to magnetite content for some Precambrian igneous and ore rocks.

From H.M. Mooney and R. Bleifuss, "Magnetic Susceptibility Measurements in Minnesota: II—Analysis of Field Results," *Geophysics*, 18 (1953), in R.S. Carmichael (ed.), *Handbook of Physical Properties of Rocks*, vol. II (1982), CRC Press, Inc., Boca Raton, Florida.

field, the dipole moments tend to line up with the field. The effect augments the net magnetization in the direction of the applied field. Like diamagnetism, paramagnetism is weak and exists only in the presence of an applied field, but since the effect enhances the applied field, the sign of the paramagnetic susceptibility is always positive. The susceptibility of a paramagnetic substance is on the order of 10^{-4} to 10^{-6} emu/cm^3.

Ferromagnetism also exists because of the magnetic properties of the electron. Unlike paramagnetism, however, ferromagnetism can occur even if no external field is applied. The magnetic dipole moments of the atoms spontaneously line up with one another because it is energetically favourable for them to do so. A remanent magnetization can be retained. Complete alignment of the dipole moments would take place only at a temperature of absolute zero (0 kelvin [K], or −273.15° C). Above absolute zero, thermal motions begin to disorder the magnetic moments. At a temperature called the Curie temperature, which varies from material to material, the thermally induced disorder overcomes the alignment, and the ferromagnetic properties of the substance disappear. The susceptibility of ferromagnetic materials is large and positive. It is on the order of 10 to 10^4 emu/cm^3. Only a few materials—iron, cobalt, and nickel—are ferromagnetic in the strict sense of the word and have a strong residual magnetization. In general usage, particularly in engineering, the term ferromagnetic is frequently applied to any material that is appreciably magnetic.

Antiferromagnetism occurs when the dipole moments of the atoms in a material assume an antiparallel arrangement in the absence of an applied field. The result is that the sample has no net magnetization. The strength of the susceptibility is comparable to that of paramagnetic materials. Above a temperature called the Néel temperature, thermal motions destroy the antiparallel arrangement, and the material then becomes paramagnetic. Spincanted (anti)ferromagnetism is a special condition which occurs when antiparallel magnetic moments are deflected from the antiferromagnetic plane, resulting in a weak net magnetism. Hematite (α-Fe_2O_3) is such a material.

Ferrimagnetism is an antiparallel alignment of atomic dipole moments which does yield an appreciable net magnetization resulting from unequal moments of the magnetic sublattices. Remanent magnetization is detectable (see below). Above the Curie temperature the substance becomes paramagnetic. Magnetite (Fe_3O_4), which is the most magnetic common mineral, is a ferrimagnetic substance.

Superparamagnetism occurs in materials having grains so small (about 100 angstroms) that any cooperative alignment of dipole moments is overcome by thermal energy.

Rocks and minerals may retain magnetization after the removal of an externally applied field, thereby becoming permanent weak magnets. This property is known as remanent magnetization and is manifested in different forms, depending on the magnetic properties of the rocks and minerals and their geologic origin and history. Delineated below are the kinds of remanent magnetization frequently observed.

Types of remanent magnetization

CRM (chemical, or crystallization, remanent magnetization) can be induced after a crystal is formed and undergoes one of a number of physicochemical changes, such as oxidation or reduction, a phase change, dehydration, recrystallization, or precipitation of natural cements. The induction, which is particularly important in some (red) sediments and metamorphic rocks, typically takes place at constant temperature in the Earth's magnetic field.

DRM (depositional, or detrital, remanent magnetization) is formed in clastic sediments when fine particles are deposited on the floor of a body of water. Marine sediments, lake sediments, and some clays can acquire DRM. The Earth's magnetic field aligns the grains, yielding a preferred direction of magnetization.

IRM (isothermal remanent magnetization) results from the application of a magnetic field at a constant (isothermal) temperature, often room temperature.

NRM (natural remanent magnetization) is the magnetization detected in a geologic in situ condition. The NRM of a substance may, of course, be a combination of any of the other remanent magnetizations described here.

Table 47: Measured Susceptibilities for Rock Types

rock type	% of samples with k (in 10^{-6} emu/cm^3)			
	<100	100–1,000	1,000–4,000	>4,000
Basic extrusive (*e.g.*, basalt)	5	29	47	19
Basic intrusive (*e.g.*, gabbro)	24	27	28	21
Granite	60	23	16	1
Metamorphic (gneiss, schist, slate)	71	22	7	0
Sedimentary	73	19	4	4

Source: After D.H. Lindsley, G.E. Andreasen, and J.R. Balsley, "Magnetic Properties of Rocks and Minerals" in *Handbook of Physical Constants*, S.P. Clark, ed., Memoir 97, Geological Society of America, 1966, and L.B. Slichter, "Magnetic Properties of Rocks" in *Handbook of Physical Constants*, F. Birch, ed. (1942).

PRM (pressure remanent, or piezoremanent, magnetization) arises when a material undergoes mechanical deformation while in a magnetic field. The process of deformation may result from hydrostatic pressure, shock impact (as produced by a meteorite striking the Earth's surface), or directed tectonic stress. There are magnetization changes with stress in the elastic range, but the most pronounced effects occur with plastic deformation when the structure of the magnetic minerals is irreversibly changed.

TRM (thermoremanent magnetization) occurs when a substance is cooled, in the presence of a magnetic field, from above its Curie temperature to below that temperature. This form of magnetization is generally the most important, because it is stable and widespread, occurring in igneous and sedimentary rocks. TRM also can occur when dealing exclusively with temperatures below the Curie temperature. In PTRM (partial thermoremanent magnetization) a sample is cooled from a temperature below the Curie point to yet a lower temperature.

VRM (viscous remanent magnetization) results from thermal agitation. It is acquired slowly over time at low temperatures and in the Earth's magnetic field. The effect is weak and unstable but is present in most rocks.

Table 46: Approximate "Apparent Susceptibilities" for Rock Types

rock	k_{app} (emu/cm^3)
Iron ores	over 0.1
Basalt	10^{-2}
Andesite	10^{-3}
Dacite	10^{-4}
Metamorphic rocks	10^{-4}
Sedimentary rocks	10^{-5}

Source: From T. Nagata, ed., *Rock Magnetism*, Maruzen Co., Tokyo (1961).

Hysteresis

The concept of hysteresis is fundamental when describing and comparing the magnetic properties of rocks. Hysteresis is the variation of magnetization with applied field and illustrates the ability of a material to retain its magnetization, even after an applied field is removed. Figure 103 illustrates this phenomenon in the form of a plot of magnetization (J) versus applied field (H_{ex}). J_s is the saturation (or "spontaneous") magnetization when all the magnetic moments are aligned in their configuration of maximum order. It is temperature-dependent, reaching zero at the Curie temperature. $J_{r,sat}$ is the remanent magnetization that remains when a saturating (large) applied field is removed, and J_r is the residual magnetization left by some process apart from IRM saturation, as, for example, TRM. H_c is the coercive field (or force) that is required to reduce $J_{r,sat}$ to zero, and $H_{c,r}$ is the field required to reduce J_r to zero.

Magnetic susceptibility is a parameter of considerable diagnostic and interpretational use in the study of rocks. This is true whether an investigation is being conducted in the laboratory or magnetic fields over a terrain are being studied to deduce the structure and lithologic character of buried rock bodies. Susceptibility for a rock type can vary widely, depending on magnetic mineralogy, grain size and shape, and the relative magnitude of remanent magnetization present, in addition to the induced magnetization from the Earth's weak field. The latter is given as $J_{induced} = kH_{ex}$, where k is the (true) magnetic susceptibility and H_{ex} is the external (*i.e.*, the Earth's) magnetic field. If there is an additional remanent magnetization with its ratio (Q_n) to induced magnetization being given by

$$Q_n = \frac{J_{remanent}}{kH_{ex}},$$

then the total magnetization is

$$\begin{aligned} J &= J_{induced} + J_{remanent} \\ &= kH_{ex} + Q_n kH_{ex} \\ &= k(1 + Q_n)H_{ex} \\ &= k_{app}H_{ex}, \end{aligned}$$

where k_{app}, the "apparent" magnetic susceptibility, is $k(1 + Q_n)$.

Magnetic minerals

The major rock-forming magnetic minerals are the following iron oxides: the titanomagnetite series, $x\mathrm{Fe_2TiO_4} \cdot (1 - x)\mathrm{Fe_3O_4}$, where $\mathrm{Fe_3O_4}$ is magnetite, the most magnetic mineral; the ilmenohematite series, $y\mathrm{FeTiO_3} \cdot (1 - y)\mathrm{Fe_2O_3}$, where α-$\mathrm{Fe_2O_3}$ (in its rhombohedral structure) is hematite; maghemite, γ-$\mathrm{Fe_2O_3}$ (in which some iron atoms are missing in the hematite structure); and limonite (hydrous iron oxides). They also include sulfides—namely, the pyrrhotite series, $y\mathrm{FeS} \cdot (1 - y)\mathrm{Fe}_{1-x}\mathrm{S}$.

Table 46 gives some typical values of the apparent susceptibility for various rock types, which usually include some remanent as well as induced magnetization. Values are higher for mafic igneous rocks, especially as the content of magnetite increases. This is illustrated in Figure 104, which illustrates that susceptibility increases with magnetite content for igneous and ore rocks.

A distribution of measured (true) susceptibilities for various rock types is shown in Table 47. Basic refers to those rocks high in iron and magnesium silicates and magnetite, extrusive means formed by cooling after extruding onto the land surface or seafloor. The data in each category are based on at least 45 samples.

Table 48 lists representative values for the magnetic properties J_n (natural remanent magnetization), k (susceptibility), and ratio Q_n. Natural remanent magnetization is some combination of remanences; typically TRM in an igneous rock, perhaps DRM or CRM or both in a sedimentary rock, and all with an additional VRM. The ratio Q_n is typically higher for rocks with a strong, stable remanence—*e.g.*, magnetite-rich and fine-grained extrusive rocks such as seafloor basalts. (R.S.Ca.)

Table 48: Typical Magnetic Properties of Rocks

rock	J_n (10^{-3} emu/cm^3)	k (10^{-3} emu/cm^3)	$Q_n = \frac{J_n^*}{k \cdot H_{ex}}$
Igneous			
Granite	10–80	50–400	0.3–1
Diabase	190–400	100–230	2–3.5
Basalt	200–1,000	100–700	5–10
Seafloor basalt (1–6 metres)	500–800	30–60	25–45
Typical (average)	10–4,000	5–500	1–40
Sedimentary			
Red sediments	0.2–2	0.04–6	2–4
Sandstone		1–40	
Shale		1–50	
Limestone		0.5–20	
Typical (average)	0.1–10	0.3–30	0.02–10
Ores			
Magnetite ore	300,000–1,000,000	30,000–100,000	~10–50
Hematite ore		10–70	

*For $H_{ex} = 0.5$ oersted, the cgs electromagnetic unit of magnetic field intensity.
Source: After Robert S. Carmichael, ed., *Handbook of Physical Properties of Rocks*, vol. II, CRC Press, Inc. (1982).

IGNEOUS ROCKS

Igneous rocks, as previously noted, are those formed from the solidification of magma, which is a hot (600° to 1,300° C, or 1,100° to 2,400° F) molten or partially molten rock material. The Earth is composed predominantly of a large mass of igneous rock with a very thin veneer of weathered material—namely, sedimentary rock. Whereas sedimentary rocks are produced by processes operating mainly at the Earth's surface by the disintegration of mostly older igneous rocks, igneous—and metamorphic—rocks are formed by internal processes that cannot be directly observed and that necessitate the use of physical-chemical arguments to deduce their origins. Because of the high temperatures within the Earth, the principles of chemical equilibrium are applicable to the study of igneous and metamorphic rocks, with the latter being restricted to those rocks formed without the direct involvement of magma.

Magma is thought to be generated within the plastic asthenosphere (the layer of partially molten rock underlying the Earth's crust) at a depth below about 60 kilometres (40 miles). Because magma is less dense than the surrounding solid rocks, it rises toward the surface. It may settle within the crust or erupt at the surface from a volcano as a lava flow. Rocks formed from the cooling and solidification of magma deep within the crust are distinct from those erupted at the surface mainly owing to the differences in physical and chemical conditions prevalent in the two environments. Within the Earth's deep crust the temperatures and pressures are much higher than at its surface; consequently, the hot magma cools slowly and crystallizes completely, leaving no trace of the liquid magma. The slow cooling promotes the growth of minerals large enough to be identified visually without the aid of a microscope (called phaneritic, from the Greek *phaneros*, meaning "visible"). On the other hand, magma erupted at the surface is chilled so quickly that the individual minerals have little or no chance to grow. As a result, the rock is either composed of minerals that can be seen only with the aid of a microscope (called aphanitic, from the Greek *aphanēs*, meaning "invisible") or contains no minerals at all (in the latter case, the rock is composed of glass, which is a highly viscous liquid). This results in two groups: (1) plutonic intrusive igneous rocks that solidified deep within the crust and (2) volcanic, or extrusive, igneous rocks formed at the Earth's surface. Some intrusive rocks, known as subvolcanic, were not formed at great depth but were instead injected near the surface where lower temperatures result in a more rapid cooling process; these tend to be aphanitic and are referred to as hypabyssal intrusive rocks.

Intrusive and extrusive rocks

The deep-seated plutonic rocks can be exposed at the surface for study only after a long period of denudation or by some tectonic forces that push the crust upward or

by a combination of the two conditions. (Denudation is the wearing away of the terrestrial surface by processes including weathering and erosion.) Generally, the intrusive rocks have cross-cutting contacts with the country rocks that they have invaded, and in many cases the country rocks show evidence of having been baked and thermally metamorphosed at these contacts. The exposed intrusive rocks are found in a variety of sizes, from small veinlike injections to massive dome-shaped batholiths, which extend for more than 100 square kilometres (40 square miles) and make up the cores of the great mountain ranges.

Extrusive rocks occur in two forms: (1) as lava flows that flood the land surface much like a river and (2) as fragmented pieces of magma of various sizes (pyroclastic materials), which often are blown through the atmosphere and blanket the Earth's surface upon settling. The coarser pyroclastic materials accumulate around the erupting volcano, but the finest pyroclasts can be found as thin layers located hundreds of kilometres from the opening. Most lava flows do not travel far from the volcano, but some low-viscosity flows that erupted from long fissures have accumulated in thick (hundreds of metres) sequences, forming the great plateaus of the world (*e.g.*, the Columbia River plateau of Washington and Oregon and the Deccan Plateau in India). Both intrusive and extrusive magmas have played a vital role in the spreading of the ocean basin, in the formation of the oceanic crust, and in the formation of the continental margins. Igneous processes have been active since the formation of the Earth some 4.6 billion years ago. Their emanations have provided the water for the oceans, the gases for the primordial oxygen-free atmosphere, and many valuable mineral deposits.

Composition

CHEMICAL COMPONENTS

The great majority of the igneous rocks are composed of silicate minerals (meaning that the basic building blocks for the magmas that formed them are made of silicon [Si] and oxygen [O]), but minor occurrences of carbonate-rich igneous rocks are found as well. Indeed, in 1960 a sodium carbonate (Na_2CO_3) lava with only 0.05 weight percent silica (SiO_2) was erupted from Ol Doinyo Lengai, a volcano in northern Tanzania, Africa. Because of the limited occurrence of such carbonate-rich igneous rocks, however, the following discussion will consider the chemistry of silicate rocks only. The major oxide components of the silicate igneous rocks are given in Table 49. The major oxides of the rocks generally correlate well with their silica content: those rocks with low silica content are enriched in magnesium oxide (MgO) and iron oxides (FeO, Fe_2O_3, and Fe_3O_4) and are depleted in soda (Na,O) and potash (K_2O); those with a large amount of silica are depleted in magnesium oxide and iron oxides but are enriched in soda and potash. Both calcium oxide (CaO) and alumina (Al_2O_3) are depleted in the rocks that have a silica content of less than about 45 weight percent, but, above 45 percent, calcium oxide can be as high as 10 percent; this amount decreases gradually as the silica increases. Alumina in rocks that contain more than 45 percent silica is generally above approximately 14 weight percent, with the greatest abundance occurring at an intermediate silica content of about 56 weight percent. Because of the importance of silica content, it has become common practice to use this feature of igneous rocks as a basis for subdividing them into the following groups: silicic (or acid, an old and discredited but unfortunately entrenched term), rocks having more than 66 percent silica; intermediate, rocks with 55 to 66 percent silica; and subsilicic, rocks containing less than 55 percent silica. The latter may be further divided into two groups: basic, rocks with 45 to 55 percent silica and ultrabasic, those containing less than 45 percent. The subsilicic rocks, enriched as they are in iron (Fe) and magnesium (Mg), are termed femic (from *f*errous iron and *m*agnesium), whereas the silicic rocks are referred to as sialic (from *si*lica and *al*uminum, with which they are enriched) or salic (from silica and *al*uminum).

Silica content

The silica content also reflects the mineral composition of the rocks. As the magma cools and begins to crystallize, silica is taken from the magma to be combined with the other cationic oxides to form the silicate minerals. For example, one mole of SiO_2 is combined with one mole of MgO to make the magnesium-rich pyroxene, $MgSiO_3$ (enstatite): $SiO_2 + MgO \rightarrow MgSiO_3$. Two moles of SiO_2 are needed to be combined with one mole each of CaO and Al_2O_3 to make the calcium-rich plagioclase, $CaAl_2Si_2O_8$ (anorthite). However, in a case where magma does not have enough silica relative to the magnesium oxide to produce the pyroxene, the magma will compensate by making a magnesium-olivine (forsterite; Mg_2SiO_4), along with the pyroxene, since the olivine requires only one-half as much silica for every mole of magnesium oxide. On the other hand, a silicic magma may have excess silica such that some will be left after all the silicate minerals were formed from the combination of the oxides; the remaining "free" silica crystallizes as quartz or its polymorphs. The former case usually occurs in subsilicic rocks that characteristically will have silicate minerals like magnesium-olivine, sodium-nepheline ($NaAlSiO_4$, which requires only one mole of silicon for every mole of sodium [Na]), and leucite ($KAlSi_2O_6$, which requires only two moles of silicon to one mole of potassium [K]). These three minerals substitute in part for enstatite, albite ($NaAlSi_3O_8$, requiring three moles of silicon for one mole of sodium), and orthoclase feldspar ($KAlSi_3O_8$, requiring three moles of silicon for one mole of potassium), respectively. Quartz clearly will not be present in these rocks. Minerals such as magnesium-olivine, nepheline, and leucite are termed undersaturated (with respect to silica), and the subsilicic rocks that contain them are termed undersaturated as well. In the case of rocks that have excess silica, the silicic rocks will have quartz and magnesium-pyroxene, which are considered saturated minerals, and the rocks that contain them are termed supersaturated.

Table 49: Average Compositions of Selected Igneous Rocks* (in percentages by weight)

	granite	granodiorite	andesite	basalt	peridotite
SiO_2	74.20	67.30	54.70	51.30	43.90
TiO_2	0.20	0.57	1.32	2.05	0.82
Al_2O_3	13.80	15.80	17.30	14.20	4.02
Fe_2O_3	0.78	1.34	3.51	2.91	2.53
FeO	1.14	2.61	5.54	9.14	9.92
MnO	0.05	0.07	0.15	0.18	0.21
MgO	0.26	1.58	4.40	6.40	34.28
CaO	0.72	3.58	7.99	10.50	3.49
Na_2O	3.53	3.87	3.70	2.25	0.56
K_2O	5.15	3.09	1.12	0.83	0.25
P_2O_5	0.14	0.21	0.28	0.23	0.05

*Water-free basis.
Source: After S.R. Nockolds, "Average Chemical Compositions of Some Igneous Rocks," *Geological Society of America Bulletin*, vol. 65 (1954).

MINERALOGICAL COMPONENTS

The major mineralogical components of igneous rocks can be divided into two groups: felsic (from *fel*dspar and *si*lica) and mafic (from *ma*gnesium and *f*errous iron). The felsic minerals include quartz, tridymite, cristobalite, feldspars (plagioclase and alkali feldspar), feldspathoids (nepheline and leucite), muscovite, and corundum. Because felsic minerals lack iron and magnesium, they are generally light in colour and consequently are referred to as such or as leucocratic. The mafic minerals include olivine, pyroxenes, amphiboles, and biotites, all of which are dark in colour. Mafic minerals are said to be melanocratic. These terms can be applied to the rocks, depending on the relative proportion of each type of mineral present. In this regard, the term colour index, which refers to the total percentage of the rock occupied by mafic minerals, is useful. Felsic rocks have a colour index of less than 50, while mafic rocks have a colour index above 50. Those rocks that have a colour index above 90 are referred to as ultramafic. These terms are to be used only for the mineralogical content of igneous rocks because they do not necessarily correlate directly with chemical terms. For example, it is common to find a felsic rock composed almost entirely of the mineral plagioclase, but in chemical terms, such a rock is a subsilicic basic rock. Another example is an ig-

Felsic and mafic rocks

neous rock consisting solely of pyroxene. Mineralogically it would be termed ultramafic, but chemically it is a basic igneous rock with a silica content of about 50 percent.

The influence of supersaturation and undersaturation on the mineralogy of a rock was noted above. During the crystallization of magmas, supersaturated minerals will not be formed along with undersaturated minerals. Supersaturated minerals include quartz and its polymorphs and a low-calcium orthorhombic pyroxene (called hypersthene). These cannot coexist with any of the feldspathoids (*e.g.*, leucite and nepheline) or magnesium-rich olivine. In volcanic rocks that have been quenched (cooled rapidly) such that only a small part of the magma has been crystallized, it is possible to find a magnesium-rich olivine crystal surrounded by a glass that is saturated or supersaturated. In this case, the outer rim of the olivine may be corroded or replaced by a magnesium-rich pyroxene (called a reaction rim). The olivine was the first to be crystallized, but it was in the process of reacting with the saturated magma to form the saturated mineral when an eruption halted the reaction. Had the magma been allowed to crystallize fully, all the magnesium-rich olivine would have been transformed into the magnesium-rich pyroxene and quartz may have been crystallized.

Accessory minerals present in igneous rocks in minor amounts include allanite, apatite, garnets, ilmenite, magnetite, sphene, spinel, and zircon. Glass may be a major phase in some volcanic rock but, when present, is usually found in minor amounts. Igneous rocks that were exposed to weathering and circulating groundwater have undergone some degree of alteration. Common alteration products are talc or serpentine formed at the expense of olivine, chlorites replacing pyroxene and amphiboles, iron oxides replacing any mafic mineral, clay minerals and epidote formed from the feldspars, and calcite that may be formed at the expense of any calcium-bearing mineral by interaction with a carbon dioxide (CO_2)-bearing solution. Glass is commonly altered to clay minerals and zeolite. In some cases, however, glass has undergone a devitrification process (in which it is transformed into a crystalline material) initiated by reaction of the glass with water or by subsequent reheating. Common products of devitrification include quartz and its polymorphs, alkali feldspar, plagioclase, pyroxene, zeolite, clays, and chlorite.

Alteration products

(A.M.K.)

Textural features

The texture of an igneous rock normally is defined by the size and form of its constituent mineral grains and by the spatial relationships of individual grains with one another and with any glass that may be present. Texture can be described independently of the entire rock mass, and its geometric characteristics provide valuable insights into the conditions under which the rock was formed.

Among the most fundamental properties of igneous rocks are crystallinity and granularity, two terms that closely reflect differences in magma composition and the differences between volcanic and various plutonic environments of formation. Crystallinity generally is described in terms of the four categories shown in Table 50.

Table 50: Crystallinity Categories of Igneous Rocks

crystallinity	rock term
Entirely crystalline	holocrystalline
Crystalline material and subordinate glass	hemicrystalline or hypocrystalline
Glass and subordinate crystalline material	hemihyaline or hypohyaline
Entirely glassy	holohyaline or hyaline

Those holocrystalline rocks in which mineral grains can be recognized with the unaided eye are called phanerites, and their texture is called phaneritic; some examples are shown in Figure 105. Those with mineral grains so small that their outlines cannot be resolved without the aid of a hand lens or microscope are termed aphanites, and their texture is termed aphanitic (see Figure 106). Aphanitic rocks are further described as either microcrystalline or cryptocrystalline, according to whether or not their individual constituents can be resolved under the microscope. The subaphanitic, or hyaline, rocks are referred to as glassy, or vitric, in terms of granularity.

Aphanitic and glassy textures represent relatively rapid cooling of magma and, hence, are found mainly among the volcanic rocks. Slower cooling, either beneath the Earth's surface or within very thick masses of lava, promotes the formation of crystals and, under favourable circumstances of magma composition and other factors, their growth to relatively large sizes. The resulting phaneritic rocks are so widespread and so varied that it is convenient to specify their grain size as shown in Table 51.

Crystal formation

Table 51: Categories of Rock Grain Size

terms in common use	general grain size	
	igneous rocks in general	pegmatites
Fine-grained	<1 mm	<1 in.
Medium-grained	1–5 mm	1 in.–4 in.
Coarse-grained	5 mm–2 cm	4 in.–12 in.
Very coarse-grained	>2 cm	>12 in.

The general grain size ordinarily is taken as the average diameter of dominant grains in the rock; for the pegmatites, which are special rocks with extremely large crystals, it can refer to the maximum exposed dimensions of dominant grains. Most aphanitic rocks are characterized by mineral grains less than 0.3 millimetre (0.01 inch) in diameter, and those in which the average grain size is less than 0.1 millimetre (0.004 inch) are commonly described as dense.

A major part of rock texture is fabric or pattern, which is a function of the form and outline of its constituent grains, their relative sizes, and their mutual relationships in space. Many specific terms have been employed to shorten the description of rock fabrics, and even the sampling offered here may seem alarmingly extensive. It should be noted, however, that fabric provides some of the most useful clues to the nature and sequence of magmatic crystallization.

The degree to which mineral grains show external crystal faces can be described as euhedral or panidiomorphic (fully crystal-faced), subhedral or hypidiomorphic (partly faced), or anhedral or allotriomorphic (no external crystal faces). Quite apart from the presence or absence of crystal faces, the shape, or habit, of individual mineral grains is described by such terms as equant, tabular, platy, elongate, fibrous, rodlike, lathlike, needlelike, and irregular. A more general contrast can be drawn between grains of equal (equant) and inequal dimensions. Even-grained, or equigranular, rocks are characterized by essential minerals that all exhibit the same order of grain size, but this implied equality need not be taken too literally. For such rocks the combination terms panidiomorphic-granular, hypidiomorphic-granular, and allotriomorphic-granular are applied according to the occurrence of euhedral, subhedral, and anhedral mineral grains within them. Many fine-grained allotriomorphic-granular rocks are more simply termed sugary, saccharoidal, or aplitic.

Rocks that are unevenly grained, or inequigranular, are generally characterized either by a seriate fabric, in which the variation in grain size is gradual and essentially continuous, or by a porphyritic fabric, involving more than one distinct range of grain sizes. Both of these kinds of texture are common. The relatively large crystals in a porphyritic rock ordinarily occur as separate entities, known as phenocrysts, set in a groundmass or matrix of much finer-grained crystalline material or glass (see Figure 106). Quite commonly in many volcanic rocks, phenocrysts are aggregated. When this is observed, the term glomeroporphyritic is used to describe the texture, and the aggregate is referred to as a glomerocryst. In some cases, such glomerocrysts are monomineralic, but more commonly they are composed of two or more minerals. Based on chemical composition, texture, and other criteria such as isotopic analysis, it has been demonstrated that some phenocrysts and glomerocrysts were not crystallized from the

Porphyritic texture

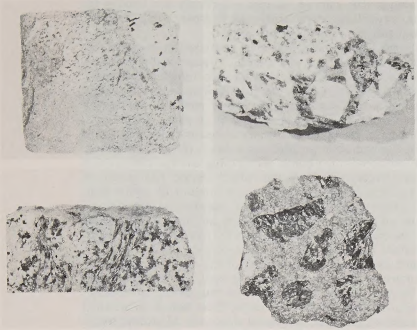


Figure 105: *Textural and structural features of typical phaneritic intrusive rocks.*
(Top left) Fine-grained quartz monzonite in contact with coarse-grained leucocratic granite, Milford, Mass., U.S. (Top right) Coarse-grained quartz monzonite grading downward into coarser-grained pegmatite, Milford, N.H., U.S. (Bottom left) Coarse-grained granite showing flow structure formed by movements in the magma during late-stage crystallization, Conway, N.H. (Bottom right) Very coarsely porphyritic lamprophyre (camptonite) with anhedral phenocrysts of hornblende, near Hoover Dam, Arizona-Nevada border, U.S. The specimens range from four to six inches in maximum dimension.
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host magma but rather were accidentally torn from the country rock by the magma as it rose to the surface. When this has occurred, these phenocrysts are referred to as xenocrysts, while the aggregates can be termed xenoliths. The size of phenocrysts is essentially independent of their abundance relative to the groundmass, and they range in external form from euhedral to anhedral. Most of them are best described as subhedral. Because the groundmass constituents span almost the full ranges of crystallinity and granularity, porphyritic fabric is abundantly represented among the phaneritic, aphanitic, and glassy rocks.

The sharp break in grain size between phenocrysts and groundmass reflects a corresponding change in the conditions that affected the crystallizing magma. Thus, the phenocrysts of many rocks probably grew slowly at depth, following which the nourishing magma rose to the Earth's surface as lava, cooled much more rapidly, and congealed to form a finer-grained or glassy groundmass. A porphyritic volcanic rock with a glassy groundmass is described as having a vitrophyric texture and the rock can be called a vitrophyre. Other porphyritic rocks may well reflect less drastic shifts in position and perhaps more subtle and complex changes in conditions of temperature, pressure, or crystallization rates. Many phenocrysts could have developed at the points where they now occur, and some may represent systems with two fluid phases, magma and coexisting gas. Appraisals of the composition of phenocrysts, their distribution, and their periods of growth relative to the accompanying groundmass constituents are important to an understanding of many igneous processes.

The articulation of mineral grains is described in terms of planar, smoothly curved, sinuous, sutured, interlocked, or irregular surfaces of mutual boundary. The distribution and orientation of mineral grains and of mineral grains and glass are other elements of fabric that can be useful in estimating the conditions and sequence of mineral formation in igneous rocks. The following are only a few of the most important examples:

Directive textures are produced by the preferred orientation of platy, tabular, or elongate mineral grains to yield grossly planar or linear arrangements; they are generally a result of magmatic flowage.

Graphic texture refers to the regular intergrowth of two minerals, one of them generally serving as a host and the other appearing on surfaces of the host as striplike or cuneiform units with grossly consistent orientation; the graphic intergrowth of quartz in alkali feldspar is a good example.

Ophitic texture is the association of lath-shaped euhedral crystals of plagioclase, grouped radially or in an irregular mesh, with surrounding or interstitial large anhedral crystals of pyroxene; it is characteristic of the common rock type known as diabase.

Poikilitic texture describes the occurrence of one mineral that is irregularly scattered as diversely oriented crystals within much larger host crystals of another mineral.

Reaction textures occur at the corroded margins of crystals, from the corrosive rimming of crystals of one mineral by finer-grained aggregates of another, or as a result of other features that indicate partial removal of crystalline material by reaction with magma or other fluid.

Pyroclastic texture

Pyroclastic texture results from the explosive fragmentation of volcanic material, including magma (commonly the light, frothy pumice variety and glass fragments called shards), country rock, and phenocrysts. Fragments less than 2 millimetres in size are called ash, and the rock formed of these is called tuff; fragments between 2 and 64 millimetres are lapilli and the rock is lapillistone; fragments greater than 64 millimetres are called bombs if rounded or blocks if angular, and the corresponding rock is termed agglomerate or pyroclastic breccia, respectively. Commonly, many of these pyroclastic rocks have been formed by dense hot clouds that hug the ground and behave much like a lava flow and hence are given the name pyroclastic flow. Most of these flows are composed of ash-size material; therefore, they are called ash flows and the rocks deposited by them are called ash-flow tuffs. A more general term for rocks deposited by these flows that does not specify size of fragments is ignimbrite. Ash-flow tuffs and other ignimbrites often have zones in which the fragments have been welded. These zones are termed welded tuffs and display a directive planar texture (called eutaxitic) that results from compaction and flattening of pumice fragments. Such pyroclastic flows were responsible for many of the deposits of the eruption of Mount St. Helens in Washington State, U.S., on May 18, 1980. Most eruptions eject fragments that are borne by the wind and deposited subaerially (on the land surface). These deposits are said to be ash-fall tuffs and are recognized by their

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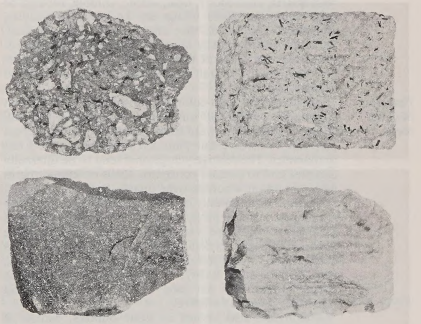


Figure 106: *Textural and structural features of typical aphanitic and glassy volcanic rocks.*
(Top left) Vesicular basalt with large crystals of plagioclase (labradorite), Sonora, Mex. (Top right) Porphyritic andesite with bladelike phenocrysts of hornblende in aphanitic matrix, Mount Shasta, Calif., U.S. (Bottom left) Aphanitic basalt with scattered white crystals of plagioclase, Lassen Peak, Calif. (Bottom right) Felsite with taffylike flow layering, Iron Mountain, N.M., U.S. The specimens are from four to five inches in maximum dimension.

lamination (formation in thin layers that differ in grain size or composition). They commonly blanket the topography in contrast to the ash-flow deposits, which flow around topographic highs and which are completely unsorted.

Replacement textures occur where a mineral or mineral aggregate has the external crystal form of a preexisting different mineral (pseudomorphism) or where the juxtaposition of two minerals indicates that one was formed at the expense of the other.

Finally, crystal zoning describes faintly to very well-defined geometric arrangements of portions within individual crystals that differ significantly in composition (or some other property) from adjacent portions; most common are successive shells grouped concentrically about the centres of crystals, presumably reflecting shifts in conditions during crystal growth.

Structural features

The structure of an igneous rock is normally taken to comprise the mutual relationships of mineral or mineral-glass aggregates that have contrasting textures, along with layering, fractures, and other larger-scale features that transect or bound such aggregates. Structure often can be described only in relation to masses of rock larger than a hand specimen, and most of its individual expressions can be closely correlated with physical conditions that existed when the rock was formed.

SMALL-SCALE STRUCTURAL FEATURES

Among the most widespread structural features of volcanic rocks are the porelike openings left by the escape of gas from the congealing lava. Such openings are called vesicles, and the rocks in which they occur are said to be vesicular. Where the openings lie close together and form a large part of the containing rock, they impart to it a slaglike, or scoriaceous, structure. Their relative abundance is even greater in the type of sialic glassy rock known as pumice, which is essentially a congealed volcanic froth. Most vesicles can be likened to peas or nuts in their ranges of size and shape; those that were formed when the lava was still moving tend to be flattened and drawn out in the direction of flow. Others are cylindrical, pearlike, or more irregular in shape, depending in part on the manner of escape of the gas from the cooling lava; most of the elongate ones occur in subparallel arrangements.

Many vesicles have been partly or completely filled with quartz, chalcedony, opal, calcite, epidote, zeolites, or other minerals. These fillings are known as amygdules, and the rock in which they are present is amygdaloidal. Some are concentrically layered, others also include centrally disposed series of horizontal layers, and still others are featured by central cavities into which well-formed crystals project.

Features of glassy rocks

Spherulites are light-coloured subspherical masses that commonly consist of tiny fibres and plates of alkali feldspar radiating outward from a centre. Most range from pinpoint to nut size, but some are as much as several feet in diameter. The relatively large ones tend to be internally complex and to contain concentric shells of feldspar fibres with or without accompanying quartz, tridymite, or glass. Spherulites occur mainly in glassy volcanic rocks; they also are present in some partly or wholly crystalline rocks that include shallow-seated intrusive types. Many evidently are products of rapid crystallization, perhaps at points of gas concentration in the freezing magmas. Others, in contrast, were formed more slowly, by devitrification of volcanic glasses, presumably not long after they congealed and while they were still relatively hot.

Lithophysae, also known as stone bubbles, consist of concentric shells of finely crystalline alkali feldspar separated by empty spaces; thus, they resemble an onion or a newly blooming rose. Commonly associated with spherulites in glassy and partly crystalline volcanic rocks of salic composition, many lithophysae are about the size of walnuts. They have been ascribed to short episodes of rapid crystallization, alternating with periods of gas escape when the open spaces were developed by thrusting the feldspathic shells apart or by contraction associated with cooling. The curving cavities commonly are lined with tiny crystals of quartz, tridymite, feldspar, topaz, or other minerals deposited from the gases.

Some glassy rocks of silicic composition are marked by domains of strongly curved, concentrically disposed fractures that promote breakage into rounded masses of pinhead to walnut size. Because their surfaces often have a pearly or shiny lustre, the name perlite is applied to such rocks. Perlite is most common in glassy silicic rocks that have interacted with water to become hydrated. During the hydration process, water enters the glass, breaking the silicon-oxygen bonds and causing an expansion of the glass structure to form the curved cracks. The extent of hydration of glass, indicating the amount of perlite that has been formed from the glass, depends on the climate and on time. In a given area where the climate is expected to be consistent, the thickness of the hydration of the glass surface has been used by archaeologists to date artifacts such as arrowheads composed of the dark volcanic glass known as obsidian and made by early native Americans.

Numerous structural features of comparably small scale occur among the intrusive rocks; these include miarolitic, orbicular, plumose, and radial structures. Miarolitic rocks are salic phanerites distinguished by scattered pods or layers, ordinarily several centimetres in maximum thickness, within which their essential minerals are coarser-grained, subhedral to euhedral, and otherwise pegmatitic in texture. Many of these small interior bodies, called miaroles, contain centrally disposed crystal-lined cavities that are known as druses or miarolitic cavities. An internal zonal disposition of minerals also is common, and the most characteristic sequence is alkali feldspar with graphically intergrown quartz, alkali feldspar, and a central filling of quartz. Miarolitic structure probably represents local concentration of gases during very late stages in consolidation of the host rocks.

The term orbicular is applied to rounded, onionlike masses with distinct concentric layering that are distributed in various ways through otherwise normal-appearing phaneritic rocks of silicic to basic composition. The layers within individual masses are typically thin, irregular, and sharply defined, and each differs from its immediate neighbours in composition or texture. Some layers contain tabular or prismatic mineral grains that are oriented radially with respect to the containing orbicule and, hence, are analogous to spherulitic layers in volcanic rocks. The minerals of most orbicules are the same as those of the enclosing rock, but they are not necessarily present in the same proportions. The concentric structure appears to reflect rhythmic crystallization about specific centres, commonly at early stages in consolidation of the general rock mass.

Orbicular structures

The normal fabric of some relatively coarse-grained plutonic rocks is interrupted by clusters of crystals with radial grouping but without concentric layering. A characteristic plumelike, spraylike, or rosettelike structure is imparted by the markedly elongate form of the participating crystals or crystal aggregates, which seem to have developed outward from common centres by direct crystallization from magma or by replacement of preexisting solid material.

LARGE-SCALE STRUCTURAL FEATURES

Many kinds of larger-scale features occur among both the intrusive and the extrusive rocks (see Figure 107). Most of these are mentioned later in connection with rock occurrence or are discussed in other articles, but several are properly introduced here:

Clastic structures. These are various features that express the accumulation of fragments or the rupturing and dislocation of solid material. In volcanic environments they generally result from explosive activity or the incorporation of solid fragments by moving lava; as such, they characterize the pyroclastic rocks. Among the plutonic rocks, they appear chiefly as local to very extensive zones of pervasive shearing, dislocation, and granulation, commonly best recognized under the microscope. Those developed prior to final consolidation of the rock are termed protoclastic; those developed after final consolidation, cataclastic.



Figure 107: Irregular branching dikes and tongues of medium-grained quartz diorite in darker-coloured gabbro and metamorphic rocks, near Escondido, Calif., U.S. The boundaries are sharply defined, and very thin, straight stringers of light-coloured aplite transect all the other rocks.
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Flow structures. These are planar or linear features that result from flowage of magma with or without contained crystals. Various forms of faintly to sharply defined layering and lining typically reflect compositional or textural inhomogeneities, and they often are accentuated by concentrations or preferred orientation of crystals, inclusions, vesicles, spherulites, and other features.

Fractures. These are straight or curving surfaces of rupture directly associated with the formation of a rock or later superimposed upon it. Primary fractures generally can be related to emplacement or to subsequent cooling of the host rock mass. The columnar jointing found in many basic volcanic rocks is a typical result of contraction upon cooling.

Inclusions. These are rounded to angular masses of solid material enclosed within a rock of recognizably different composition or texture. Those consisting of older material not directly related to that of their host are known as xenoliths, and those representing broken-up and detached older parts of the same igneous body that encloses them are termed cognate xenoliths or autolithes.

Xenoliths and autolithes

Pillow structures. These are aggregates of ovoid masses, resembling pillows or grain-filled sacks in size and shape, that occur in many basic volcanic rocks. The masses are separated or interconnected, and each has a thick vesicular crust or a thinner and more dense glassy rind. The interiors ordinarily are coarser-grained and less vesicular. Pillow structure is formed by rapid chilling of highly fluid lava in contact with water or water-saturated sediments, accompanied by the development of budlike projections with tough, elastic crusts. As additional lava is fed into each bud, it grows into a pillow and continues to enlarge until rupture of the skin permits escape of fresh lava to form a new bud and a new pillow.

Segregations. These are special types of inclusions that are intimately related to their host rocks and in general are relatively rich in one or more of the host-rock minerals. They range from small pods to extensive layers and from early-stage crystal accumulations formed by gravitational settling in magma to very late-stage concentrations of coarse-grained material developed in place.

Zonal structures. These are arrangements of rock units with contrasting composition, or texture, in an igneous body, commonly in a broadly concentric pattern. Chilled margins, the fine-grained or glassy edges along the borders of many extrusive and shallow-seated intrusive bodies, represent quenching of magma along contacts with cooler country rock. Other kinds of zones generally reflect fractional crystallization of magma and are useful in tracing courses of magmatic differentiation, as will be noted later.

Classification of igneous rocks

Igneous rocks are classified on the basis of mineralogy, chemistry, and texture. As discussed earlier, texture is used to subdivide igneous rocks into two major groups: (1) the plutonic rocks, with mineral grain sizes that are visible to the naked eye, and (2) the volcanic and hypabyssal types, which are usually too fine-grained or glassy for their mineral composition to be observed without the use of a petrographic microscope. Being rather coarsely grained, phaneritic rocks readily lend themselves to a classification based on mineralogy since their individual mineral components can be discerned, but the volcanic rocks are more difficult to classify because either their mineral composition is not visible or the rock has not fully crystallized owing to fast cooling. As a consequence, various methods employ chemical composition as the criterion for volcanic igneous rock classification. A commonly used technique was introduced at the beginning of the 20th century by the American geologists C. Whitman Cross, Joseph P. Iddings, Louis V. Pirsson, and Henry S. Washington. In this method, the mineral composition of the rock is recalculated into a standard set of typically occurring minerals that theoretically could have developed from the complete equilibrium crystallization at low temperatures of a magma of the indicated bulk composition. The calculated hypothetical mineral composition is called the norm, and the minerals constituting the standard set are termed normative minerals, since they are ordinarily found in igneous rocks. The rock under analysis may then be classified according to the calculated proportions of the normative minerals.

Because other methods for calculating the norm have been devised, this original norm is referred to as the CIPW norm after the initials of the four petrologists who devised the system. The norm calculation allows the petrologist studying an aphanitic rock to "see" the mineral assemblage that corresponds well with the actual mineral assemblage of a plutonic rock of the same composition that had crystallized under equilibrium conditions. Moreover, the norm has been shown to have a thermodynamic basis. The concept of silica saturation discussed above is incorporated into the norm, which will show whether a magma of a certain composition is supersaturated, saturated, or undersaturated by the presence or absence of normative minerals such as quartz, hypersthene, olivine, and the feldspathoids.

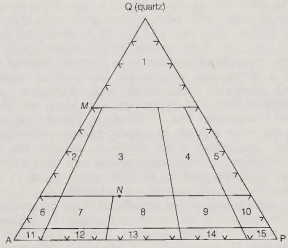
CIPW norm

CLASSIFICATION OF PLUTONIC ROCKS

A plutonic rock may be classified mineralogically based on the actual proportion of the various minerals of which it is composed (called the mode). In any classification scheme, boundaries between classes are set arbitrarily; however, if the boundaries can be placed closest to natural divisions or gaps between classes, they will seem less random and subjective, and the standards will facilitate universal understanding. In order to set boundaries nearest to the population lows (of constituent minerals) and to achieve an international consensus, a poll among the world's petrologists was conducted and a modal classification for plutonic igneous rocks was devised. Based mainly on this poll, the International Union of Geological Sciences (IUGS) Subcommission on the Systematics of Igneous Rocks in 1973 suggested the use of the modal composition for all plutonic igneous rocks with a colour index less than 90 (Figure 108) and for those plutonic ultramafic rocks with a colour index greater than 90 (Figure 109).

The plotting of rock modes on these triangular diagrams is simpler than it may appear. If the colour index is less than 90 and quartz (Q) is present, then the three components, Q + A (alkali feldspar) + P (plagioclase), are recalculated from the mode to sum to 100 percent and Figure 108 is used. Each component is represented by the corners of the equilateral triangle, the length of whose sides are divided into 100 equal parts. Any composition plotting at a corner, therefore, has a mode of 100 percent of the corresponding component. Any point on the sides of the triangle represents a mode composed of the two adjacent corner components. For example, a rock with 60 percent Q and 40 percent A will plot on the QA side at a location 60 percent of the distance from A to Q (see point *M* in Figure 108). A rock containing all three components will plot within the triangle. Since the sides of the triangle

Plot of rock modes



1	Q greater than 60%	not igneous
2	Q = 20–60%, P = 0–10%	alkali granite (alkali rhyolite)
3	Q = 20–60%, P = 10–65%	granite (rhyolite)
4	Q = 20–60%, P = 65–90%	granodiorite (dacite)
5	Q = 20–60%, P = 90–100%	tonalite (dacite)
6	Q = 5–20%, P = 0–10%	alkali quartz syenite (alkali quartz trachyte)
7	Q = 5–20%, P = 10–35%	quartz syenite (quartz trachyte)
8	Q = 5–20%, P = 35–65%	quartz monzonite (quartz latite)
9	Q = 5–20%, P = 65–90%	
	sodic plagioclase	quartz monzodiorite (andesite)
	calcic plagioclase	quartz monzogabbro (basalt)
10	Q = 5–20%, P = 90–100%	
	sodic plagioclase	quartz diorite (andesite)
	calcic plagioclase	quartz gabbro (basalt)
	mafics = 0–10%	quartz anorthosite
11	Q = 0–5%, P = 0–10%	alkali syenite (alkali trachyte)
12	Q = 0–5%, P = 10–35%	syenite (trachyte)
13	Q = 0–5%, P = 35–65%	monzonite (latite)
14	Q = 0–5%, P = 65–90%	
	sodic plagioclase	monzodiorite (andesite)
	calcic plagioclase	monzogabbro (basalt)
15	Q = 0–5%, P = 90–100%	
	sodic plagioclase	diorite (andesite)
	calcic plagioclase	gabbro (basalt)

Figure 108: Modal classification of plutonic igneous rocks with less than 90 percent mafic minerals. The names in parentheses are the equivalent volcanic rocks.

After IUGS Subcommission on the Systematics of Igneous Rocks, "Plutonic Rocks, Classification and Nomenclature," *Geotimes*, 18, no. 10 (1973). Reprinted with permission from *Geotimes*

are divided into 100 parts, a rock having a mode of 20 percent Q and 80 percent A + P (in unknown proportions for the moment) will plot on the line that parallels the AP side and lies 20 percent of the distance toward Q from the side AP. If this same rock has 30 percent P and 50 percent A, the rock mode will plot at the intersection of the 20 percent Q line described above, with a line paralleling the QA side at a distance 30 percent toward P from the QA side (see point *N* in Figure 108). The third intersecting line for the point is necessarily the line paralleling the QP side at 50 percent of the distance from the side QP toward A.

A rock with 25 percent Q, 35 percent P, and 40 percent A plots in the granite field, whereas one with 25 percent Q, 60 percent P, and 15 percent A plots in the granodiorite field. The latter is close to the average composition of the continental crust of the Earth. Igneous rocks normally do not exceed about 50 percent quartz, and the feldspathoidal rocks are relatively rare. The most common plutonic rocks are those in fields numbered 3, 4, 5, 8, 9, 10, and 15. These are found in what have been called granite (used in a loose sense) batholiths, which are irregularly shaped large bodies covering an area greater than 100 square kilometres. Batholiths constitute the cores of the great mountain ranges, such as the Rockies in western North America and the Sierra Nevada in California, U.S. Typically these batholiths are composites of smaller intrusions, each of which may display several different rock types. The average composition is close to that of a granodiorite, but in many batholiths the sequence of intrusions progresses from basic to acidic, with gabbro or quartz diorite being emplaced first. In the Sierra Nevada batholith, the dominant rocks are quartz monzonite and granodiorite, with intrusions including quartz diorite in the far western rim and granite in the east. Batholiths contain medium- to coarse-grained rocks with hypidiomorphic-granular texture. The rocks are generally leucocratic; diorites and quartz diorites typically contain less than 30 percent mafic minerals—*e.g.*, hornblende and biotite. Pyroxenes are rare but are more commonly found in the gabbros. Mineralogically the ratio of hornblende to biotite, the colour index, the calcium content of the plagioclase feldspar, and the ratio of plagioclase to alkali feldspar decrease from diorite to quartz diorite to granodiorite and granite. Common accessory minerals include apatite, sphene, and an opaque mineral such as magnetite or ilmenite.

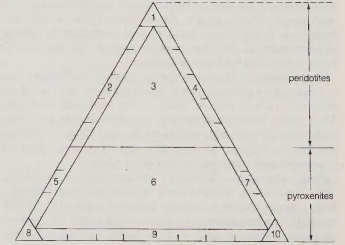
Ideally it would be preferable to use the same modal scheme for volcanic rocks. This is recommended whenever possible; hence, for this purpose, the volcanic or hypabyssal equivalent of the plutonic rocks are listed in parentheses in Figure 108. It should be noted that the dividing lines and boxes are identical to those for the plutonic rocks.

CLASSIFICATION OF VOLCANIC AND HYPABYSSAL ROCKS

Owing to the aphanitic texture of volcanic and hypabyssal rocks, their modes cannot be readily determined; consequently, a chemical classification is widely accepted and employed by most petrologists. One popular scheme is based on the use of both chemical components and normative mineralogy. Because most lay people have little access to analytic facilities that yield igneous rock compositions, only an outline will be presented here in order to provide an appreciation for the classification scheme.

The first major division is based on the alkali (soda + potash) and silica contents (see Figure 110), which yield two groups, the subalkaline and alkaline rocks. The subalkaline rocks have two divisions based mainly on the iron content (Figure 111) with the iron-rich group called the tholeiitic series and the iron-poor group called calc-alkalic. The former group is most commonly found along the oceanic ridges and on the ocean floor; the latter group is characteristic of the volcanic regions of the continental margins (convergent, or destructive, plate boundaries; see below *Forms of occurrence: Distribution of igneous rocks on the Earth's surface*). In some magmatic arcs (groups of islands arranged in a curved pattern), notably Japan, both the tholeiitic and calc-alkalic series occur. This is the case, for example, in the volcanoes of northeastern Honshu, the largest of Japan's four main islands, and both series may be found within the same volcano. The alkaline rocks frequently occur on oceanic islands (usually formed during the late stages of magma consolidation after tholeiitic eruptions) and in continental rifts (extensive

Tholeiitic and calc-alkalic series



1	dunite	6	olivine websterite
2	harzburgite	7	olivine clinopyroxenite
3	lherzolite	8	orthopyroxenite
4	wehrlite	9	websterite
5	olivine orthopyroxenite	10	clinopyroxenite

Figure 109: Modal classification of phaneritic igneous rocks with more than 90 percent mafic minerals.

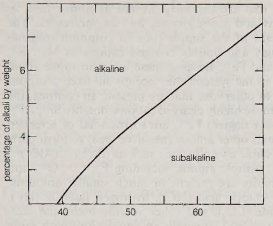


Figure 110: Alkali-silica (SiO_2) plot subdividing the area into alkaline and subalkaline fields. The rare peralkaline field is not illustrated.

After T. Irvine and W. Baragar, "A Guide to the Chemical Classification of the Common Volcanic Rocks," *Canadian Journal of Earth Sciences*, vol. 8 (1971)

fractures). Based on the relative proportions of soda and potash, the calc-alkalic series is subdivided into the sodic and potassic series.

Chemically the subalkaline rocks are saturated with respect to silica; consequently, they have normative minerals such as hypersthene [low-calcium orthopyroxene, $(Mg, Fe)_2Si_2O_6$] and quartz but lack nepheline and olivine (in the presence of quartz). This chemical property also is reflected in the mode of the basic members that have two pyroxenes, hypersthene and augite [$Ca(Mg, Fe)Si_2O_6$], and perhaps quartz. Plagioclase is common in phenocrysts, but it can also occur in holocrystalline rocks in the microcrystalline matrix along with the pyroxenes and an iron–titanium oxide phase. In addition to the differences in iron content between the tholeiitic and calc-alkalic series, the latter has a higher alumina content (16 to 20 percent), and the range in silica content is larger (48 to 75 percent compared to 45 to 63 percent for the former). Hornblende and biotite phenocrysts are common in the calc-alkalic andesites and dacites but are lacking in the tholeiites except as alteration products. The dacites and rhyolites commonly have phenocrysts of plagioclase, alkali feldspar (usually sanidine), and quartz in a glassy matrix. Hornblende and plagioclase phenocrysts are more widespread in dacites than in rhyolites, which have more biotite and alkali feldspar. When occurring near volcanic vents, (openings from which volcanic materials are brought to the Earth's surface), basalts and andesites of both series are found as tuffs or agglomerates; otherwise, they typically occur as flows. Dacite and rhyolite occur as flows near vents but are most commonly found as tuffs composed of fragmented pieces of glass, phenocrysts, and rock.

The alkaline rocks typically are chemically undersaturated with respect to silica; hence they lack normative hypersthene (*i.e.*, they have only one pyroxene, the calcium-rich augite) and quartz but have normative nepheline. Microscopic examination of the alkali olivine basalts usually reveals phenocrysts with an abundance of olivine, one pyroxene (augite, which is usually titanium-rich), and plagioclase. Nepheline may be seen in the matrix. Trachytes typically are leucocratic with an abundance of feldspars aligned roughly parallel to the direction of the lava flow.

After T. Irvine and W. Baragar, "A Guide to the Chemical Classification of the Common Volcanic Rocks," *Canadian Journal of Earth Sciences*, vol. 8 (1971)

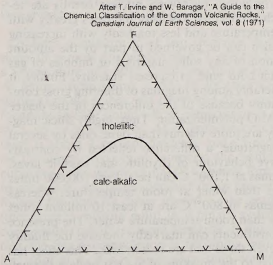


Figure 111: Plot used to separate tholeiitic rocks from calc-alkalic rocks. F = total Fe expressed as FeO = weight percent FeO + (0.9 × weight percent Fe_2O_3), M = weight percent MgO, and A = weight percent $Na_2O + K_2O$.

Origin and distribution

ORIGIN OF MAGMAS

Basaltic magmas that form the oceanic crust of the Earth are generated in the asthenosphere at a depth of about 70 kilometres. The mantle rocks located at depths from about 70 to 200 kilometres are believed to exist at temperatures slightly above their melting point, and possibly 1 or 2 percent of the rocks occur in the molten state. As a result, the asthenosphere behaves plastically, and upon penetrating this zone seismic waves experience a slight drop in velocity; this shell came to be known as the low velocity zone. Only after the acceptance of the plate tectonic theory has this zone become known as the asthenosphere (see PLATE TECTONICS). The most common mantle rock within the asthenosphere is peridotite, which is composed predominantly of magnesium-rich olivine, along with lesser amounts of chromium diopside and enstatite and an even smaller quantity of garnet. Peridotite may undergo partial melting to produce magmas with different compositions.

Low velocity zone

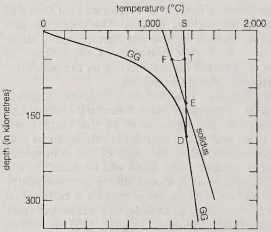


Figure 112: A proposed temperature distribution within the Earth. The geothermal gradient is represented by the curve GG. The melting curve (solidus) for a representative mantle rock is shown. The adiabatic rise of mantle rock is illustrated by the curve DS. See text for further explanation.

Theories on the generation of basaltic magma mainly attribute its origin to the derivation of heat from within peridotite rather than by some outside source such as the radioactive decay of uranium, thorium, and potassium, which are only of minor consequence. Because of the difference in composition between basalt and peridotite, only a small amount of heat is needed to produce about 3 to at most 25 percent melt. Many theories have been proposed, but only the simplest and most popular is discussed here. The change in the temperature of the Earth as a function of depth, given by the estimated geothermal gradient, and the experimentally based melting curve (solidus) of the peridotite are illustrated in Figure 112. At depth D, the geothermal gradient curve and the solidus of the peridotite have their closest approach, but the peridotite is still solid. Diverse mechanisms have been proposed to explain the cause for the intersection here of the two curves. One theory suggests that a decrease in pressure (equivalent to depth) at constant composition and without loss of heat will cause the peridotite to melt along the curve DS. This is identical to an adiabatic cooling process (one without an overall loss or gain of heat) in which temperature will drop slightly owing to the expansion of the rock that occurs in response to the pressure decrease. The drop in temperature is about 10 times smaller than the drop in temperature along the solidus for the same decrease in pressure. Physically, the peridotite rises to a lesser depth

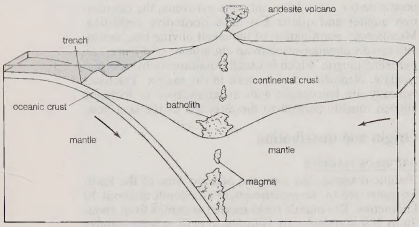


Figure 113: Collision of a continental plate with an oceanic plate. The oceanic plate is shown subducting below the continental crust. Melting of the crust or of the mantle above the subducting plate occurs only at a depth of about 100 kilometres below the Earth's surface.

owing to convection in the mantle (the zone below the Earth's crust) without any exchange of heat. Melting is initiated when the curve DS intersects the melting curve at point E. As the peridotite continues to rise, it will follow the melting curve, continually producing more melt. This results from the peridotite providing its own heat. To illustrate this, consider the peridotite following the adiabatic curve DS from E to point T where it is (T − F) degrees above the melting curve. Allowing the peridotite to cool at this pressure from T to F releases heat that will be consumed in the melting process. The peridotite can be thought of as making similar but infinitesimally small steps like E to T to F as it moves along the solidus. In this way heat is provided for the melting as the peridotite moves continuously along the solidus.

Granitic and andesitic magmas

Granitic, or rhyolitic, magmas and andesitic magmas are generated at convergent plate boundaries where the oceanic lithosphere (the outer layer of the Earth composed of the crust and upper mantle) is subducted so that its edge is positioned below the edge of the continental plate or another oceanic plate. Heat will be added to the subducting lithosphere as it moves slowly into the hotter depths of the mantle. The andesitic magma is believed to be generated in the wedge of mantle rock below the crust and above the subducted plate (Figure 113) or within the subducted plate itself. The former requires the partial melting of a "wet" peridotite. Experiments conducted at pressures simulating mantle conditions have demonstrated that peridotite will produce andesitic melts during partial melting under hydrous conditions. The latter theory suggests that the subducted basaltic crust is partially melted and may be combined with some subducted oceanic sediments to form andesites. A third theory involves the mixing of basaltic magma that was generated in the mantle with granitic or rhyolitic magma or with crustal rocks. The silicic magmas can be formed by a combination of two processes; the presence of water under pressure lowers the melting temperature by as much as 200° C (392° F) and thereby expedites magma generation. At a convergent plate boundary, the lower continental crust is heated to a temperature near its melting point by being pushed downward into hotter regions of the mantle. Basaltic or andesitic magma generated below the crust may accumulate near the Moho, which is a discontinuity that separates the Earth's crust from its mantle. As the magma cools, it crystallizes and releases its latent heat of crystallization. This evolved heat is transferred to the lower crustal rocks along with the simple heat released by cooling. If the lower crustal rocks contain some water, their melting temperatures would be lowered and the heating provided by the above processes would possibly be sufficient to partially melt the crustal rocks producing rhyolitic magma.

NATURE OF MAGMAS

Magmas are chemically complex fluid systems that differ in many ways from ordinary solutions, in which water is the solvent and the dominant constituent. They can be thought of as mutual solutions, or melts, of rock-forming components that are variously present as simple ions, as complex ions and ionic groups, and as molecules. The most abundant of the simple ions in common magmas are such singly and doubly charged cations as Na^+, K^+, Ca^{2+}, Mg^{2+}, and Fe^{2+}. Because these ions can move about rather freely in the system, they occupy no fixed positions with respect to other ions that are present. In contrast, the smaller and more highly charged cations, notably Si^{4+}, Al^{3+}, and (to a lesser degree) Fe^{3+}, are surrounded or screened by O^{2-} ions and other anions (negative ions) to form parts of relatively stable complex ions such as $(SiO_4)^4$, $(AlO_4)^{5-}$, and $(FeO_4)^{9-}$. Simple anions, including F^-, Cl^-, O^{2-}, and $(OH)^-$, ordinarily are present in much smaller amounts. Water, hydrochloric acid (HCl), hydrogen fluoride (HF), carbon dioxide (CO_2), and other volatile molecular substances occur as well, generally in equilibrium with ionic forms such as $(OH)^-$, Cl^-, F^-, and $(CO_3)^{2-}$.

Because the bond that unites silicon and oxygen is a remarkably strong one, $(SiO_4)^{4-}$ ions are stable in magmas even at exceedingly high temperatures. They also tend to join with one another, or polymerize, to form more complex anionic groups, a tendency that is especially great in the more silicic magmas. The joining is accomplished by a sharing of oxygen ions between adjacent silicon ions to form Si-O-Si bridges like those in many silicate and aluminosilicate minerals; in the simplest such case, $(Si_2O_7)^{6-}$ ions are the result. Because the $(AlO_4)^{5-}$ ions also have a strong tendency to polymerize, most of the large ionic groups in magmas probably contain both silicon and aluminum ions. These groups, which resemble the frameworks of many rock-forming minerals but are geometrically less regular, significantly affect the viscosity and crystallization of magmas.

Viscosity of magmas

The viscosity of magmas, which spans an enormous range of values, affects their flow behaviour, the movements of crystals and inclusions of foreign matter within them, the diffusion of materials through them, the growth of crystals from them, and the explosivity of eruptions (when aided by growth of gas bubbles near the surface). Lava flows are thin and rapid for low-viscosity magmas, but thick and slow for viscous flows. Fluid magma promotes the growth of large crystals such as the ones found in pegmatites, but crystal growth is prevented in viscous magmas, which usually are quenched as glass. Highly explosive eruptions such as occurred at Mount St. Helens commonly result from gas bubbles nucleating, growing, and rising in a highly viscous magma. It can be demonstrated thermodynamically that the overpressure (excess rock pressure) developed in growing and rising bubbles is inversely proportional to their radii. In fluid magmas, gas bubbles grow large in size and rise quickly, which causes their pressures to be expended; hence, only a spectacular fountaining of hot lava is observed at the surface. In contrast, a viscous magma prevents the growth of bubbles, so that they will rise slowly while retaining excess pressure; as a result, the associated volcano erupts violently. Energies equivalent to the amount produced by several nuclear bombs are released in such explosions. Viscosity increases greatly with decreasing temperature and less markedly with increasing pressure. It also can be governed in part by the amount and distribution of any solid materials or bubbles of gas present, which both tend to increase viscosity. Finally, it varies considerably among magmas of differing gross composition, mainly because of the differences in the degree of Si-O and Al-O polymerization. Thus, highly silicic magmas generally are more viscous than basic ones by several orders of magnitude, a difference reflected by contrasts in the eruptive behaviour of rhyolitic and basaltic lavas. Basaltic magmas at 1,100° C can be at least 100,000 times more viscous than water at room temperature, whereas rhyolitic magmas at 800° C are at least 10 million times more viscous than room-temperature water. The presence of volatile constituents can markedly increase the fluidity of magmas, even those that are rich in SiO_2. This effect has been attributed to the breaking of Si-O-Si bridges through substitution of ions such as F^- and $(OH)^-$ for shared O^{2-} ions in elements of the polymerized groups.

A typical magma can be broadly viewed as an assemblage of relatively large and rather closely packed oxygen ions,

among which some cations have considerable mobility; others, such as Si^{4+} and Al^{3+}, tend to occupy positions that are more fixed. The entire system is a dynamic one, however, and even the largest of the Si-O and Al-O ion groups are constantly changing form and position as bonds are broken and new ones are established. If the magma quickly loses thermal energy and cools to a glass, these internal movements are sharply restricted, and the various constituents become essentially frozen in position. If cooling is slower, the contained complex ions and polymerized ion groups have time to assume more regular arrangements and to be stabilized by cations of appropriate size, charge, and other properties. Crystalline solids are thereby formed. Their regular internal structure is relatively conserving of space, and so they have somewhat higher specific gravities than the magma from which they were nourished.

CRYSTALLIZATION FROM MAGMAS

Crystallization temperatures

Because magmas are multicomponent solutions, they do not crystallize at a single temperature at a given pressure like water at 0° C and one atmosphere pressure. Rather, they crystallize over a wide range of temperatures beginning at liquidus temperatures for basaltic magmas as high as 1,150° C and ending as a complete solid at a low solidus temperature of about 800° C. During their crystallization at constant pressure, common minerals that make up basaltic magma (*e.g.*, olivine) become unstable at some temperature and react with the liquid to form a more stable phase. In the case of olivine, this phase is pyroxene. This reaction relationship is best illustrated with the use of a phase diagram of a portion of the olivine Mg_2SiO_4 (forsterite) + SiO_2 (cristobalite, a high-temperature form of quartz) binary system at one atmosphere (see Figure 114).

After N. Bowen and O. Andersen, "The Binary System MgO-SiO_2," *American Journal of Science*, vol. 37 (1914)

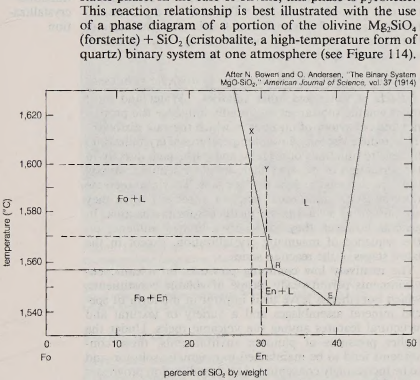


Figure 114: Phase diagram of a part of the Mg_2SiO_4 (forsterite, or Fo)–SiO_2 (silica) system at one atmosphere of pressure. En = enstatite and L = liquid. See text for further discussion.

Consider a mixture X of two minerals in the proportions 28 percent cristobalite and 72 percent forsterite. At a temperature of 1,601° C, this mixture is entirely liquid. At temperatures below 1,557° C, forsterite (Fo) and enstatite (En) are stable, but between 1,557° and 1,600° C, forsterite and the liquid whose composition is represented by L are in equilibrium. At a temperature of 1,570° C, there is about 7 percent forsterite and 93 percent liquid. As the liquid X cools, it intersects the liquidus freezing curve at a temperature of 1,600° C, where forsterite begins to crystallize. As the temperature drops further, the liquid follows the liquidus down toward R, the peritectic point (incongruent melting point in a binary system), while it continually crystallizes more forsterite. It should be noted that the liquid composition is becoming enriched in silica, until at R, it has more silica than enstatite. At this point the forsterite reacts with the liquid to yield two moles of $MgSiO_3$ (enstatite) for every mole of Mg_2SiO_4 that combines with one mole of SiO_2 removed from the liquid R. This can be written as a chemical equation:

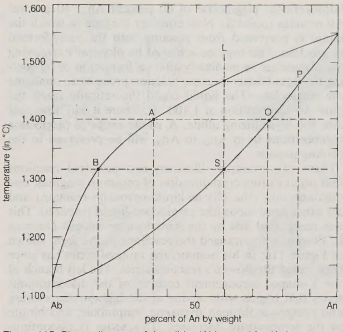


Figure 115: Phase diagram of the albite (Ab)–anorthite (An) system at one atmosphere of pressure. The curve that includes points A and B is the liquidus, and the curve with points P, O, and S is the solidus (see text).

After N. Bowen, "Melting Phenomena of the Plagioclase Feldspars," *American Journal of Science*, vol. 34 (1913)

$Mg_2SiO_4 + SiO_2 \rightleftarrows 2MgSiO_3$. Because SiO_2 is removed from the liquid R, a proportionate amount of enstatite must be crystallized from the liquid to keep its composition at point R. In the case of the starting composition X, which is depleted in SiO_2 relative to enstatite, the peritectic liquid, R, will be consumed by the reaction prior to the forsterite, and the resultant mixture will consist of forsterite and enstatite. However, in the case in which the starting composition is Y, which is enriched in silica relative to enstatite, the forsterite will be depleted before the liquid, and the reaction will yield the liquid and enstatite. Only in the case where the starting composition matches that of enstatite will the liquid and the forsterite be consumed at the same time, leaving only enstatite. The starting composition X represents the most common crystallization behaviour for saturated tholeiitic basaltic magmas; consequently, these magmas will experience a reaction between the liquid and the olivine, forsterite, at some point during their crystallization. This means that the liquid will be consumed by the reaction with forsterite and crystallization will cease. If, however, forsterite can be removed physically from the liquid before the reaction can occur, the reaction will be prevented and the peritectic liquid (like R in the figure) will remain to crystallize the pyroxene, enstatite, and move down toward the eutectic temperature (like E in the figure) where cristobalite and enstatite will crystallize. (For further explanation of eutectic and peritectic systems, see also MATTER: *Phase changes and equilibria: Phase diagrams: Binary systems.*)

Albite-anorthite system

Most of the common minerals found in igneous rocks are solid-solution phases. These include olivine, pyroxene, amphibole, biotite, and plagioclase feldspars. Crystallization behaviour is illustrated best by using the $NaAlSi_3O_8$ (albite or Ab)–$CaAl_2Si_2O_8$ (anorthite or An) plagioclase system shown in Figure 115. Consider a liquid of composition L (60 percent An + 40 percent Ab) which is at an initial temperature of 1,500° C. On cooling it will begin crystallizing plagioclase with 85 percent An (point P on the solidus) at the liquidus temperature of about 1,470° C. As cooling continues further, the liquid will move down the liquidus toward B while simultaneously reacting continuously with the early-formed plagioclase to convert it to a homogeneous plagioclase that is more albitic and in equilibrium with the liquid. For example, when the liquid has reached A, at 1,400° C, about 65 percent plagioclase with about 73 percent An (point O on the solidus) has crystallized from the liquid, which is now at about 36 percent An and 64 percent Ab. Finally, when the temperature of about 1,330° C is reached (B in the figure), the last small amount of the liquid of composition 20 percent An + 80 percent Ab is consumed in the reaction and a

homogeneous plagioclase of 60 percent An + 40 percent Ab remains (point S). Now consider the case in which the liquid is prevented from reacting with the early-formed plagioclase. This may be achieved by physically removing the plagioclase immediately after its formation or by cooling the liquid faster than the reaction process can consume the plagioclase. The liquid could theoretically reach the pure Ab composition at 1,100° C, where it will disappear into the crystallizing albite. A whole range of plagioclase compositions from An_{84} to An_{00} will be preserved in the cooling process.

These two examples illustrate two principal reactions that occur during crystallization of common magmas, one discontinuous (the olivine-liquid-pyroxene reaction) and the other continuous (the plagioclase-liquid reaction). This was recognized first by the American petrologist Norman L. Bowen, who arranged the reactions in the form shown in Figure 116; in his honour, the mineral series has since been called the Bowen's reaction series. The left branch of the Y-shaped arrangement consists of the discontinuous series that begins with olivine at the highest temperature and progresses through pyroxene, amphibole, and biotite as the temperature decreases. This series is discontinuous because the reaction occurs at a fixed temperature at constant pressure wherein the early-formed mineral is converted to a more stable crystal. Each mineral in the series displays a different silicate structure that exhibits increased polymerization as the temperature drops; olivine belongs to the island silicate structure type; pyroxene, the chain; amphibole, the double chain; and biotite, the sheet. On the other hand, the right branch is the continuous reaction series in which plagioclase is continuously reacting with the liquid to form a more albitic phase as the temperature decreases. In both cases, the liquid is consumed in the reaction. When the two reaction series converge at a low temperature, minerals that will not react with the remaining liquid approach eutectic crystallization. Potash feldspar, muscovite, and quartz are crystallized. The phases that are crystallized first are the common minerals that compose basalt or gabbro, like bytownite or labradorite with pyroxene and minor amounts of olivine. Andesite or diorite minerals, such as andesine with either pyroxene or amphibole, crystallize next and are followed by orthoclase and quartz, which are the essential constituents of rhyolite or granite. A basaltic liquid at the top of the Y can descend to the bottom of the series to crystallize quartz only if the earlier reactions are prevented. As demonstrated above, complete reactions between early-formed minerals and the liquid depletes the supply of the liquid, thereby curtailing the progression down the series. One means by which basaltic magma can be transformed to rocks lower in the series is by fractional crystallization. In this process, the early-formed minerals are removed from the liquid by gravity (such minerals as olivine and pyroxene are denser than the liquid from which they crystallized), and so unreacted liquid remains later in the series.

Bowen's reaction series

Another method of creating different daughter magmas

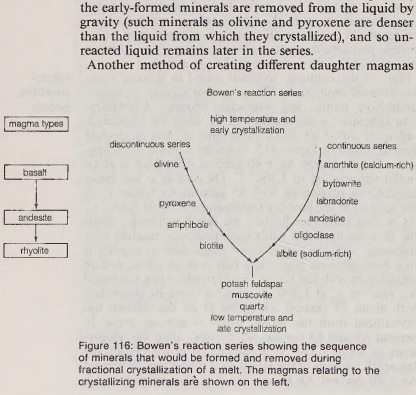


Figure 116: Bowen's reaction series showing the sequence of minerals that would be formed and removed during fractional crystallization of a melt. The magmas relating to the crystallizing minerals are shown on the left.

from a parent is by having the latter react with its wall rocks. Consider a magma that is crystallizing pyroxene and labradorite. If the magma tears from its wall minerals, say, olivine and anorthite, which are formed earlier than pyroxene and labradorite in the series, they will react with the liquid to form these same minerals with which the magma is in equilibrium. The heat for driving this reaction comes directly from the magma itself. More pyroxene and labradorite will crystallize during the reaction and will release their latent heats of crystallization. On the other hand, if a mineral (quartz, for example) formed at a later stage than pyroxene or labradorite falls from the rock wall into the magma, the latent heat provided by further crystallization of pyroxene and labradorite will cause it to dissolve. This situation will occur only if the quartz from the wall rock is at a lower temperature than the magma. It will cause the magma to transfer its heat to the quartz in a cooling process. The cooling of the magma will necessarily be accompanied by the crystallization of the minerals already present. In both cases, the composition of the parent magma will be changed by the xenolithic (foreign rock) contamination. The contaminant need not belong to the reaction series in order for it to cause reactions or dissolution. In most cases, the end result will be a shift from the original composition of the parent magma toward that of the contaminant. This process in which wall rocks are incorporated into the magma is called assimilation. Because assimilation is accompanied by crystallization, it is likely that both fractional crystallization and assimilation will take place simultaneously. This combined process, referred to as AFC for assimilation–fractional crystallization, has been proposed as the mechanism by which andesites are produced from basalts.

Assimilation–fractional crystallization

VOLATILE CONSTITUENTS AND LATE MAGMATIC PROCESSES

Effects of water and other volatiles. Water and most other volatile substances profoundly influence the properties and behaviour of magmas in which they are dissolved. They reduce viscosity, lower temperatures of crystallization by tens to hundreds of degrees, and participate directly in the formation of minerals that contain essential hydroxyl (OH) or elements such as the halogens. They also increase rates of crystallization and reaction, especially when they are present as a fluid phase distinct from the magma. In general, however, they have only a limited influence on the sequence of magmatic crystallization, except in the latest stages of the reaction series.

The relatively low confining pressures in volcanic environments permit ready escape of volatile constituents, which nonetheless leave their imprint in the form of special mineral assemblages and a variety of textural and structural features among the volcanic rocks. Under the higher pressures of plutonic environments, these constituents tend to be maintained in magmatic solution and to be increasingly concentrated as crystallization progresses with falling temperature. Few members of the reaction series require them as compositional contributors; water, for example, is not thus used until amphiboles or micas begin to form, and even then the amounts removed from the melt rarely are large. Escape of volatiles from the system can occur "osmotically" if the enclosing rocks are pervious to them but not to the magma, but in general they are fractionated in favour of the residual melt until their concentration reaches the limit of solubility under the prevailing conditions of temperature and effective confining pressure. When this happens, normally at a very late stage of magmatic crystallization, they are exsolved from the melt as a separate fluid phase that under most circumstances is a supercritical gas. This process has been referred to as resurgent boiling, a somewhat misleading term because the exsolved fluid is not necessarily expelled from the system.

Pegmatites and late-stage mineralization. Coexistence of residual magma and a volatile-rich fluid (generally aqueous) promotes the partitioning and segregation of constituents, as well as the growth of very large crystals. The exsolved fluid, with its very low viscosity, not only can move readily through open spaces in the nearly solid igneous rock and in adjacent rocks but also serves as

a medium through which various substances can diffuse rapidly in response to concentration gradients. Thus, it plays an important role in the formation of such special rock types as the pegmatites (Figure 117) and lamprophyres, special features such as miaroles and plumose mineral aggregates, and many kinds of ore deposits whose constituents are derived from the original magma.

Most plutonic systems remain at elevated temperatures for long periods of time after all magma has been used up, and during these periods hydrothermal conditions normally obtain. These depend upon the continued presence of a typically aqueous fluid that further facilitates crystallization and exchanges of materials. It speeds up exsolution within homogeneous solid phases and devitrification of any glass that may be present, and it is a potent agent in the alteration, leaching, and replacement of minerals. Rock textures thereby are modified, especially along boundaries between original mineral grains, and details of composition also can be much changed. In some instances the bulk chemistry of the rock is markedly affected.

Hydrothermal alteration

The hydrothermal alterations favour development of phases such as albite, carbonates, chlorites, clay minerals, epidotes, iron oxides, micas, silica minerals, talc, and zeolites, and many of them are accompanied by gross changes in volume. (R.H.J./A.M.K.)

Richard H. Jahns



Figure 117: Giant lathlike crystals of spodumene in very coarse-grained pegmatite, Harding mine, Dixon, N.M., U.S. These crystals, 1.2 to 3 metres (4 to 10 feet) long, have been warped, cross fractured, and "healed" with quartz (dark). Spodumene, a lithium pyroxene, forms the largest crystals known among the igneous rocks.

Forms of occurrence

EXTRUSIVE IGNEOUS ROCKS

Extrusive igneous rocks are the products of volcanic activity. They appear at the surface as molten lava that spreads in sheets and hardens, or they are made up of fragments of magma ejected from vents by violent gaseous explosions. Large-scale extrusive features include stratovolcanoes (composite cones), shield volcanoes, lava domes, and cinder cones. Smaller extrusive features include lava flows known as pahoehoe and aa. For a detailed description of the principal forms of extrusive igneous rocks, see VOLCANISM: *Volcanic landforms: Major types of volcanic landforms.*

INTRUSIVE IGNEOUS ROCKS

Erosion of volcanoes will immediately expose shallow intrusive bodies such as volcanic necks and diatremes (see Figure 118). A volcanic neck is the "throat" of a volcano and consists of a pipelike conduit filled with hypabyssal rocks. Ship Rock in New Mexico and Devil's Tower in Wyoming are remnants of volcanic necks, which were exposed after the surrounding sedimentary rocks were eroded away. Many craterlike depressions may be filled with angular fragments of country rock (breccia) and juvenile pyroclastic debris. When eroded, such a depression exposes a vertical funnel-shaped pipe that resembles a volcanic neck with the exception of the brecciated filling.

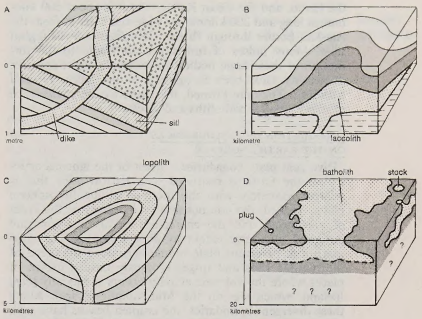


Figure 118: Forms of intrusive igneous rock bodies in hypothetical sections of Earth strata. Note the change of scale from A through D.

These pipes are dubbed diatremes. Many diatremes are formed by explosion resulting from the rapid expansion of gas—carbon dioxide and water vapour. These gases are released by the rising magma owing to the decrease in pressure as it nears the surface. Some diatremes contain kimberlite, a peridotite that contains a hydrous mineral called phlogopite. Kimberlite may contain diamonds.

Dikes are usually tabular bodies that may radiate from the central vent of a volcano or from a volcanic neck (see Figure 118). Not all dikes are associated with volcanoes, but they can be distinguished by their discordant relationship with the structure of the country rock that they cut across. Many dikes are only a few metres wide, but large ones, such as the dike that feeds the Muskox intrusion in the Northwest Territories of Canada, reach widths of more than 150 metres. Related to dikes are features that maintain a concordant relationship with the structure of the country rocks. Magmas may force their way between layers of country rock and solidify parallel to them to form sills (see Figure 118). On the west bank of the Hudson River opposite New York City, the 300-metre-thick Palisades sill is exposed and can be traced for 80 kilometres. A laccolith also is concordant with country rock, but it is distinguished from a sill by having a flat floor with a domed (mushroom-shaped) roof (see Figure 118). Laccoliths were first described in the Henry Mountains of Utah, where they may measure up to 200 metres thick with basal diameters exceeding three kilometres. Rocks of intermediate silica content generally make up these domed intrusions. In contrast, lopoliths are saucer-shaped bodies with a concave upward roof and floor and are commonly composed of mafic rocks. Lopoliths are huge in size; the Bushveld intrusive complex in South Africa, for example, has an area of about 66,000 square kilometres and an exposed thickness of 8 kilometres. The Muskox intrusion, mentioned above, is another large lopolith, which is estimated to be about 80 kilometres long and 11 kilometres wide (roof rocks covering part of the intrusion prevent an exact measurement). These lopoliths are commonly layered with igneous minerals and rocks; in the Bushveld intrusion, one layer about 1 metre thick consisting of almost pure chromite (an ore of chromium) extends for tens of kilometres. Large irregularly shaped plutons are called either stocks or batholiths (see Figure 118), depending on their sizes. Plutons larger than 100 square kilometres in area are termed batholiths, while those of lesser size are called stocks. It may be possible, however, that some stocks are the visible portions of batholiths that have not been exposed by erosion. Batholiths (from the Greek word *bathos*, meaning depth) are deep-seated crustal intrusions, whereas stocks may be formed at shallow depths only a few kilometres below the surface. Rocks ranging from quartz diorite to granite are commonly found in batholiths. Large batholiths in North America include the Sierra Nevada,

Laccoliths and lopoliths

the Idaho, and the Coast Range, which is about 600 kilometres long and 200 kilometres wide and extends from the Alaskan border through British Columbia to Washington state. Many pulses of intrusions contribute to the formation of these large bodies; for example, eight episodes of activity have been recognized in the Sierra Nevada batholith. They are formed, therefore, by the coalescence of many smaller batholiths and stocks.

DISTRIBUTION OF IGNEOUS ROCKS ON THE EARTH'S SURFACE

Divergent plate boundaries. Most of the igneous activity on the Earth is restricted to a narrow zone that is related intimately with the motions of the lithospheric plates. Indeed, the composition of the magma, the types of volcanism, and the characteristics of intrusions are governed to a large extent by plate tectonics. The magmatism at divergent plate boundaries along the crests of the oceanic rises and ridges is mostly unseen except in places where the volcanic activity occurs subaerially (*e.g.,* Iceland, which sits on the Mid-Atlantic Ridge). Along these divergent boundaries, the erupted basalts have such a restricted compositional range that they are referred to as mid-ocean-ridge basalt (MORB). They are subalkaline tholeiites that contain olivine in the norm and less than 0.25 percent potash. The chemistry suggests that MORB was generated from a mantle that was depleted of volatile elements (*e.g.,* lanthanum [La], cerium [Ce], sodium, and potassium) in a previous partial melting process. A wide rift valley marks the crest of most of the oceanic ridges and rises. The valley is bounded by faults created by the divergent forces and is floored in its centre by a fracture zone (a mass of rock with many small breakages). These faults and fractures are the conduits for the MORB magmas that flood the valley, build volcanoes, and produce dikes by filling the conduits. Layer 2 of the oceanic crust results from these magmatic activities (see Figure 119). As the plates diverge, MORB becomes the ocean floor on which oceanic sediments (layer 1) are deposited. This makes MORB the most abundant rock on the surface of the Earth.

Mid-ocean-ridge basalt

Below the collection of lavas and dikes in layer 2 are found gabbro and diorite. They represent the plutonic rocks formed as a result of differentiation of the MORB magma that fed the volcanic activity along the rift. (Differentiation is the process in which more than one rock type is derived from a single parent magma.) These coarse-grained intrusives account for about 4 to 5 kilometres of layer 3, which rests on a sequence of layered ultramafic rocks. The rocks were formed by the gravitative accumulation of mafic minerals from the original MORB magma that filled a large chamber below the ridge axis.

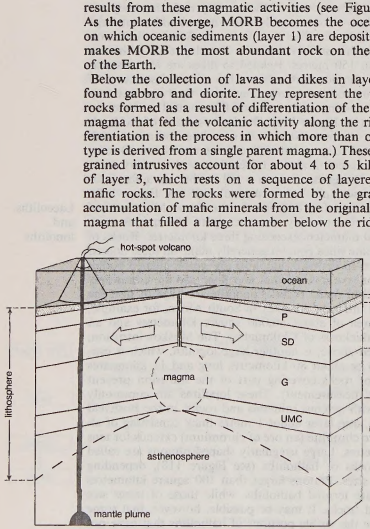


Figure 119: Idealized cross section of a divergent plate boundary showing the structure of the oceanic lithosphere. Layer 1 is composed of sedimentary rocks. P = pillow basalts, SD = sheeted dike complex, G = gabbro, UMC = ultramafic cumulate. Arrows indicate the direction of movement of the diverging plates. Also shown is a hot-spot volcano formed from a rising mantle plume anchored beneath the lithosphere.

Below this layered sequence is mantle rock that is highly deformed and depleted (of elements such as lanthanum, cerium, sodium, and potassium that have been removed by repeated partial melting). Because seismic waves cannot distinguish between layered ultramafic rocks, which are not true mantle rocks, and ultramafic mantle rocks, the Moho actually is positioned between layer 3 and the layered ultramafics. The sequences consisting of layer 1 (limestone and chert sedimentary rocks), layer 2 of MORB lavas and dikes, and layer 3 of gabbro and diorite and the ultramafic rocks are known as ophiolites. Many geologists believe that ophiolites formed at oceanic ridges were emplaced by tectonic forces at convergent plate boundaries and then became exposed in highly deformed orogenic (mountain) belts. In fact, the same sequences of rocks were first reported in the Alps and were considered deep-seated intrusions. Some geologists still argue that all ophiolites were not formed at divergent plate boundaries.

Away from the axis of divergence, the composition of the volcanic rocks becomes more diverse. Most of the magmatism is related to hot spots, which are hot rising plumes of mantle rock that are anchored beneath the moving lithospheric plates (see Figure 119). The Hawaiian Islands owe their existence to the magmatism associated with a hot spot that currently is located just southeast of the large island of Hawaii. This mantle plume not only provides magma for the eruptions at Kilauea Volcano but also is responsible for the submarine volcano named Loihi that will eventually become a new island. Most of the islands are built on a tholeiite basalt base, but the caps of the volcanoes are alkali basalts. The final episodes of volcanic activity on an island are extremely undersaturated; nephelinites and olivine melilite nephelinites are common products. The alkali basalts have differentiated to more silica-rich compositions, with hawaiites, mugearites, and trachytes being erupted in minor amounts. The two active volcanoes on Hawaii, Mauna Loa and Kilauea, are still erupting tholeiite basalts. Tholeiites on all the islands far from the ocean ridge crests are different from MORB in that they are enriched in lanthanum, cerium, sodium, and potassium.

Mauna Loa and Kilauea

Convergent plate boundaries. Igneous rocks associated with convergent plate boundaries have the greatest diversity. In this case, granite batholiths underlie the great composite volcanoes and consist of rocks ranging from basalt through andesite to dacite and rhyolite. These boundaries are destructive and consume the subducting oceanic lithosphere formed at the divergent centres. The rocks generated, however, are added on (accreted) to the continent. Oceanic trenches outline the junction of the colliding plates, but the igneous activity takes place on the overriding plate along a line at least about 100 kilometres above the subducting plate (see Figure 113). In other words, no volcanism occurs between this 100-kilometre line (called the volcanic front) and the trench. The horizontal distance between the trench and the volcanic front depends on the angle of subduction; the steeper the angle, the shorter the distance. Volcanism occurs from this volcanic axis inland for a few hundred kilometres. The dominant rock constituting the composite volcanoes is andesite, but in some younger island arcs basalt tends to be more common, and in older volcanic areas dacite or rhyolite becomes prominent. Two different series of rocks are found in some volcanic chains. In Japan a tholeiitic series and a calc-alkalic series sometimes erupt from the same volcano. The former is characterized by lower magnesium, potassium, nickel, chromium, uranium, and thorium and a higher iron:magnesium ratio. Mineralogically, the tholeiitic series characteristically contains pigeonite (a low-calcium monoclinic pyroxene) in the groundmass of the basalts and andesites. The calc-alkalic series lacks pigeonite but instead has hypersthene. Most of the composite volcanoes of the Cascades Range in Oregon and Washington in the northwestern United States are characteristically calc-alkalic. In some volcanic arcs in areas farthest from the trench, a potassic series is found. In Japan the volcanoes within the Japan Sea and farthest from the Japan Trench have alkali basalt compositions.

In older areas of convergence, the composite volcanoes

have been eroded, exposing the deeper plutonic granite batholiths that extend the entire length of the convergent boundaries. The batholiths are predominantly granodiorite, but gabbro through granite occur as well. It seems anomalous to find diorite, the plutonic equivalent of andesite, in low abundance since andesite is the dominant rock type of the volcanoes that were above these batholiths. Two basic types of granite have been recognized. The more common variety is located closer to the trench, has hornblende as its mafic mineral, is enriched in sodium and calcium, and has mantle chemical signatures; it is called I-type granite. The other type, called S-type granite, has muscovite and biotite and is depleted in sodium but enriched in aluminum such that corundum occurs in the norm and isotopic signatures. This suggests that such granites were formed by partial fusion of sedimentary rocks.

Flood basalts. On the continental plates at areas away from active convergence, the magmatism is confined to rift valleys and local hot spots. The volume of magma produced is minor in comparison to that generated at oceanic rises and at convergent plate boundaries. Flood basalts are the most common form of occurrence. They span the rock record from the Precambrian to the Tertiary (from about 3.9 billion to 1.6 million years ago) and are found worldwide. The 1.1-billion-year-old Keweenawan flood basalts in the Lake Superior region of northern Michigan may have formed in a rift that failed. The rifting of Pangaea that began during Jurassic time (approximately 208 to 144 million years ago) generated flood basalt eruptions all along the newly opened Atlantic Ocean. Two voluminous eruptions associated with the opening of the South Atlantic produced the Paraná basalt in Brazil and the Karroo (or Karoo) in South Africa. The Deccan Plateau basalts in India were formed in the rift valleys associated with the breakup of Gondwana during the Cretaceous Period (approximately 144 to 66.4 million years ago). Chemically, the most abundant basalts are supersaturated tholeiites with normative quartz, but olivine tholeiites and alkali basalts also are found. Feeder dike swarms (groups consisting of many parallel dikes) and sills are common in flood basalt plateaus. Alkaline rocks, such as those found in the East African Rift System, occur as well but are less abundant. This rift system stretches southward from the Red Sea–Gulf of Aden to Lake Victoria. Undersaturated basalts are most common in these rifts. During one eruption, a magma composed mostly of sodium carbonate issued from a volcanic vent that had been erupting alkali basalts.

Other terrestrial occurrences. Other diverse and unusual igneous rocks are found in the stable continental areas far from plate boundaries. These include the large layered basaltic intrusions—namely, the Stillwater Complex in Montana, the Muskox intrusion in the Northwest Territories of Canada, the Bushveld Complex in South Africa, and the Skaergaard intrusion in eastern Greenland. Tholeiitic magma underwent a fractional crystallization process that deposited layers of ultramafic rocks overlain by gabbroic and anorthositic layers. The end products of this fractionation are quartz- and feldspar-bearing rocks with a peculiar texture (known as graphic intergrowth) in which quartz and feldspar are intimately intergrown with each other. These rocks are called granophyres. Such layered intrusions have some economic importance; some of them contain thick (a few metres) layers of chromite, which is the source of chromium and also platinum. Two other rare occurrences in cratonic (stable) areas of the Earth's crust are the kimberlites and carbonatites. Both are of economic value because they yield diamonds and niobium, respectively. Kimberlites are mica peridotites that are found in pipes. The stable interiors of South Africa and Siberia have widespread occurrences, but these pipes also are found in North America, Australia, Brazil, and India. In North America, near Murfreesboro, Ark., individuals can pay a fee to search for diamonds in the Prairie Creek kimberlite pipe located in the Crater of Diamonds State Park. Not all kimberlites contain diamonds. When diamonds do occur, they constitute less than one part per million of the rock. Carbonatites are igneous rocks rich in carbonate (containing at least 50 percent) that commonly occur in ring complexes in association with other silica-poor rocks such as nepheline syenites. In North America, carbonatites have been found in dozens of localities in northern Ontario and western Quebec.

Basaltic intrusions

Extraterrestrial occurrences. The dominant igneous rock on the Earth's surface is basalt. It appears that such is also the case on Earth's close neighbours. The lunar maria are covered with basalt lava flows. These lunar basalts have a mineralogy similar to that of terrestrial basalts, but chemically they have no water, a lower amount of alkalis and alumina, and a higher iron oxide and chromium content. On the lunar highlands, plagioclase-rich rocks are most common; these include anorthosites, gabbros, troctolites (olivine-plagioclase rock), and minor basalt. It appears that basalt is common on Mars as well. The large shield volcano Olympus Mons must have been formed from eruptions of fluid basalt flows. The X-ray fluorescence analyses performed by the Vikings 1 and 2 landers showed that the rocks are basaltic. Venus apparently has volcanic features, but full chemical analysis has not yet revealed the rock compositions. (A.M.K.)

SEDIMENTARY ROCKS

Definition, formation, and significance

Sedimentary rocks are produced by the weathering of preexisting rocks and the subsequent transportation and deposition of the weathering products. Weathering refers to the various processes of physical disintegration and chemical decomposition that occur when rocks at the Earth's surface are exposed to the atmosphere (mainly in the form of rainfall) and the hydrosphere. These processes produce soil, unconsolidated rock detritus, and components dissolved in groundwater and runoff. Erosion is the process by which weathering products are transported away from the weathering site, either as solid material or as dissolved components, eventually to be deposited as sediment. Any unconsolidated deposit of solid weathered material constitutes sediment. It can form as the result of deposition of grains from moving bodies of water or wind, from the melting of glacial ice, and from the downslope slumping (sliding) of rock and soil masses in response to gravity, as well as by precipitation of the dissolved products of weathering under the conditions of low temperature and pressure that prevail at or near the surface of the Earth.

Sedimentary rocks are the lithified equivalents of sediments. They typically are produced by cementing, compacting, and otherwise solidifying preexisting unconsolidated sediments. Some varieties of sedimentary rock, however, are precipitated directly into their solid sedimentary form and exhibit no intervening existence as sediment. Organic reefs and bedded evaporites are examples of such rocks. Because the processes of physical (mechanical) weathering and chemical weathering are significantly different, they generate markedly distinct products and two fundamentally different kinds of sediment and sedimentary rock: (1) terrigenous clastic sedimentary rocks and (2) allochemical and orthochemical sedimentary rocks.

Clastic terrigenous sedimentary rocks consist of rock and mineral grains, or clasts, of varying size, ranging from clay-, silt-, and sand- up to pebble-, cobble-, and boulder-size materials. These clasts are transported by gravity, mudflows, running water, glaciers, and wind and eventually are deposited in various settings (*e.g.*, in desert dunes, on alluvial fans, across continental shelves, and in river deltas). Because the agents of transportation commonly sort out discrete particles by clast size, terrigenous clastic sedimentary rocks are further subdivided on the basis of average clast diameter. Coarse pebbles, cobbles, and boulder-size gravels lithify to form conglomerate and breccia; sand becomes sandstone; and silt and clay form siltstone, claystone, mudrock, and shale.

Chemical sedimentary rocks form by chemical and or-

ganic reprecipitation of the dissolved products of chemical weathering that are removed from the weathering site. Allochemical sedimentary rocks, such as many limestones and cherts, consist of solid precipitated nondetrital fragments (allochems) that undergo a brief history of transport and abrasion prior to deposition as nonterrigenous clasts. Examples are calcareous or siliceous shell fragments and oöids, which are concentrically layered spherical grains of calcium carbonate. Orthochemical sedimentary rocks, on the other hand, consist of dissolved constituents that are directly precipitated as solid sedimentary rock and thus do not undergo transportation. Orthochemical sedimentary rocks include some limestones, bedded evaporite deposits of halite, gypsum, and anhydrite, and banded iron formations.

Sedimentary rock shell

Sediments and sedimentary rocks are confined to the Earth's crust, which is the thin, light outer solid skin of the Earth ranging in thickness from 40–100 kilometres (25 to 62 miles) in the continental blocks to 4–10 kilometres in the ocean basins. Igneous and metamorphic rocks constitute the bulk of the crust. The total volume of sediment and sedimentary rocks can be either directly measured using exposed rock sequences, drill-hole data, and seismic profiles or indirectly estimated by comparing the chemistry of major sedimentary rock types to the overall chemistry of the crust from which they are weathered. Both methods indicate that the Earth's sediment-sedimentary rock shell forms only about 5 percent by volume of the terrestrial crust, which in turn accounts for less than 1 percent of the Earth's total volume. On the other hand, the area of outcrop and exposure of sediment and sedimentary rock comprises 75 percent of the land surface and well over 90 percent of the ocean basins and continental margins. In other words, 80–90 percent of the surface area of the Earth is mantled with sediment or sedimentary rocks rather than with igneous or metamorphic varieties. The sediment-sedimentary rock shell forms only a thin superficial layer. The mean shell thickness in continental areas is 1.8 kilometres; the sediment shell in the ocean basins is roughly 0.3 kilometre. Rearranging this shell as a globally encircling layer (and depending on the raw estimates incorporated into the model), the shell thickness would be roughly 1–3 kilometres.

Despite the relatively insignificant volume of the sedimentary rock shell, not only are most rocks exposed at the terrestrial surface of the sedimentary variety, but many of the significant events in Earth history are most accurately dated and documented by analyzing and interpreting the sedimentary rock record instead of the more voluminous igneous and metamorphic rock record. When properly understood and interpreted, sedimentary rocks provide information on ancient geography, termed paleogeography. A map of the distribution of sediments that formed in shallow oceans along alluvial fans bordering rising mountains or in deep, subsiding ocean trenches will indicate past relationships between seas and landmasses. An accurate interpretion of paleogeography and depositional settings allows conclusions to be made about the evolution of mountain systems, continental blocks, and ocean basins, as well as about the origin and evolution of the atmosphere and hydrosphere. Sedimentary rocks contain the fossil record of ancient life-forms that enables the documentation of the evolutionary advancement from simple to complex organisms in the plant and animal kingdoms. Also, the study of the various folds or bends and breaks or faults in the strata of sedimentary rocks permits the structural geology or history of deformation to be ascertained.

Finally, it is appropriate to underscore the economic importance of sedimentary rocks. For example, they contain essentially the world's entire store of oil and natural gas, coal, phosphates, salt deposits, groundwater, and other natural resources.

Geologic sciences

Several subdisciplines of geology deal specifically with the analysis, interpretation, and origin of sediments and sedimentary rocks. Sedimentary petrology is the study of their occurrence, composition, texture, and other overall characteristics, while sedimentology emphasizes the processes by which sediments are transported and deposited. Sedimentary petrography involves the classification and study of sedimentary rocks using the petrographic microscope. Stratigraphy covers all aspects of sedimentary rocks, particularly from the perspective of their age and regional relationships as well as the correlation of sedimentary rocks in one region with sedimentary rock sequences elsewhere. (For further information about these fields, see EARTH SCIENCES: *Geologic sciences.*)

Classification systems

In general, geologists have attempted to classify sedimentary rocks on a natural basis, but some schemes have genetic implications (*i.e.,* knowledge of origin of a particular rock type is assumed), and many classifications reflect the philosophy, training, and experience of those who propound them. No scheme has found universal acceptance, and discussion here will centre on some proposals.

The book *Rocks and Rock Minerals* by Louis V. Pirsson was first published in 1908, and it has enjoyed various revisions. Sedimentary rocks are classified there rather simplistically according to physical characteristics and composition into detrital and nondetrital rocks (see Table 52).

Table 52: Terms Designating Composition and Physical Characteristics

detrital rocks	nondetrital rocks
Rudites (coarse)	**Precipitates**
Conglomerates (rounded clasts)	Chemical precipitates (rocks formed by precipitation from seawater or freshwater)
Breccias (angular clasts)	
Basal, or transgression Fanglomerates (in alluvial fans)	Evaporites (products of evaporation from saline brines)
Tillites (glacially transported)	Duricrust rocks (hardened surface or mean-surface layer of any composition)
Arenites (medium-grained)	
Sandstone	**Organic**
Arkose (feldspar-rich)	Zoogenic (made up of hard parts of animals; *e.g.,* crinoidal limestone)
Graywacke (sandstone with mud matrix)	
Quartzite (orthoquartzite)	Phytogenic (made up of plant remains; *e.g.,* algal limestone)
Lutites (fine-grained)	
Siltstone	
Shale	
Mudstone or claystone	
Argillite	
Loess (transported and deposited by wind)	

Numerous other attempts have been made to classify sedimentary rocks. The most significant advance occurred in 1948 with the publication in the *Journal of Geology* of three definitive articles by the American geologists Francis J. Pettijohn, Robert R. Shrock, and Paul D. Krynine. Their classifications provide the basis for all modern discussion of the subject. The nomenclature associated with several schemes of classifying clastic and nonclastic rocks will be discussed in the following sections, but a rough division of sedimentary rocks based on chemical composition is shown in Figure 120.

Categories of sedimentary rocks

For the purposes of the present discussion, three major categories of sedimentary rocks are recognized: (1) terrigenous clastic sedimentary rocks, (2) carbonates (limestone and dolomite), and (3) noncarbonate chemical sedimentary rocks. Terrigenous clastic sedimentary rocks are composed of the detrital fragments of preexisting rocks and minerals and are conventionally considered to be equivalent to clastic sedimentary rocks in general. Because most of the clasts are rich in silica, they are also referred to as siliciclastic sedimentary rocks. Siliciclastics are further subdivided on the basis of clast diameter into conglomerate and breccia, sandstone, siltstone, and finer-than-silt-sized mudrock (shale, claystone, and mudstone). The carbonates, limestones and dolomites, consist of the minerals aragonite, calcite, and dolomite. They are chemical sedimentary rocks in the sense that they possess at least in part a crystalline, interlocking mosaic of precipitated carbonate mineral grains. However, because individual grains such as fossil shell fragments exist for some period of time as sedimentary clasts, similar to transported quartz or feldspar clasts, most carbonates bear some textural affinities to the terrigenous clastic sedimentary rocks. The noncar-

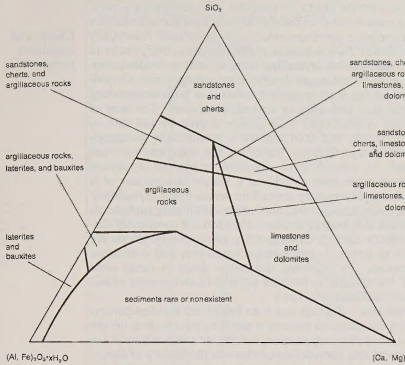


Figure 120: Chemical composition of sedimentary rocks.
From B. Mason, *Principles of Geochemistry* (1966); John Wiley and Sons

bonate chemical sedimentary rocks include several rock types that are uncommon in the sedimentary rock record but remain important either from an economic point of view or because their deposition requires unusual settings. Specific varieties discussed below include siliceous rocks (cherts), phosphate rocks (phosphorites), evaporites, iron-rich sedimentary rocks (iron formations and ironstones), and organic-rich (carbonaceous) deposits in sedimentary rocks (coal, oil shale, and petroleum).

Despite the diversity of sedimentary rocks, direct measurement of the relative abundance of the specific types based on the study of exposed sequences suggests that only three varieties account for the bulk of all sedimentary rocks: mudrock, 47 percent; sandstone, 31 percent; and carbonate, 22 percent. Another method, which involves comparing the chemical composition of major sedimentary rock types with the chemistry of the Earth's continental crust, yields somewhat different numbers: mudrock, 79 percent; sandstone, 13 percent; and carbonate, 8 percent. Most sedimentary petrologists concede that the sedimentary rock record preserved and exposed within the continental blocks is selectively biased in favour of shallow-water carbonates and sandstones. Mudrocks are preferentially transported to the ocean basins. Consequently, indirect estimates based on chemical arguments are probably more accurate.

TERRIGENOUS CLASTIC ROCKS

A prominent physical feature of terrigenous clastic rocks is texture—that is, the size, shape, and arrangement of the constituent grains. These rocks have a fragmental texture: discrete grains are in tangential contact with one another. Terrigenous clastic sedimentary rocks are further subdivided on the basis of the mean grain diameter that characterizes most fragments, using the generally accepted size limits shown in Table 53. Granules, pebbles, cobbles, boulders, and blocks constitute the coarse clastic sediments; sand-size (arenaceous) clasts are considered medium clastic sediments; and fine clastics sediments consists of silt- and clay-size materials.

The simplest way of classifying coarse clastic sedimentary rocks is to name the rock and include a brief description of its particular characteristics. Conglomerates and breccias differ from one another only in clast angularity. The former consist of abraded, somewhat rounded, coarse clasts, whereas the latter contain angular, coarse clasts. Thus, a pebble conglomerate is a coarse clastic sedimentary rock whose discrete particles are rounded and range from 4 to 64 millimetres (0.2 to 2.5 inches) in diameter. A more precise description reveals the rock types of the mineral fragments that compose the conglomerate—for example, a granite-gneiss pebble conglomerate.

Sandstones have long intrigued geologists because they are well exposed, are abundant in the geologic record, and provide an enormous amount of information about depositional setting and origin. Many classification schemes have been developed for sandstones, only the most popular of which are reviewed below. Most schemes emphasize the relative abundance of sand-size quartz, feldspar, and rock fragment components, as well as the nature of the material housed between this sand-size "framework" fraction (see below *Sandstones*). Sandstone classification

Fine clastics are commonly, but rather simplistically, referred to as mudrocks. Mudrocks actually can include any

Table 53: Size Limits of Common Grades and Rock Terms

size	sedimentary particles: rounded, subrounded, subangular — fragment		sedimentary particles: rounded, subrounded, subangular — aggregate	sedimentary particles: angular — fragment	sedimentary particles: angular — aggregate	volcanic particles — fragment	volcanic particles — aggregate
256 mm	boulder	"roundstone"	boulder gravel boulder conglomerate	block	breccia	block*	volcanic breccia
64 mm	cobble	"roundstone"	cobble gravel cobble conglomerate	...	breccia	bomb†	agglomerate
4 mm	pebble	"roundstone"	pebble gravel pebble conglomerate	...	breccia	— 32 mm — lapilli — 4 mm —	lapilli tuff
2 mm	granule		granule gravel	...	breccia		
1/16 mm	sand		sand sandstone	...	— 1 mm — grit — ¼ mm —	coarse ash	coarse tuff
1/256 mm	silt		silt siltstone	...		— ¼ mm — fine ash	fine tuff
	clay		clay shale	...			

*Broken from previously consolidated igneous rock. †Solidified from plastic material while in flight.
Source: from F.J. Pettijohn, *Sedimentary Rocks*.

clastic sedimentary rock in which the bulk of the clasts have diameters finer than $^1/_{16}$ millimetre. Varieties include siltstone (average grain size between $^1/_{16}$ and $^1/_{256}$ millimetre) and claystone (discrete particles are mostly finer than $^1/_{256}$ millimetre). Mud is a mixture of silt- and clay-size material, and mudrock is its indurated product. Shale is any fine clastic sedimentary rock that exhibits fissility, which is the ability to break into thin slabs along narrowly spaced planes parallel to the layers of stratification. Despite the great abundance of the fine clastics, disagreement exists as to what classification schemes are most useful for them, and an understanding of their origin is hindered by analytical complexities (see below *Mudrocks*).

CARBONATE ROCKS: LIMESTONES AND DOLOMITES

Limestones and dolostones (dolomites) make up the bulk of the nonterrigenous sedimentary rocks. Limestones are for the most part primary carbonate rocks. They consist of 50 percent or more calcite and aragonite (both $CaCO_3$). Dolomites are mainly produced by the secondary alteration or replacement of limestones; *i.e.*, the mineral dolomite [$CaMg(CO_3)_2$] replaces the calcite and aragonite minerals in limestones during diagenesis. A number of different classification schemes have been proposed for carbonates, and the many categories of limestones and dolomites in the geologic record represent a large variety of depositional settings (see below *Limestones and dolomites*).

NONCARBONATE CHEMICAL SEDIMENTARY ROCKS

Noncarbonate chemical sedimentary rocks differ in many respects from carbonate sedimentary rocks and terrigenous clastic sedimentary rocks, and there is no single classification that has been universally accepted. This is a reflection of the great variation in mineral composition, texture, and other properties of these rock types. Such rocks as ironstones and banded iron formations (limonite, goethite, hematite, siderite, and chamosite), phosphorites, evaporites (rock salt, gypsum, and other salts), siliceous rocks (cherts), and organic-rich (carbonaceous) deposits of oil, natural gas, and coal in sedimentary rocks occur in much less abundance than carbonates and siliciclastic sedimentary rocks, although they may form thick and widespread deposits.

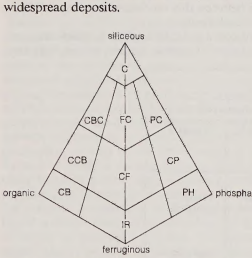


Figure 121: Common noncarbonate, nonclastic sedimentary rocks. C, cherts; CBC, carbonaceous chert; FC, ferruginous chert; PC, phosphatic chert; CCB, cherty carbonaceous rock; CF, cherty ironstone; CP, cherty phosphorite; CB, carbonaceous rock; PH, phosphorite; and IR, ironstone.

Classification schemes that incorporate all types of noncarbonate chemical sedimentary rocks do not exist because no triangular or tetrahedral scheme can accommodate all of them. Several of the major types are shown in the tetrahedron in Figure 121 (see also the discussion of noncarbonate sedimentary rocks below). (H.J.Bi./F.L.S.)

Properties of sedimentary rocks

TEXTURE

Texture refers to the physical makeup of rock—namely, the size, shape, and arrangement (packing and orientation) of the discrete grains or particles of a sedimentary rock. Two main natural textural groupings exist for sedimentary rocks: clastic (or fragmental) and nonclastic (essentially crystalline). Noncarbonate chemical sedimentary rocks in large part exhibit crystalline texture, with individual mineral grains forming an interlocking arrangement. Depositional setting is an insignificant factor in both determining crystal size and altering crystalline texture. The size of crystals is controlled to a greater degree by the rate of precipitation, and their texture is modified by postdepositional recrystallization (reflecting the diagenetic environment). As a result, little attention is paid to crystalline textures other than providing a simple description of it (for example, coarsely crystalline versus finely crystalline). Also, even though carbonate rocks commonly include allochems that behave as clasts, they too are commonly diagenetically altered. Consequently, only cursory efforts are made to texturally characterize limestones and dolomites. Therefore, the following discussion deals in detail only with the textural techniques applied to terrigenous (siliciclastic) sedimentary rocks.

Clastic and nonclastic rocks

Grain size. Particle size is an important textural parameter of clastic rocks because it supplies information on the conditions of transportation, sorting, and deposition of the sediment and provides some clues to the history of events that occurred at the depositional site prior to final induration. Determining the sizes of the discrete particles that constitute a sedimentary rock can be difficult, particularly if the rock is firmly indurated (cemented, compacted, and lithified). Various methods of measuring grain-size distribution have been devised; likewise several different grade-size schemes exist.

The size of particulate materials that make up sediments and sedimentary rocks are measured by weighing the proportions that accumulate in a series of wire mesh screen sieves, by visually counting grains with a petrographic microscope, or by determining the rate at which particles of varying diameter accumulate in a water-filled glass cylinder (known as a settling tube).

The millimetre and phi unit grade scales and terminology given in Table 54 are the standard ones used for sediments and sedimentary rocks. In the millimetre scale, each size grade differs from its predecessor by the constant ratio of 1:2; each size class has a specific class name used to refer to the particles included within it. This millimetre, or Udden-Wentworth, scale is a geometric grade scale since there is a constant ratio between class limits. Such a scheme is well suited for the description of sediments because it gives equal significance to size ratios, whether they relate to gravel, sand, silt, or clay. The phi scale is a useful, logarithmic-based modification of the Udden-Wentworth scale. Grain-size diameters in millimetres are converted to phi units using the conversion formula: phi (φ) $= -\log_2 S$, where φ is size expressed in phi units and S is the grain size in millimetres. Phi values for grains coarser than one millimetre are negative, while those for grains finer than one millimetre are positive.

Phi scale

After the grain-size distribution for a given sediment or sedimentary rock has been determined by sieving, microscopic analysis, or use of a settling tube, it can be characterized using standard statistical measures in either of two ways: (1) visual inspection of various types of graphs that plot overall percent abundance versus grain-size diameter (*e.g.*, histograms or bar diagrams, size frequency and cumulative size frequency curves, and probability curves that compare the actual grain-size distribution to a normal straight-line Gaussian distribution) or (2) arithmetic calculations made using diameter values in either millimetres or phi units that are read off the graphic plots and inserted into standard formulas. For siliciclastic sedimentary rocks, the following standard statistical measures are conventionally described for grain-size distributions: (1) mode, the most frequently occurring particle size or size class, (2) median, the midpoint size of any grain-size distribution, (3) mean, an estimate of the arithmetic average particle size, (4) sorting or standard deviation, a measure of the range, scatter, or variation in grain size, (5) skewness, the degree of symmetry or asymmetry of the grain-size distribution, which is in turn a function of the coincidence

Table 54: Grain-Size Scale for Sediments

	U.S. standard sieve mesh	millimetres		phi (φ) units	Wentworth size class
Gravel		4,096		− 12	
		1,024		− 10	boulder
		256	256	− 8	
		64	64	− 6	cobble
	5	4	4	− 2	pebble
	6	3.36		− 1.75	
	7	2.83		− 1.5	granule
	8	2.38		− 1.25	
	10	2.00	2	− 1.0	
Sand	12	1.68		− 0.75	
	14	1.41		− 0.5	very coarse sand
	16	1.19		− 0.25	
	18	1.00	1	0	
	20	0.84		0.25	
	25	0.71		0.5	coarse sand
	30	0.59		0.75	
	35	0.50	½	1.0	
	40	0.42		1.25	
	45	0.35		1.5	medium sand
	50	0.30		1.75	
	60	0.25	¼	2.0	
	70	0.210		2.25	
	80	0.177		2.5	fine sand
	100	0.149		2.75	
	120	0.125	⅛	3.0	
	140	0.105		3.25	
	170	0.088		3.5	very fine sand
	200	0.074		3.75	
	230	0.0625	1/16	4.0	
Mud: Silt	270	0.053		4.25	
	325	0.044		4.5	coarse silt
		0.037		4.75	
		0.031	1/32	5.0	
		0.0156	1/64	6.0	medium silt
		0.0078	1/128	7.0	fine silt
Mud: Clay		0.0039	1/256	8.0	very fine silt
		0.0020		9.0	
		0.00098		10.0	
		0.00049		11.0	clay
		0.00024		12.0	
		0.00012		13.0	
		0.00006		14.0	

Source: Adapted with permission of Merrill, an imprint of Macmillan Publishing Company, from *Principles of Sedimentology and Stratigraphy*, by Sam Boggs, Jr. Copyright © 1987 by Merrill Publishing Company.

or noncoincidence of mean, median, and mode, and (6) kurtosis (peakedness) of a grain-size distribution, which compares sorting in the central portion of the population with that in the tails.

Analysis of grain-size distribution is conducted with the disputed assumption that particular transporting agents and depositional settings (*e.g.*, river delta deposits versus shallow marine longshore-bar sands) impose a distinctive textural "fingerprint" on the sediments they produce. Despite continuing efforts, the success of the various graphic and arithmetic approaches in characterizing grain-size distributions is debatable, as is their reliability in pinpointing ancient depositional settings. The grain-size distribution of sediments in many settings commonly appears to be inherited or to exhibit as much variation within a single environment as between different ones.

Form, roundness, and surface texture

Particle shape. Three different but related properties determine particle shape: form, roundness, and surface texture. Particle form is the overall shape of particles, typically defined in terms of the relative lengths of the longest, shortest, and intermediate axes. Particles can be spherical, prismatic, or bladelike. Roundness or angularity is a measure of the smoothness of particles. Surface texture refers to the presence or absence of small, variously shaped markings (pits, polish, scratches) that may occur on grain surfaces.

Each of these attributes of particle shape is traditionally measured in a standard fashion for the purpose of identifying the transporting agent and the depositional environment. Form is determined either by painstakingly measuring individual particles in three dimensions or by Fourier shape analysis, which uses harmonics analysis and computer digitizing to provide a precise description of particles in two dimensions. Form alone has limited usefulness in inferring depositional setting but more accurately reflects the mineralogy of the grains involved. Roundness is characterized by visually comparing grains to standard silhouette profiles as, for example, those shown in Figure 122. It is largely the result of abrasion history, which is controlled by the depositional agent and environment. For example, windblown and surf zone sands are well-rounded, while glacial sands and turbidity current deposits are angular. Particle roundness or angularity also reflects mineralogy (soft minerals are abraded more readily than hard minerals), clast size (coarse particles become rounded more rapidly than do fine ones), and transport distance

(sands become more abraded and hence rounder as the distance traveled increases). Particle surfaces can be visually examined for pitting, markings, and polish through the use of a microscope or hand lens, or in some cases, a scanning electron microscope (SEM). Certain surface textures have been genetically linked to specific depositional agents; for example, classic V-shaped percussion marks identify quartz grains of the beach and nearshore zones.

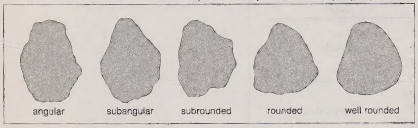


Figure 122: Roundness classes of sedimentary particles.

Fabric. The fabric of a sedimentary rock controls the rock's porosity and permeability and therefore its ability to hold and/or transmit fluids such as oil and water. The orientation, or lack thereof, of the crystals or grains that make up a sedimentary rock constitutes one aspect of fabric. Genetically, there are two principal varieties of oriented fabrics: primary (or depositional) and secondary (or deformational). Primary fabrics are produced while the sediment is accumulating. For example, river currents and some submarine gravity flows generate sediments whose flaky and prismatic constituent particles have long or short axes parallel with one another to produce an oriented fabric. Secondary fabrics result from a rotation of the constituent elements under stress or from the growth of new elements during diagenesis. Fabrics in coarse clastic sedimentary rocks like conglomerates and sandstones can be determined by measuring and plotting dimensional directions, such as the long axes of pebbles or sand grains. In mudrocks, fabrics can be ascertained by studying the platelike arrangement of mica and clay minerals.

Orientation and packing

In addition to orientation, a factor known as packing contributes to a rock's fabric. Packing refers to the distribution of grains and intergranular spaces (either empty or filled with cement or fine-grained matrix) in a sedimentary rock. It is controlled by grain size and shape and by the degree of compaction of a sedimentary rock; in turn it determines the rock's bulk density. A description of packing is generally based on the analysis of thin sections of a sedimentary rock using a petrographic microscope. Particular attention is paid to the number of grain-to-grain contacts (packing proximity) and to comparisons between the sum of the lengths of grains to the total length of a traverse across a thin section (packing density).

MINERALOGICAL AND GEOCHEMICAL COMPOSITION

Minerals that make up sedimentary rocks are of two principal types—namely, detrital and authigenic. Detrital minerals, such as grains of quartz and feldspar, survive weathering and are transported to the depositional site as clasts. Authigenic minerals, like calcite, halite, and gypsum, form in situ within the depositional site in response to geochemical processes. The chemical compounds that constitute them ultimately are generated by chemical weathering and are transported from the weathering site to the point of precipitation primarily in solution. Clay minerals are abundant in sedimentary rocks, particularly mudrocks, and some are detrital. They may have been produced at the weathering site by the partial decomposition of minerals like feldspar. They are transported as clasts, however, and thus can be regarded simply as fine- to very fine-textured detrital particles. Other clay minerals form authigenically at the site of deposition. Some of the important clay minerals are kaolinite, halloysite, montmorillonite, illite, vermiculite, and chlorite (see above *Major rock-forming minerals: Clay minerals*).

The mean chemical composition of the major varieties of sedimentary rocks exhibits wide variation as shown above in Figure 120. Significant contrasts in overall composition among sandstones, carbonates, and mudrocks reflect fundamental differences not only in the mechanisms by which detrital minerals of different sizes are transported and deposited but also in the chemical conditions that permit precipitation of various authigenic minerals.

Diagenesis includes all physicochemical, biochemical, and physical processes (short of metamorphism) that modify sediments in the time between their deposition and their analysis. Lithification, the process by which sediment is converted into solid sedimentary rock, is one result of diagenesis. Many diagenetic processes such as cementation, recrystallization, and dolomitization are essentially geochemical processes; others like compaction are fundamentally physical processes. All diagenetic changes occur at the low temperatures and pressures characteristic of surface and near-surface environments. These changes can take place almost immediately after sediment formation, or they can occur hundreds or even millions of years later.

Sedimentary structures

Sedimentary structures are the larger, generally three-dimensional physical features of sedimentary rocks; they are best seen in outcrop or in large hand specimens rather than through a microscope. Sedimentary structures include features like bedding, ripple marks, fossil tracks and trails, and mud cracks. They conventionally are subdivided into categories based on mode of genesis. Structures that are produced at the same time as the sedimentary rock in which they occur are called primary sedimentary structures. Examples include bedding or stratification, graded bedding, and cross-bedding. Sedimentary structures that are produced shortly after deposition and as a result of compaction and dessication are called penecontemporaneous sedimentary structures. Examples include mud cracks and load casts. Still other sedimentary structures like concretions, vein fillings, and stylolites form well after deposition and penecontemporaneous modification; these are known as secondary structures. Finally, others like stromatolites and organic burrows and tracks, though they may in fact be primary, penecontemporaneous, or even secondary, may be grouped as a fourth category—organic sedimentary structures.

Considerable attention is paid to the sedimentary structures exhibited by any sedimentary rock. Primary sedimentary structures are particularly useful because their abundance and size suggest the probable transporting and depositional agents. Certain varieties of primary sedimentary structures like cross-bedding and ripple marks display orientations that are consistently related to the direction

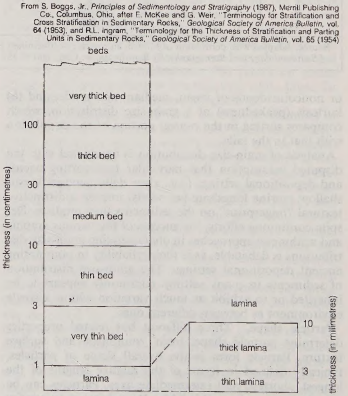


Figure 123: Descriptive terms for the thickness of beds and laminae.

of current movement. Such structures are referred to as directional sedimentary structures because they can be used to infer the ancient paleocurrent pattern or dispersal system by which a sedimentary rock unit was deposited.

Top and bottom indicators

Other sedimentary structures are stratigraphic "top and bottom" indicators. For example, the progressive upward decrease in clastic grain size diameters, known as graded bedding, would allow a geologist to determine which way is stratigraphically "up"—*i.e.,* toward the younger beds in a dipping sedimentary bed. The suite (repeated sequence) of sedimentary structures in any single stratigraphic unit is another attribute by which that unit may be physically differentiated from others in the region. (F.L.S.)

EXTERNAL STRATIFICATION

Stratification (or bedding) is expressed by rock layers (units) of a general tabular or lenticular form that differ in rock type or other characteristics from the material with which they are interstratified (sometimes stated as interbedded, or interlayered). These beds, or strata, are of varying thickness and areal extent. The term stratum identifies a single bed, or unit, normally greater than one centimetre in thickness and visibly separable from superjacent (overlying) and subjacent (underlying) beds. "Strata" refers to two or more beds, and the term lamina is sometimes applied to a unit less than one centimetre in thickness. Thus, lamination consists of thin units in bedded, or layered, sequence in a natural rock succession, whereas stratification consists of bedded layers, or strata, in a geologic sequence of interleaved sedimentary rocks.

For most stratified sedimentary rocks, the arrangement of layers is one of unequal thickness, ranging from very thin laminae to discrete beds that measure a few to many metres in thickness. The terms thick and thin as applied to bedding, or stratification, are relative, reflecting the training of a particular geologist as well as experience with a specific stratigraphic section or sections. Some quantitative values that have been proposed are shown in Figure 123.

BEDDING TYPES AND BEDDING-PLANE FEATURES

Types. It is common to discover a rhythmic pattern in a pile of stratified sedimentary rocks represented by a repetitive sequence of rock types. In most instances of such cyclic sedimentation, the bedding, or stratification, is horizontal or essentially so; that is, the transporting, sorting, and depositing agents of wind, running water, and lake and ocean currents and waves accumulated the laminae and strata in a flat-lying or horizontal arrangement. They are termed well-bedded, a type of primary stratification.

Primary stratification in sediments and sedimentary rocks can be cross-bedded (cross-stratified), graded, and imbricate and can also display climbing laminae, ripples, and beds. A simplified classification of cross-stratification into three principal types (simple, planar, and trough) is shown in Figure 124.

Graded and imbricate bedding

Graded bedding simply identifies strata that grade upward from coarse-textured clastic sediment at their base to finer-textured materials at the top (Figure 125). The stratification may be sharply marked so that one layer is set off visibly from those above and beneath it. More commonly, however, the layers are blended. This variety of bedding results from a check in the velocity of the transporting agent, and thus coarse-textured sediment (gravel, for example) is deposited first, followed upward by pebbles, granules, sand, silt, and clay. It is commonly associated with submarine density currents.

Imbricate bedding is a shingle structure in a deposit of flattened or disk-shaped pebbles or cobbles (Figure 125). That is to say, elongated and commonly flattened pebbles and cobbles in gravelly sediment are deposited so that they overlap one another like roofing shingles. Imbricate bedding forms where high-velocity currents move over a streambed or where strong currents and waves break over a gradually sloping beach, thereby forming beach shingle.

Growth structures in sedimentary rocks are in situ features that accumulate largely as the result of organic buildups within otherwise horizontal or nearly flat-lying strata. Reefs and stromatolites are two common varieties of such growth structures.

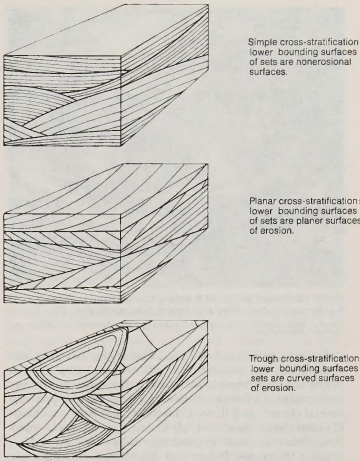


Figure 124: Basic elements of cross-stratification classification.

By courtesy of E.D. McKee and G.W. Weir, *Geological Society of America Bulletin*, vol. 64 (1953), Geological Society of America

Bedding-plane features. Upper surfaces of beds commonly display primary sedimentary features that are classified as bedding-plane structures. A three-dimensional view may be obtained if some of these can be seen from the side as well as from the top of a pile of strata. They include such features as ripples (ripple marks), climbing ripples, rills, pits, mud cracks, trails and tracks, salt and ice casts and molds, and others. Bedding-plane markings and irregularities can be allocated to one of three classes: (1) those on the base of a bed (load and current structures and organic markings), (2) those within a bed (parting lineation), and (3) those on top of a bed (ripple marks, pits, impressions, mud cracks, tracks and trails of organisms, and others).

DEFORMATION STRUCTURES

In addition to sedimentary structures that are normally associated with bedding planes, there are other such structures that result from deformation during or shortly after

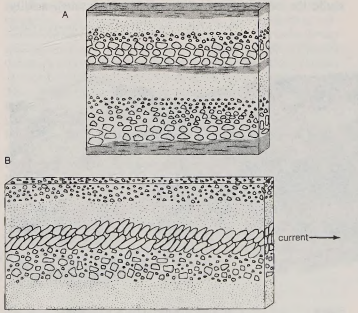


Figure 125: (A) Graded bedding. (B) Imbricate bedding.

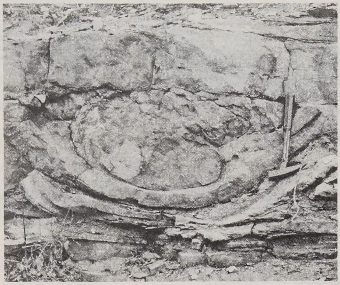


Figure 126: Cross section of a large pillow structure in Thorold Sandstone (Silurian). New Jolly road cut, Hamilton, Ont., Can.

From F.J. Pettijohn and P.E. Potter, *Atlas and Glossary of Primary Sedimentary Structures*; Springer-Verlag New York Inc.

sedimentation but before induration of the sediment into rock. These are nontectonic features—*i.e.*, they are not bends and folds brought about by metamorphism or other such causes. Deformation structures can be grouped into several classes, as follows: (1) founder and load structures, (2) convoluted structures, (3) slump structures, (4) injection structures, such as sandstone dikes or sills, and (5) organic structures. Pillow and convoluted structures are shown in Figures 126 and 127.

Structures found on the bottom of a bed are called sole markings, because they formed on the "sole" of the bed. Sole marks are commonly formed on sandstone and limestone beds that rest upon shale beds. They are termed casts, because they are fillings of depressions that formed on the surface of the underlying mud. They originate (1) by unequal loading upon the soft and plastic wet mud, (2) by the action of currents across the upper mud surface, or (3) by the activities of organisms on this surface. Load casts form as the result of downsinking of sandstone or limestone into the mud beneath. Current marks can form by the action of water currents on upper surfaces of the beds or by "tools" (such as wood and fossils) that are transported by currents over soft sediment.

Casts

Sedimentary environments

The sedimentary environment is the specific depositional setting of a particular sedimentary rock and is unique in terms of physical, chemical, and biological characteristics. The physical features of a sedimentary environment include water depth and the velocity and persistence of currents. Chemical characteristics of an environment include the salinity (proportion of dissolved salts), acidity or basicity (pH), oxidation potential (Eh), pressure, and temperature. The biological characteristics are mainly the assemblage of fauna and flora that populate the setting. These conditions, combined with the nature of the transporting agent and the source area, largely determine the properties of the sediments deposited within the environment. A number of ways of classifying depositional environments exist, but most modern schemes employ a geomorphologic approach. That is to say, an environment is defined in terms of a distinct geomorphic unit or landform, modern examples of which are readily visible for comparative purposes—*e.g.*, a river delta, an alluvial fan, a submarine fan, or the abyssal floor of an ocean basin.

Individual environments are further grouped into (1) marine environments, which include the nearshore, shallow littoral zone and the offshore, deep littoral zone, as well as deepwater realms, (2) mixed marine and nonmarine settings such as the beach and supratidal zones, and (3) nonmarine settings like lacustrine and various alluvial settings. Each environment is associated with a set of criteria that constitutes its distinguishing features. (H.J.Bi./F.L.S.)

Sedimentary rock types

CONGLOMERATES AND BRECCIAS

Conglomerates and breccias are sedimentary rocks composed of coarse fragments of preexisting rocks held together either by cement or by a finer-grained clastic matrix. Both contain significant amounts (at least 10 percent) of coarser-than-sand-size clasts. Breccias are consolidated rubble; their clasts are angular or subangular as shown in Figure 128. Conglomerates are consolidated gravel whose clasts are subrounded to rounded. Sometimes the term rudite (or rudaceous) is used to collectively refer to both breccias and conglomerates.

A number of classification schemes have been proposed to further subdivide conglomerates and breccias. One scheme is purely descriptive, partitioning these coarse clastic sedimentary rocks on the basis of grain size (*e.g.*, boulder breccia versus cobble conglomerate) or composition or both (chert pebble breccia versus limestone cobble conglomerate). Yet another scheme differentiates individual conglomerates and breccias according to depositional agency and environmental setting (alluvial fan conglomerate as opposed to beach conglomerate). The best classification systems incorporate objective physical characteristics of both composition and texture as well as mode of genesis. Conglomerates and breccias belong to four genetic categories: (1) epiclastic, produced by the physical disintegration (weathering) of preexisting rocks, (2) pyroclastic, produced by the explosive activity of volcanoes, (3) cataclastic, formed by local earth movements (fault breccias) or solution phenomena (collapse breccias), and (4) meteoritic, produced by the impact of extraterrestrial bodies on the Earth's surface. In a strict sense, epiclastic conglomerates and breccias are the only true sedimentary rocks, because they alone are produced by weathering. (E.t.H./F.L.S.)

Genetic categories

From F.J. Pettijohn and P.E. Potter, *Atlas and Glossary of Primary Sedimentary Structures*; Springer-Verlag New York Inc.



Figure 127: Convolute lamination, Krosno Beds (Oligocene), from Mymon, central Carpathians, Pol.

There are two principal types of epiclastic conglomerates and breccias: intraformational, derived penecontemporaneously by eroding, transporting, and depositing material from within the depositional basin itself; and interformational, derived from source rocks that lie outside the area in which the deposit occurs. Epiclastic conglomerates and breccias together probably make up no more than 1 or 2 percent of the conventional sedimentary rock record.

Epiclastic conglomerates and breccias

Intraformational conglomerates and breccias are widespread in the geologic record but are volumetrically unimportant. They occur as laterally continuous bands or horizons within sequences of shallow-water marine or nonmarine deposits. Their origin is commonly related to the existence of brief episodes of strong bottom-hugging currents capable of ripping up recently deposited, unconsolidated sediment. For example, shallow marine limestone deposits commonly have thin bands of boulder-, cobble-, and pebble-size carbonate clasts (edgewise conglomerate or breccia beds) that are generated when storm waves erode and redeposit carbonate mud layers. Likewise, high-velocity river currents that accompany torrential rains



Figure 128: Quartzite slope breccia of Cambrian age from Ardennes, Belg.
By courtesy of Ernst ten Haaf

give rise to shale pebble conglomerates and breccias within sequences of floodplain alluvium. Other intraformational conglomerates and breccias mix shallow- and deep-water sedimentary rock clasts encased in a finer-grained matrix of deeper-water material. Such deposits accumulate as depositional aprons that flank the scarps (steep slopes) bounding shallow-water platformal areas such as the modern Great Bahama and Little Bahama banks off Florida in the southeastern United States.

Interformational conglomerates and breccias, the coarse clastic sedimentary rocks derived by the weathering of preexisting rocks outside the depositional basin, are most important from the points of view of both volume and geologic significance (see Figure 129). They can be subdivided into two specific categories: (1) orthoconglomerates (and breccias) and (2) paraconglomerates (and breccias).

Orthoconglomerates. These rocks contain less than 15 percent matrix—*i.e.,* material composed of clasts finer than granule size (2-millimetre diameter or less). They typically exhibit an intact fabric that has a clast-supported framework such that the individual granules, pebbles, cobbles, and boulders touch each other. The space between framework components either is empty or is filled with chemical cement, finer-than-granule clasts, or both. Orthoconglomerates may be composed of large clasts of a single rock or mineral type (oligomictic orthoconglomerates), or they may contain a variety of rock and mineral clast types (petromictic orthoconglomerates).

Oligomictic and petromictic

Orthoconglomerates (and orthobreccias) are deposited by highly turbulent water. For example, beach deposits commonly contain lenses and bands of oligomictic orthoconglomerate, composed mainly (95 percent or more) of stable, resistant, coarse clasts of vein quartz, quartzite, quartz sandstone, and chert. Such deposits are typically generated in the upper reaches of winter storm beaches where strong surf can sift, winnow, and abrade coarse pebbles and boulders. The most indestructible components are thereby consolidated as orthoconglomeratic lenses that are interfingered with finer-grained, quartz-rich beach sandstones. Petromictic orthoconglomerates and breccias, on the other hand, reflect the existence of high-relief (mountainous) source areas. Topographically high source areas signify tectonic mobility in the form of active folding or faulting or both. The existence of petromictic orthoconglomerates and breccias in the geologic record is therefore significant: their presence and age not only pinpoint the timing and location of mountain building accompanied by sharp uplift and the possibility of regionally significant fault scarps but also can be used to infer the past distribution of physiographic features such as mountain fronts, continental block margins, continental shelf-continental slope boundaries, and the distribution of oceanic trenches and volcanic island arcs.

Bedding (layering and stratification) in orthoconglomerates, if apparent at all, is typically thick and lenticular. Graded bedding, in which size decreases from bottom to top, is common: because agitated waters rarely subside at once, declining transport power causes a gradual upward decrease in maximum clast size. Relative to the bedding, the pebbles in sandy conglomerates tend to lie flat, with their smallest dimension positioned vertically and the greatest aligned roughly parallel to the current. In closely packed orthoconglomerates, however, there is often a distinct imbrication; *i.e.,* flat pebbles overlap in the same direction like roof shingles. Imbrication is upstream on riverbeds and seaward on beaches.

Orthoconglomerates are quite important economically because they hold enormous water reserves that are easily released through wells. This feature is attributable to their high porosity and permeability. Porosity is the volume percentage of "void" (actually fluid- or air-filled) space in a rock, whereas permeability is defined as the rate of flow of water at a given pressure gradient through a unit volume. The interconnectedness of voids in orthoconglomerates contributes to their permeability. Also, because the chief resistance to flow is generally due to friction and capillary effects, the overall coarse grain size makes conglomerates even more permeable. The high degree of porosity and permeability causes orthoconglomerates to generate excellent surface drainage, so they are to be avoided as dam and reservoir sites.

Paraconglomerates. Paraconglomerates and breccias, also called diamictites, exhibit a disrupted, matrix-supported fabric; they contain 15 percent or more (sometimes as much as 80 percent) sand-size and finer clastic matrix. The coarse detrital clasts "float" in a finer-grained detrital matrix. They actually are mudrocks in which there is a sprinkling of granules, pebbles, cobbles, or boulders, or some combination of them. Accordingly, they are sometimes referred to as conglomerate mudstones or pebbly mudstones.

Although diamictites originate in a variety of ways, they are not deposited by normal currents of moving water. Some are produced by submarine landslides, massive slumping, or dense, sediment-laden, gravity-driven turbidity flows. Paraconglomerates that can be definitively related to such mechanisms are called tilloids. Tilloids commonly make up olistostromes, which are large masses of coarse blocks chaotically mixed within a muddy matrix.

Tills and tillites

The terms till (when unconsolidated) and tillite (when lithified) are used for diamictites that appear to have been directly deposited by moving sheets of glacial ice. Tillites typically consist of poorly sorted angular and subangular, polished and striated blocks of rock floating in an unstratified clay matrix. The clasts may exhibit a weak but distinct alignment of their long axes approximately parallel to the direction of ice flow. Tillites are notoriously heterogeneous in composition: clasts appear to be randomly mixed together without respect to size or compositional stability. These clasts are derived mainly from the underlying bedrock. Extremely coarse, far-traveled blocks and boulders are called erratics.

Other rarer diamictites, known as laminated pebbly (or cobbly or bouldery) mudstones, consist of delicately laminated mudrocks in which scattered coarser clasts occur. Laminations within the muddy component are broken

By courtesy of the Geological Institute, Utrecht

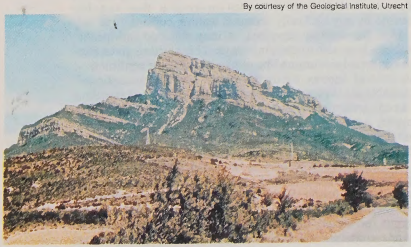


Figure 129: Tilted conglomerates of the Pyrenean Molasse at Peña de Oroel near Jaca, Spain.

and bent. They are located beneath and adjacent to the larger clasts but gently overlap or arch over them, suggesting that the coarse clasts are dropstones (*i.e.*, ice-rafted blocks released as floating masses of ice melt).

SANDSTONES

Sandstones are siliciclastic sedimentary rocks that consist mainly of sand-size grains (clast diameters from 2 to 1/16 millimetre) either bonded together by interstitial chemical cement or lithified into a cohesive rock by the compaction of the sand-size framework component together with any interstitial primary (detrital) and secondary (authigenic) finer-grained matrix component. They grade, on the one hand, into the coarser-grained siliciclastic conglomerates and breccias described above, and, on the other hand, into siltstones and the various finer-grained mudrocks described below. Like their coarser analogues—namely, conglomerates and breccias—sand-size (also called arenaceous) sedimentary rocks are not exclusively generated by the physical disintegration of preexisting rocks. Varieties of limestone that contain abundant sand-size allochems like oöids and fossil fragments are, in at least a textural sense, types of sandstones, although they are not terrigenous siliciclastic rocks. Such rocks, called calcarenites when lithified or carbonate sands when unconsolidated, are more properly discussed as limestones. Also, pyroclastic sandstones or tuffs formed by lithifying explosively produced volcanic ash deposits can be excluded from this discussion because their origin is unrelated to weathering.

Sandstones are significant for a variety of reasons. Volumetrically they constitute between 10 and 20 percent of the Earth's sedimentary rock record. They are resistant to erosion and therefore greatly influence the landscape. When they are folded, they create the backbone of mountain ranges like the Appalachians of eastern North America, the Carpathians of east-central Europe, the Pennines of northern England, and the Apennine Range of Italy; when flat-lying, they form broad plains and plateaus like the Colorado and Allegheny plateaus. Sandstones are economically important as major reservoirs for both petroleum and water, as building materials, and as valuable sources of metallic ores. Most significantly, they are the single most useful sedimentary rock type for deciphering Earth history. Sandstone mineralogy is the best indicator of sedimentary provenance: the nature of a sedimentary rock source area, its composition, relief, and location. Sandstone textures and sedimentary structures also are reliable indexes of the transportational agents and depositional setting.

Uses of sandstones

Sandstone components and colour. There are three basic components of sandstones: (1) detrital grains, mainly transported, sand-size minerals such as quartz and feldspar, (2) a detrital matrix of clay or mud, which is absent in "clean" sandstones, and (3) a cement that is chemically precipitated in crystalline form from solution and that serves to fill up original pore spaces.

The colour of a sandstone depends on its detrital grains and bonding material. An abundance of potassium feldspar often gives a pink colour; this is true of many arkoses, which are feldspar-rich sandstones. Fine-grained, dark-coloured rock fragments, such as pieces of slate, chert, or andesite, however, give a salt-and-pepper appearance to a sandstone. Iron oxide cement imparts tones of yellow, orange, brown, or red, whereas calcite cement imparts a gray colour. A sandstone consisting almost wholly of quartz grains cemented by quartz may be glassy and white. A chloritic clay matrix results in a greenish black colour and extreme hardness; such rocks are wackes.

Formation of sandstones today. Sandstones occur in strata of all geologic ages. Much scientific understanding of the depositional environment of ancient sandstones comes from detailed study of sand bodies forming at the present time. One of the clues to origin is the overall shape of the entire sand deposit. Inland desert sands today cover vast areas as a uniform blanket; some ancient sandstones in beds a few hundred metres thick but 1,600 kilometres or more in lateral extent, such as the Nubian Sandstone of North Africa, of Mesozoic age (about 245 to 66.4 million years old), also may have formed as blankets of desert sand. Deposits from alluvial fans form thick, fault-bounded prisms. River sands today form shoestring-shaped bodies, tens of metres thick, a few hundred metres wide, up to 60 kilometres or more long, and usually oriented perpendicularly to the shoreline. In meandering back and forth, a river may construct a wide swath of sand deposits, mostly accumulating on meander-point bars. Beaches, coastal dunes, and barrier bars also form "shoestring" sands, but these are parallel to the shore. Deltaic sands show a fanlike pattern of radial, thick, finger-shaped sand bodies interbedded with muddy sediments. Submarine sand bodies are diverse, reflecting the complexities of underwater topography and currents. They may form great ribbons parallel with the current; huge submarine "dunes" or "sand waves" aligned perpendicularly to the current; or irregular shoals, bars, and sheets. Some sands are deposited in deep water by the action of density currents, which flow down submarine slopes by reason of their high sediment concentrations and, hence, are called turbidity currents. These characteristically form thin beds interbedded with shales; sandstone beds often are graded from coarse grains at the base to fine grains at the top of the bed and commonly have a clay matrix.

Bedding structure. One of the most fruitful methods of deciphering the environment of deposition and direction of transport of ancient sandstones is detailed field study of the sedimentary structures.

Bedding in sandstones, expressed by layers of clays, micas, heavy minerals, pebbles, or fossils, may be tens of feet thick, but it can range downward to paper-thin laminations. Flagstone breaks in smooth, even layers a few centimetres thick and is used in paving. Thin, nearly horizontal lamination is characteristic of many ancient beach sandstones. Bedding surfaces of sandstones may be marked by ripples (almost always of subaqueous origin), by tracks and trails of organisms, and by elongated grains that are oriented by current flow (fossils, plant fragments, or even elongated sand grains). Sand-grain orientation tends to parallel direction of the current; river-channel trends in fluvial sediments, wave-backwash direction in beach sands, and wind direction in eolian sediments are examples of such orientation.

Bedding-plane markings and cross-bedding

A great variety of markings, such as flutes and scour and fill grooves, can be found on the undersides of some sandstone beds. These markings are caused by swift currents during deposition; they are particularly abundant in sandstones deposited by turbidity currents.

Within the major beds, cross-bedding is common. This structure is developed by the migration of small ripples, sand waves, tidal-channel large-scale ripples, or dunes and consists of sets of beds that are inclined to the main horizontal bedding planes. Almost all sedimentary environments produce characteristic types of cross-beds; as one example, the lee faces of sand dunes (side not facing the wind) may bear cross-beds as much as 33 metres (108 feet) high and dipping 35°.

Some sandstones contain series of graded beds. The grains at the base of a graded bed are coarse and gradually become finer upward, at which point there is a sharp change to the coarse basal layer of the overlying bed. Among the many mechanisms that can cause these changes in grain size are turbidity currents, but in general they can be caused by any cyclically repeated waning current.

After the sand is deposited, it may slide downslope or subside into soft underlying clays. This shifting gives rise to contorted or slumped bedding on a scale of centimetres to tens of metres. Generally these are characteristic of unstable areas of rapid deposition.

Local cementation may result in concretions of calcite, pyrite, barite, and other minerals. These can range from sand crystals or barite roses to spheroidal or discoidal concretions tens of metres across.

The fossil content also is a useful guide to the depositional environment of sandstones. Desert sandstones usually lack fossils. River-channel and deltaic sandstones may contain fossil wood, plant fragments, fossil footprints, or vertebrate remains. Beach and shallow marine sands contain mollusks, arthropods, crinoids, and other marine creatures, though marine sandstones are much less fossiliferous than marine limestones. Deepwater sands

are frequently devoid of skeletal fossils, although tracks and trails may be common. The fossils are not actually structures, of course, but the living organisms were able to produce them. Burrowing by organisms, for example, may cause small-scale structures, such as eyes and pods or tubules of sand.

Texture. The texture of a sandstone is the sum of such attributes as the clay matrix, the size and sorting of the detrital grains, and the roundness of these particles. To evaluate this property, a scale of textural maturity that involved four textural stages was devised in 1951 (see Figure 130). These stages are described as follows.

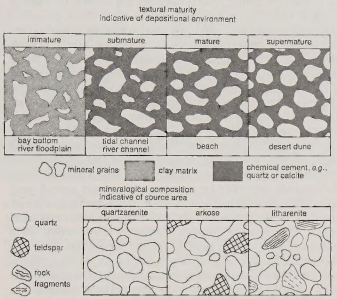


Figure 130: Textural maturity and mineralogical composition of sandstones from various environments.

Degree of textural maturity

Immature sandstones contain a clay matrix, and the sand-size grains are usually angular and poorly sorted. This means that a wide range of sand sizes is present. Such sandstones are characteristic of environments in which sediment is dumped and is not thereafter worked upon by waves or currents. These environments include stagnant areas of sluggish currents such as lagoons or bay bottoms or undisturbed seafloor below the zone of wave or current action. Immature sands also form where sediments are rapidly deposited in subaerial environments, such as river floodplains, swamps, alluvial fans, or glacial margins. Submature sandstones are created by the removal of the clay matrix by current action. The sand grains are, however, still poorly sorted in these rocks. Submature sandstones are common as river-channel sands, tidal-channel sands, and shallow submarine sands swept by unidirectional currents. Mature sandstones are clay-free, and the sand grains are subangular, but they are well sorted—that is, of nearly uniform particle size. Typically, these sandstones form in environments of current reversal and continual washing, such as beaches. Supermature sandstones are those that are clay-free and well sorted and, in addition, in which the grains are well rounded. These sandstones probably formed primarily as desert dunes, where intense eolian abrasion over a very long period of time may wear sand grains to nearly spherical shapes.

The methodology used for detailed study of siliciclastic sedimentary rock textures, particularly grain-size distribution and grain shape (angularity and sphericity) has been described above. The information that results from textural analyses is especially useful in identifying sandstone depositional environments. Dune sands in all parts of the world, for example, tend to be fine-sand-size (clast diameters from $^1/_4$ to $^1/_8$ millimetre) because sand of that dimension is most easily moved by winds. Desert (eolian) sandstones also tend to be bimodal or polymodal—*i.e.*, having two (or more) abundant grain-size classes separated by intervening, less prevalent size classes. Dune and beach sands exhibit the best sorting; river and shallow marine sands are less well sorted. River-floodplain, deltaic, and turbidity-current sand deposits show much poorer sorting. Skewness (the symmetry or asymmetry of a grain-size distribution) also varies as a function of depositional setting. Beach sands are commonly negatively skewed (they have a tail of more poorly sorted coarse grains), whereas dune and river sands tend to be positively skewed (a tail of more poorly sorted fine grains).

Shape and roundness

Careful analysis of grain roundness and grain shape also can aid in distinguishing the high-abrasion environments of beach and especially dune sands from those of fluvial or marine sands. Rounding takes place much more rapidly in sands subjected to wind action than in water-laid sands. In general, coarser sand grains are better rounded than finer grains because the coarser ones hit bottom more frequently and also hit with greater impact during transport. Sand grains may also have polished, frosted, pitted, or otherwise characteristic surfaces. These depend on the grain size, the agent of transport, and the amount of chemical attack. For example, polish can occur on medium-grained beach sands and fine-grained desert sands and can also be produced chemically by weathering processes.

Mineral composition. Mineralogical study of sandstones has proceeded along two distinct lines. One method involves cutting a thin section (0.03 millimetre thick) from the rock for examination of the mineralogy, cementation, texture, and structures with a petrographic microscope. This thin section approach was first used in the 1870s. Another method is to disaggregate the sand and place the grains in a heavy liquid such as bromoform (specific gravity about 2.9). This concentrates the heavy minerals that are present in minute amounts (0.01 to 1 or 2 percent of the rock) for detailed microscopic study. These methods offer valuable clues as to source area composition.

Although sandstones may be composed of any mineral, the most common mineral is quartz (SiO_2), which constitutes about 80 percent of the average sandstone; a few sandstones, however, lack quartz entirely, whereas others contain more than 99 percent quartz. Microscopic study reveals a great many types of quartz, recognizable by their appearance in polarized light and by inclusions of gas or liquid bubbles or other substances. Volcanic quartz, various types of metamorphic quartz, hydrothermal quartz, and other varieties are known. Other detrital minerals of common occurrence are the feldspars and micas. The abundance of these chemically less resistant silicates has been used as a climatic indicator. Sand-size fragments of older fine-grained rocks (*e.g.*, chert, slate, and basalt) are common in many sandstones. Clay matrix, if present, may consist of the minerals illite, kaolinite, montmorillonite, or clay-size micas. Some marine sandstones contain an abundance of pellets of glauconite (greensands) or phosphates in the form of bones, teeth, scales, or chemical precipitates. These sands are useful as fertilizers.

Classification of sandstones. There are many different systems of classifying sandstones, but the most commonly used schemes incorporate both texture (the presence and amount of either interstitial matrix—*i.e.*, clasts with diameters finer than 0.03 millimetre—or chemical cement) and mineralogy (the relative amount of quartz and the relative abundance of rock fragments to feldspar grains). The system presented here (Figure 131) is that of the American petrologist Robert H. Dott (1964), which is based on the concepts of P.D. Krynine and F.J. Pettijohn.

Arenites and wackes

Sandstones are first subdivided into two major textural groups, arenites and wackes. Arenites (the front triangular panel of Figure 131) consist of a sand-size framework component surrounded by pore spaces that are either empty (in the case of arenite sands) or filled with crystalline chemical cement (in the case of arenites). Wackes (the second triangular panel of Figure 131) consist of a sand-size framework component floating in a finer-grained pasty matrix of grains finer than 0.03 millimetre whose overall abundance exceeds 15 percent by volume. A third triangular panel in the background shows the natural transition from sandstones to mudrocks as the percentage of sand-size framework clasts decreases.

Further subdivision of both arenites and wackes into three specific sandstone families is based on the relative proportions of three major framework grain types: quartz (Q), feldspar (F), and rock fragments (R for rock fragment, or L for lithic fragment). For example, quartz arenites are rocks whose sand grains consist of at least 95 percent

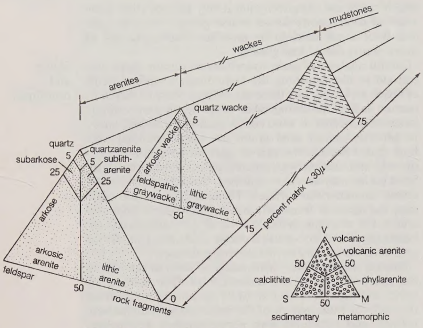


Figure 131: Classification of terrigenous sandstones.
From F.J. Pettijohn, P.E. Potter, and R. Siever, *Sand and Sandstone* (1987), 2nd ed., Springer-Verlag, Berlin

quartz. If the sand grains consist of more than 25 percent feldspar (and feldspar grains are in excess of rock fragments), the rock is termed arkosic arenite or "arkose," although such sandstones are also somewhat loosely referred to as feldspathic sandstones. In subarkosic arenite (or subarkose), feldspar sand grains likewise exceed rock fragments but range in abundance from 5 to 15 percent. Lithic arenites (or litharenites) have rock fragments that exceed feldspar grains; the abundance of rock fragments is greater than 25 percent. Sublitharenites likewise contain more rock fragments than feldspar, but the amount of rock fragments is lower, ranging from 5 to 25 percent. Lithic arenites can be further subdivided according to the nature of the rock fragments, as shown in the smaller triangle of Figure 131. This classification scheme also recognizes three major types of wackes or graywackes that are roughly analogous with the three major arenite groups: quartz wacke, feldspathic wacke (with the subvariety arkosic wacke), and lithic wacke. The three major arenite sandstone families are separately described below, but the varieties of wacke can be conveniently considered together as a single group.

Quartz arenites. Quartz arenites are usually white, but they may be any other colour; cementation by hematite, for example, makes them red. They are usually well sorted and well rounded (supermature) and often represent ancient dune, beach, or shallow marine deposits. Characteristically, they are ripple-marked or cross-bedded and occur as widespread thin blanket sands. On chemical analysis, some are found to contain more than 99 percent SiO_2 (quartz). Most commonly they are cemented with quartz, but calcite and iron oxide frequently serve as cements as well.

St. Peter Sandstone

This type of sandstone is widespread in stable areas of continents surrounding the craton, such as central North America (St. Peter Sandstone of Ordovician age [about 505 to 438 million years old]), central Australia, or the Russian Platform, and are particularly common in Paleozoic strata (that formed from 570 to 245 million years ago). Quartz arenites have formed in the past when large areas of subcontinental dimensions were tectonically stable (not subject to uplift or deformation) and of low relief, so that extensive weathering could take place, accompanied by prolonged abrasion and sorting. This process eliminated all the unstable or readily decomposed minerals such as feldspar or rock fragments and concentrated pure quartz together with trace amounts of zircon, tourmaline, and various other resistant heavy minerals.

Quartz arenites have also accumulated to thicknesses of hundreds and even thousands of metres on the continental shelf areas produced as passive continental margins develop during the early stages of continental rifting and the opening of an ocean basin. These thick, continental margin deposits form only if source areas are sufficiently stable to permit beach abrasion and intense chemical weathering capable of destroying rock fragments and feldspars. Subsequent ocean basin closure and continental collision deforms the continental shelf and rise assemblages, incorporating clean quartz arenite units into the resulting folded and faulted mountain system, typically as major ridges. Examples include the Cambrian Chilhowee Group and Silurian Tuscarora Sandstone and Clinch Sandstone formations in the Appalachian Mountains of eastern North America and the Flathead Sandstone and Tapeats Sandstone of the Rocky Mountains in the western part of the continent. Some quartz arenites are shown in Figures 132 and 133.

Arkosic sandstones. Arkosic sandstones are of two types. The most common of these is a mixture of quartz, potash feldspar, and granitic rock fragments. Chemically, these rocks are 60–70 percent silica (or silicon dioxide) and 10–15 percent aluminum oxide (Al_2O_3), with significant amounts of potassium (K), sodium (Na), and other elements. This type of arkosic sandstone, or arkose, can form wherever block faulting of granitic rocks occurs, given rates of uplift, erosion, and deposition that are so great that chemical weathering is outweighed and feldspar can survive in a relatively unaltered state. These rocks are usually reddish, generally immature, very poorly sorted, and frequently interbedded with arkose conglomerate; alluvial fans or fluvial aprons are the main depositional environments. The Triassic Newark Group of Connecticut is a classic example of this type of arkosic sandstone. Arkose

Arkoses also form under desert (or rarely Arctic) conditions in which the rate of chemical decomposition of the parent granite or gneiss is very slow. These arkoses are generally well sorted and rounded (supermature) and show other desert features, such as eolian cross-beds, associated gypsum, and other evaporitic minerals. The Precambrian Torridonian Arkose of Great Britain is thought to be of desert origin. Basal sands deposited on a granitic-gneissic craton also are usually arkosic. Subarkose sandstones (*e.g.,* Millstone Grit from the Carboniferous of England) have a feldspar content that is diminished by more extensive weathering or abrasion or by dilution from nonigneous source rocks.

By courtesy of R.L. Folk

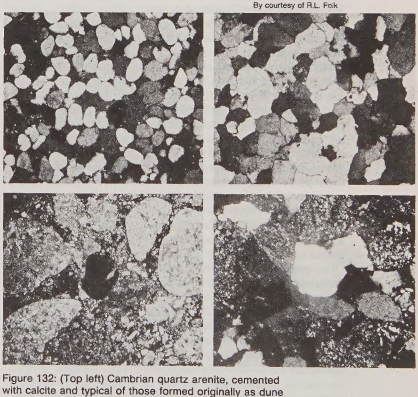


Figure 132: (Top left) Cambrian quartz arenite, cemented with calcite and typical of those formed originally as dune sands. (Top right) Silurian Tuscarora quartzite, a former beach sand. Quartz sand grains are well rounded and are completely cemented by quartz overgrowths visible as clear rims around the "dusty" detrital nuclei. (Bottom left) Submature calcilithite of the Ordovician Marathon Formation. (Bottom right) Chert-arenite consisting of about 50 percent quartz and 50 percent chert (finely speckled). It probably is a channel sandstone derived from older sedimentary rocks. (All photographs magnified about 50×.)

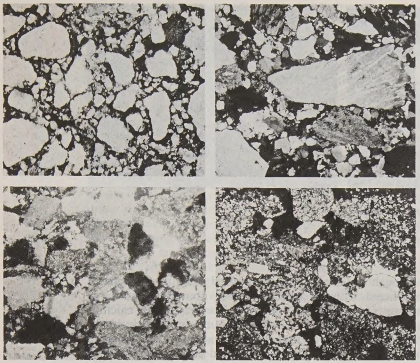


Figure 133: (Top left) Immature Devonian quartz arenite with clay matrix. This rock originated from turbidity-current deposition in a deepwater marine basin. (Top right) Precambrian submature arkose with angular and poorly sorted grains. (Bottom left) Devonian phyllarenite consisting of about 50 percent quartz and 50 percent metamorphic rock fragments (speckled grains). (Bottom right) Carboniferous volcanic arenite with clay matrix and poorly sorted grains of volcanic rock fragments containing tiny feldspar laths. This sandstone was deposited in an island arc area. (All photographs magnified about 50×.)
By courtesy of R.L. Folk

Lithic arenites. Lithic arenites occur in several subvarieties, but they are normally gray or of salt-and-pepper appearance because of the inclusion of dark-coloured rock fragments. Most commonly, fragments of metamorphic rocks such as slate, phyllite, or schist predominate, producing phyllarenite. If volcanic rock fragments such as andesite and basalt are most abundant, the rock is termed a volcanic arenite. If chert and carbonate rock fragments are predominant, the name chert or calchithite is applied.

Lithic arenites are usually rich in mica and texturally immature; the silicon dioxide content is 60–70 percent; aluminum oxide is 15 percent; and potassium, sodium, iron (Fe), calcium (Ca), and magnesium (Mg) are present in lesser amounts. Lithic arenites are very common in the geologic record, are widespread geographically, and are of all ages. They generally were formed as the result of rapid uplift, intense erosion, and high rates of deposition. Many of the classic postorogenic clastic wedge systems found in the major mountain systems of the world contain abundant lithic arenites. In the Appalachians, these include the Ordovician Juniata Formation of the Taconic clastic wedge, the Devonian Catskill Formation of the Acadian clastic wedge, and the Pocono and Mauch Chunk formations of the Alleghenian clastic wedge. Most lithic arenites are deposited as fluvial apron, deltaic, coastal plain, and shallow marine sandstones, interbedded with great thicknesses of shale and frequently with beds of coal or limestone. If they are deposited in an oxidizing environment such as a well-drained river system, they are reddish (*e.g.*, the Catskill Formation of the northeastern United States and the Devonian Old Red Sandstone of England).

(R.L.F./F.L.S.)

Wackes. Wacke, or graywacke, is the name applied to generally dark-coloured, very strongly bonded sandstones that consist of a heterogeneous mixture of rock fragments, feldspar, and quartz of sand size, together with appreciable amounts of mud matrix. Almost all wackes originated in the sea, and many were deposited in deep water by turbidity currents.

Characteristics of wackes

Wackes typically are poorly sorted, and the grain sizes present range over three orders of magnitude—*e.g.*, from 2 to 2,000 micrometres (8×10^{-5} to 8×10^{-2} inch). Commonly, the coarsest part of a wacke bed is its base, where pebbles may be abundant. Shale fragments, which represent lumps of mud eroded from bottom sediments by the depositing current, may be concentrated elsewhere in the bed.

Many wackes contain much mud, typically 15–40 percent, and this increases as the mean grain size of the rock decreases. The particles forming the rock are typically angular. This, and the presence of the interstitial mud matrix, has led to these rocks being called "microbreccias." The fabric and texture indicate that the sediments were carried only a short distance and were subject to very little reworking by currents after deposition.

The most widespread internal structure of wackes is graded bedding (Figure 134), although some sequences display it poorly. Sets of cross strata more than three centimetres thick are rare, but thinner sets are very common. Parallel lamination is widespread, and convolute bedding is usually present. These internal structures are arranged within wacke beds in a regular sequence. They appear to result from the action of a single current flow and are related to changes in the hydraulics of the depositing current. In some beds, the upper part of the sequence of structures is missing, presumably because of erosion or nondeposition. In others, the lower part is missing. This has been attributed to change in the hydraulic properties of the depositing current as it moves away from its source and its velocity decreases to the point at which the first sediment deposited is laminated, rather than massive and graded as is the case closer to the source.

The most typical external structures of wacke beds are sole markings, which occur on their undersurfaces. Flute and groove molds (Figure 134) are the most characteristic, but many other structures have been recorded.

The upper surfaces of wacke beds are less well characterized by sedimentary structures. The most typical are current lineation and various worm tracks, particularly of the highly sinuous form *Nereites*. Apart from these trace fossils, wackes are usually sparsely fossiliferous. Where fossils occur they are generally free-floating organisms (graptolites, foraminiferans) that have settled to the bottom, or bottom-living (benthic), shallow-water organisms displaced into deeper water as part of the sediment mass.

Chemical composition

Wackes are chemically homogeneous and are generally rich in aluminum oxide (Al_2O_3), ferrous oxide (FeO) + ferric oxide (Fe_2O_3), magnesium oxide (MgO), and soda (Na_2O). The abundance of soda relative to potash (K_2O) (reflecting a typically high sodium plagioclase feldspar content) and dominance of ferrous oxide over ferric oxide (reflecting large amounts of chlorite in the matrix) chemically distinguishes wackes from the three arenite families. The bulk composition of most wackes mimics that of their source owing to a lack of chemical differentiation by weathering and sorting. The matrix component, which is by definition any clasts 30 micrometres or finer, allows wackes to be differentiated from the other major sandstones. To be characterized as a wacke, its matrix component must equal or exceed 15 percent; in some cases more than 50 percent matrix has been reported. The origin of the matrix component, however, is controversial. Even though laboratory studies demonstrate that gravity-driven, bottom-hugging turbidity currents deposit sand-size grains together with mud-size clasts, modern deep-sea fan and abyssal plain sands (turbidites) have a matrix component that seldom exceeds 10 percent. A large portion of the matrix in ancient wackes must therefore be secondary, derived either from the disaggregation of feldspar and fine-grained lithic fragments like shale, phyllite, and volcanic rocks or from the postdepositional infiltration of clay- and silt-size clasts from overlying beds.

Wackes are widespread in the geologic record and occur throughout geologic history. They typically are not found in association with sedimentary rocks that accumulate upon stable continental blocks and are instead confined either to intensely deformed mountain systems or to their modern analogues: ocean trenches, the continental slope and rise, and abyssal plain areas. Many, perhaps most, wackes are redeposited marine sands derived from source areas in which weathering, erosion, and deposition are too rapid to permit chemical differentiation and the break-



Figure 134: *Sedimentary structures in wackes.*
(Left) Interbedded shales and wackes, Lower Silurian Aberystwyth Grits, Wales. (Centre) Bed of very coarse Upper Cambrian wacke, showing graded bedding and load casting, Denison Range, Tas., Australia. (Right) Groove molds on underside of wacke bed, Middle Silurian Denbigh Grits, Wales.
By courtesy of K.A.W. Crook, the Australian National University, Canberra

down of unstable components. Wackes of Archean age (those formed from 3.8 to 2.5 billion years ago) constitute the dominant sandstone type in the classic greenstone belts of the Precambrian shields (large areas of basement rocks in a craton that formed 3.8 billion to 570 million years ago around which younger sedimentary rocks have been deposited). They probably accumulated in rapidly subsiding trenches and ocean basins that surrounded primitive continental blocks. Proterozoic wackes (those formed from about 2.5 billion to 570 million years ago) are dominantly trench and ocean basin deposits, as are wackes of Phanerozoic age (those formed from 570 million years ago to the present day). They represent the accumulation of sand-size prisms of material that today are deposited both within ocean trenches (*e.g.,* the modern trenches off Indonesia) and as submarine fan aprons (*e.g.,* the Astoria Fan off the Pacific coast of Washington and Oregon in the United States) developed at the base of the continental slope at the mouths of submarine canyons. More distal carpets of wacke sand can extend for thousands of square kilometres across oceanic abyssal plains. Classic examples of the continental margin and ocean basin deposits include the late Precambrian Ocoee Supergroup and Ordovician Martinsburg Formation of the Appalachians, the Jurassic and Cretaceous Franciscan Formation of the Pacific Coast Ranges of California, much of the Alpine flysch (see below) of Switzerland and France, and many of the famous turbidite sands found in the Italian Apennines.

The feature common to all modern depositional sites is that they adjoin landmasses in areas of high submarine relief. The landmass may be a continent bordered by either a passive, aseismic margin (for example, the eastern margin of North America) or a seismically active margin like that found along the western coast of both North and South America. The landmass can also be an active volcanic arc such as the Aleutian Islands chain or the Japan islands arc. The critical factor is the close proximity of topographically high and emergent clastic source areas and steeply sloped submarine depositional slopes, basins, or trenches. (K.A.W.C./F.L.S.)

MUDROCKS

In terms of volume, mudrocks are by far the most important variety of sedimentary rock, probably constituting nearly 80 percent of the Earth's sedimentary rock column. Despite this abundance, the literature on mudrocks does not match in extent or detail that dealing with sandstones, carbonate rocks, and the various rarer sedimentary rock varieties like evaporite and phosphorite. This paradox reflects the difficulties inherent both in analyzing such rocks, owing to their poor exposure and fine grain size, and in interpreting any data obtained from their analysis because of the effects of diagenesis. Mudrocks include all siliciclastic sedimentary rocks composed of silt- and clay-size particles: siltstone ($^1/_{16}$ millimetre to $^1/_{256}$ millimetre diameters), claystone (less than $^1/_{256}$ millimetre), and mudstone (a mix of silt and clay). Shale refers specifically to mudrocks that regularly exhibit lamination or fissility or both. Mudrocks are also loosely referred to as both lutites and pelites and as argillaceous sedimentary rocks.

Though mudrocks are composed mainly of detritus weathered from preexisting rocks, many contain large amounts of chemically precipitated cement (either calcium carbonate or silica), as well as abundant organic material. Mudrocks produced from the alteration of volcanic lava flows and ash beds to clay and zeolite minerals are called bentonites.

General properties of shales. The properties of shales are largely determined by the fine grain size of the constituent minerals. The accumulation of fine clastic detritus generally requires a sedimentary environment of low mechanical energy (one in which wave and current actions are minimal), although some fine material may be trapped by plants or deposited as weakly coherent pellets in more agitated environments. The properties of the clay mineral constituents of lutites are particularly important, even when they do not make up the bulk of a rock.

Mineralogy and chemistry

The mineralogy of shales is highly variable. In addition to clay minerals (60 percent), the average shale contains quartz and other forms of silica, notably amorphous silica and cristobalite (30 percent), feldspars (5 percent), and the carbonate minerals calcite and dolomite (5 percent). Iron oxides and organic matter (about 0.5 and 1 percent, respectively) are also important. Older estimates greatly underestimated clay minerals because of incorrect assignment of potassium to feldspar minerals. The most abundant clay mineral is illite; montmorillonite and mixed-layer illite-montmorillonite are next in abundance, followed by kaolinite, chlorite, chlorite-montmorillonite, and vermiculite. The quartz-to-feldspar ratio generally mirrors that of associated sands. In pelagic (deep-sea) sediments, however, feldspar may be derived from local volcanic sources, whereas quartz may be introduced from the continents by wind, upsetting simple patterns. A large number of accessory minerals occur in shales. Some of these are detrital, but diagenetic or in situ varieties (*e.g.,* pyrite, siderite, and various phosphates) and volcanically derived varieties (*e.g.,* zeolites, zircon, and biotite) have been noted.

Transportation and deposition of sediments

Origin of shales. The formation of fine-grained sediments generally requires weak transporting currents and a quiet depositional basin. Water is the common transporting medium, but ice-rafted glacial flour (silt produced by glacial grinding) is a major component in high-latitude oceanic muds, and windblown dust is prominent, particularly in the open ocean at low and intermediate latitudes. Shale environments thus include the deep ocean; the continental slope and rise; the deeper and more protected parts of shelves, shallow seas, and bays; coastal lagoons; interdistributory regions of deltas, swamps, and lakes (including arid basin playas); and river floodplains. The deep-sea muds are very fine, but an orderly sequence from coarse sediments in high-energy nearshore environments to fine sediments at greater depths is rarely found. Sediments at the outer edges of present-day continental shelves are commonly sands, relict deposits of shallower Pleistocene (from about 1,600,000 to 10,000 years ago) glacial conditions, whereas muds are currently being deposited in many parts of the inner shelf. The nearshore deposition of clay minerals is enhanced by the tendency of riverborne dispersed

platelets to flocculate in saline waters (salinity greater than about four parts per thousand) and to be deposited just beyond the agitated estuarine environment as aggregates hydraulically equivalent to coarser particles. Differential flocculation leads to clay-mineral segregation, with illite and kaolinite near shore and montmorillonite farther out to sea. Advance of silty and sandy delta-slope deposits over clays also leads to complex grain-size patterns.

Shales may be deposited in environments of periodic agitation. Sediments deposited on submarine slopes are frequently mechanically unstable and may be redistributed by slumping and turbidity currents to form thick accumulations (possible present-day eugeosynclinal equivalents) on the lower continental slope and rise. Part of the shale in many wacke-shale alternations may be of turbidite origin. Fine sediment can be deposited in marshes and on tidal flats. Trapping by marsh plants and binding of muds in fecal pellets are important. Because of electrochemical interactions among fine particles, muds plastered on a tidal flat by an advancing tide are difficult to reerode on the ebb. This may lead, as in the present-day Waddenzee, in The Netherlands, to a size increase from nearshore tidal flat muds to lag sands seaward. Fine floodplain sediments may dry out to coherent shale pellets, and these, on reerosion, can be redistributed as sands and gravels.

Shales of economic value. Black shales are often of economic importance as sources of petroleum products and metals, and this importance will probably increase in the future. The lacustrine Eocene Green River Shales of Colorado, Wyoming, and Utah are potentially rich petroleum sources and are undergoing exploratory extraction. Bituminous layers of the Early Permian Irati Shales of Brazil are similarly important. These shales contain the remains of the marine reptile *Mesosaurus,* also found in South Africa, and played a prominent part in the development of the concepts of continental drift. The widespread thin Chattanooga Shale (Devonian-Mississippian) of the eastern United States has been exploited for its high (up to 250 parts per million) uranium content. The Kupferschiefer of the Permian (286 to 245 million years old) is a bituminous shale rich in metallic sulfides of primary sedimentary or early diagenetic origin; it covers a large area of central Europe as a band generally less than one metre thick, and in eastern Germany and in Poland there is sufficient enrichment in copper, lead, and zinc for its exploitation as an ore. (K.C.B./F.L.S.)

LIMESTONES AND DOLOMITES

Limestones and dolomites are collectively referred to as carbonates because they consist predominantly of the carbonate minerals calcite ($CaCO_3$) and dolomite ($CaMg[CO_3]_2$). Some limestones are shown in Figure 135. Almost all dolomites are believed to be produced by recrystallization of preexisting limestones, although the exact details of this dolomitization process continue to be debated (see above *Major rock-forming minerals: Dolomite: Origin and occurrence*). Consequently, the following discussion initially deals with limestones and dolomites as a single rock type and subsequently considers the complex process by which some limestones become dolomite.

Carbonates are by far the only volumetrically important nonsiliciclastic sedimentary rock type. Most are marine, and thick sequences of carbonate rocks occur in all the continental blocks, a surviving record of the transgressions and regressions of shallow marine (epeiric) seas that repeatedly blanketed the stable continental cratonic areas from time to time mainly during the late Precambrian, Paleozoic, and Mesozoic eras. Modern marine carbonate sediments, whose formation is favoured by warm, shallow water, are presently being deposited in a broad band straddling the Equator. The texture, sedimentary structures, composition, and organic content of carbonates provide numerous insights into the environment of deposition and regional paleogeography. Many important oil reservoirs of the world, especially those of the Middle East, occur in carbonate rocks.

Oil reservoirs

Mineralogy. Though ancient limestones and dolomites are composed of calcite and dolomite, respectively, other calcite group minerals such as magnesite ($MgCO_3$), rhodochrosite ($MnCO_3$), and siderite ($FeCO_3$) occur in limited amounts in restricted environments. Modern carbonate sediments are composed almost entirely of metastable aragonite ($CaCO_3$) and magnesium-rich calcite, both of which readily recrystallize during diagenesis to form calcite. Carbonate rocks commonly grade naturally into siliciclastic sedimentary rocks as the proportion of terrigenous grains of varying size and mineralogy increases. Such mixtures are the consequence of the infringement of a dominantly siliciclastic depositional setting (*e.g.,* a quartz arenitic beach area) into, for example, a lagoon or tidal flat in which carbonate mud accumulates.

Textural components. Carbonate minerals present in ancient limestones and dolomites occur in one of three textural forms: (1) discrete silt to sand to coarser carbonate grains, or allochems, such as oöids or skeletal fragments, (2) mud-size interstitial calcium carbonate matrix called microcrystalline calcite or micrite, and (3) interlocking, 0.02- to 0.1-millimetre-diameter crystals of clear interstitial calcium carbonate cement or spar. In a rather simplistic sense, these three carbonate rock textural components are comparable, respectively, to the three possible constituents in a sandstone: (1) the coarser rock and mineral grains, (2) interstitial matrix, and (3) interstitial chemical cement.

Several types of allochems exist: oöids, skeletal grains, carbonate clasts, and pellets. Ooids (also known as oölites or oöliths) are sand-size spheres of calcium carbonate mud concentrically laminated about some sort of nucleus grain, perhaps a fossil fragment or a silt-size detrital quartz grain. Oöids develop today on shallow shelf areas where strong bottom currents can wash the various kinds of material that form oöid nuclei back and forth in well-agitated, warm water that is supersaturated with calcium carbonate. The concentric layers of aragonite (in modern oöids) is produced by blue-green algae that affix themselves to the grain nucleus. Skeletal fragments, also known as bioclasts, can be whole fossils or broken fragments of organisms, depending on current and wave strength as well as depositional depth. The content and texture of the bioclast component in any carbonate will vary noticeably as a function of both age (due to evolution) and depositional setting (because of subsequent abrasion and transport as well as ecology). Carbonate clasts include fragments weathered from carbonate source rocks outside the depositional basin (lithoclasts) as well as fragments of carbonate sediment eroded from within the basin almost immediately after it was deposited (intraclasts). Silt- to sand-size particles of microcrystalline calcite or aragonite that lack the internal structure of oöids or bioclasts generally are called pellets or peloids. Most are fecal pellets generated by mud-ingesting organisms. Pellets can be cemented together into irregularly shaped composite grains dubbed lumpstones or grapestones.

Micrite and sparite

Microcrystalline carbonate mud (micrite) and sparry carbonate cement (sparite) are collectively referred to as orthochemical carbonate because, in contrast to allochems, neither exhibits a history of transport and deposition as clastic material. Micrite can occur either as matrix that fills or partly fills the interstitial pores between allochems or as the main component of a carbonate rock. It originates mainly as the result of organic activity: algae generate tiny needles of aragonite within their tissues, and after their death such needles fall to the depositional surface as unconsolidated mud, which soon recrystallizes to calcite. Some micrite is produced by inorganic precipitation of aragonite; grain-to-grain collision and the resulting abrasion of allochems also can generate modest amounts of micrite. Most of the coarser and clearer crystals of sparry calcite that fill interstitial pores as cement represent either recrystallized micrite or essentially a direct inorganic precipitate.

A number of carbonate classification schemes have been developed, but most modern ones subdivide and name carbonate rock types on the basis of the kinds of allochems present and the nature of the interstitial pore filling, whether it is micrite or spar. The most widely used scheme of this type is the descriptive classification devised by the American petrologist Robert L. Folk.

Origin of limestones. Limestones originate mainly

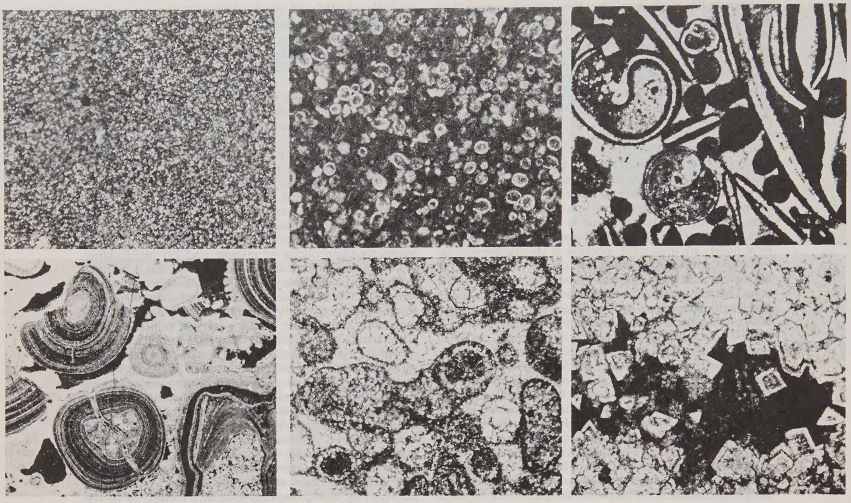


Figure 135: *Photomicrographs of carbonate rocks.*
(Top left) Micritic limestone, Triassic (magnified 18×). (Top centre) Micritic skeletal limestone, Upper Jurassic (magnified 25×). (Top right) Skeletal oölitic limestone, with clean calcite cement, Lower Triassic (magnified 18×). (Bottom left) Pisolitic dolomite, Upper Triassic (magnified 5×). (Bottom centre) Lump limestone, recrystallized, Permian (magnified 18×). (Bottom right) Diagenetic dolomite growing at the expense of existing micritic material, Middle Triassic (magnified 15×).
By courtesy of A. Boselini

through the lithification of loose carbonate sediments (see Figure 136). Modern carbonate sediments are generated in a variety of environments: continental, marine, and transitional, but most are marine. The present-day Bahama banks is the best known modern carbonate setting. It is a broad submarine shelf covered by shallow, warm seawater. The Bahama shelf, or carbonate platform, mimics the setting that repeatedly prevailed across the stable cratonic areas of the major continental blocks during late Precambrian, Paleozoic, and Mesozoic time and serves as a model for explaining the various limestone types that make up such ancient carbonate successions.

The edge of the shelf is marked by a topographically sharp escarpment flanked by coarse, angular limestone breccia. Submarine channels etched into the escarpment serve as waterways down which shallow-water carbonate sediment can be transported by turbidity currents capable of redistributing them as apronlike deposits on the oceanic abyssal plain. In many areas, the fringe of the Bahama banks is marked by wave-resistant reef rocks (sometimes classified as boundstone). Abrasion of these reefs by wave activity generates abundant skeletal debris. Variations in depth and current strength control the relative amounts of micrite and sparite, the prevalence of specific organisms and their productivity, and the likelihood of generating oöids, pellets, and carbonate rock fragments. Micrite and micritic allochemical sediments accumulate in deep-water, low-energy, protected areas like lagoons and tidal flats and on the leeward side of major islands. In high-energy, shallow-water locales such as beaches, coastal dunes, and tidal channels, currents winnow out any micrite, and these become the sites of sparry allochemical sediment deposition. Pinpointing the exact depositional setting for an ancient carbonate deposit requires detailed analysis of its texture, composition, sedimentary structures, geometry, fossil content, and stratigraphic relationships with modern carbonate depositional sites.

In addition to the ancient analogues of the modern carbonate deposits described above are freshwater limestones (marls) and limestone muds (or calcilutites) of deep-water abyssal plains. Freshwater limestones of limited extent represent a spectrum of small-scale settings developed within and along the margins of lacustrine basins. Deep-water abyssal plain limestones are quite restricted in volume and age in the geologic record for a number of reasons. First of all, abyssal plain sequences are less likely to be incorporated into the orogenic belts that develop as continental margins are compressed during ocean basin closure. Second, pelagic calcareous oozes are the obvious modern analogues of ancient abyssal plain calcilutites. These oozes are produced by aragonite-secreting plankton that float near the surface (such as foraminiferans and

Calcareous oozes

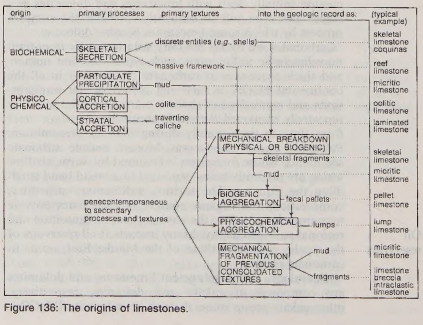


Figure 136: The origins of limestones.

coccoliths), which upon their death leave their shells, or tests, to settle slowly to the ocean bottom and accumulate. The development of such deep-sea deposits is therefore obviously dependent on the existence of calcium-secreting planktonic organisms, and these did not evolve until Mesozoic time. Finally, calcareous ooze accumulation is severely restricted both by latitude (being largely confined to a band extending 30° to 40° north and south of the Equator) and abyssal plain depth (approximately 2,000 metres). Below a depth of about 4,500 metres, which is the carbonate compensation depth (CCD), the pressure and temperature of seawater produces a rate of dissolution in excess of the rate of pelagic test accumulation.

Dolomites and dolomitization. Dolomite is produced by dolomitization, a diagenetic process in which the calcium carbonate minerals aragonite and calcite are recrystallized and converted into the mineral dolomite. Dolomitization can obscure or even obliterate all or part of the original limestone textures and structures; in the case where such original features survive, carbonate nomenclature and interpretation can still be applied to the rock with emphasis on the effects of alteration.

The exact processes by which limestones are dolomitized are not thoroughly understood, but dolomites occur widely in the geologic record. The relative proportion of dolomite to limestone progressively increases with age in carbonate rocks. This secular trend probably either reflects the earlier existence of geochemical settings that were more favourable to dolomitization or is the logical result of the fact that the likelihood for a limestone to undergo dolomitization increases proportionally with its age.

Geochemists have been unable to precipitate normal dolomite under the conditions of temperature and pressure that exist in nature; temperatures within the 200° C range are required to support precipitation. A few modern, so-called primary marine dolomite localities have been studied, but close investigation of these areas suggests that even these penecontemporaneous dolomites are produced by altering calcite or aragonite almost immediately after their initial precipitation. Dolomites generated by later alteration of older limestones are known as diagenetic dolomites.

The study of the few reported penecontemporaneous dolomite sites allows some conclusions to be formed regarding the dolomitization process. These modern dolomites develop mainly under conditions of high salinity (hypersalinity), which commonly exist in arid regions across supratidal mud flats as well as on the flat, saline plains and playa lake beds known as sabkhas. In highly saline environments, the ratio of dissolved magnesium ions to dissolved calcium ions progressively increases above the norm for seawater (5:1) as a result of the selective formation of calcium-rich evaporite minerals like gypsum and anhydrite. These magnesium-rich brines then tend to be flushed downward owing to their high density; the entire process is named evaporative reflux. Penecontemporaneous dolomites would result from the positioning of sabkhas and arid supratidal flats in a site that is in immediate contact with carbonate sediment; diagenetic dolomites would logically result when such dolomite-producing settings overlie older limestone deposits. The presence of fissures or highly permeable zones serving as channelways for downward percolation of dolomitizing fluids would also promote the alteration. Other studies have emphasized a possible role in dolomitization for dense brackish (salty) fluids formed when seawater and meteoric waters (those precipitated from the atmosphere as rain or snow) are produced along coastal zones.

Evaporative reflux

SILICEOUS ROCKS

Those siliceous rocks composed of an exceptionally high amount of crystalline siliceous material, mainly the mineral quartz (especially microcrystalline quartz and fibrous chalcedony) and amorphous opal, are most commonly known as chert. A wide variety of rock names are applied to cherty rocks reflecting their colour (flint is dark chert; jasper is usually red; prase is green) and geographic origin (novaculite of Arkansas, U.S.; silexite of France). The term chert is applied here to all fine-grained siliceous sediments and sedimentary rocks of chemical, biochemical, and organic origin.

Types of cherts. Two major varieties of chert deposits exist—namely, bedded chert and nodular chert. Bedded cherts occur in individual bands or layers ranging in thickness from one to several centimetres or even tens of metres. They are intimately associated with volcanic rocks, commonly submarine volcanic flows as well as deep-water mudrocks. Classic examples include the Miocene Monterey Formation of the Coast Ranges of California, the Permian Rex Chert of Utah and Wyoming, the Arkansas Novaculite of the Ouachita Mountains, and the Mesozoic chert deposits of the Franciscan Formation of California. Nodular cherts occur as small to large (millimetres to centimetres) knotlike and fistlike clusters of quartz, chalcedony, and opal concentrated along or parallel with bedding planes in shallow-water marine carbonate rocks as well as pelagic limestones. Individual nodules may be ovoid or semispherical in shape; masses of chert typically form an anastamosing network.

Origin of cherts. Many bedded cherts are composed almost entirely of the remains of silica-secreting organisms like diatoms and radiolarians. Such deposits are produced by compacting and recrystallizing the organically produced siliceous ooze deposits that accumulate on the present-day abyssal ocean floor. The modern oozes gather in latitudes where high organic productivity of floating planktonic radiolarians and diatoms takes place in the warm surface waters. As individual organisms die, their shells settle slowly to the abyssal floor and accumulate as unconsolidated siliceous ooze. Siliceous oozes are particularly prominent across areas of the ocean floor located far from continental blocks, where the rate of terrigenous sediment supply is low, and in deeper parts of the abyssal plain lying below the carbonate compensation depth, where the accumulation of calcareous oozes cannot occur. Some bedded cherts might not be of organic origin. They instead may be produced by precipitating silica gels derived from the same magma chambers from which the submarine basalts (pillow lava) that are intimately associated with bedded cherts are precipitated.

The origin of nodular cherts has long been debated, but most are produced by the secondary replacement of the carbonate minerals and fossils within shallow marine shelf deposits. Evidence of secondary origin includes relict structures of allochems such as skeletal fragments and oöids preserved entirely within chert nodules. Silica can be mobilized from elsewhere within a rock and transported in solution under proper conditions of temperature and geochemistry. Likely sources of silica found scattered within shallow-water shelf carbonates include siliceous sponge spicules, radiolarians or diatom shells, and windblown sand grains. The details of the process and the possible role of microscopic organisms like bacteria in dissolving, mobilizing, and reconcentrating the silica remains uncertain.

Sites of chert deposition

Finally, geysers and hot springs like those of the Yellowstone National Park area of northwestern Wyoming, U.S., are also sites of chert deposition. Encrustations of silica, known as sinter or geyserite, are volumetrically unimpressive but nevertheless are curiosities. The geyser and hot springs activity at Yellowstone is probably typical, with a subterranean body of magma as the source of silica-rich hydrothermal solutions rising periodically near or to the surface.

PHOSPHORITES

Many sedimentary rocks contain phosphate in the form of scattered bones composed of the mineral apatite (calcium phosphate), but rocks composed predominantly of phosphate are rare. Nevertheless, three principal types exist: (1) regionally extensive, crystalline nodular and bedded phosphorites, (2) localized concentrations of phosphate-rich clastic deposits (bone beds), and (3) guano deposits.

EVAPORITES

Evaporites are layered crystalline sedimentary rocks that form from brines generated in areas where the amount of water lost by evaporation exceeds the total amount of water from rainfall and influx via rivers and streams. The

mineralogy of evaporite rocks is complex, with almost 100 varieties possible, but less than a dozen species are volumetrically important. Minerals in evaporite rocks include carbonates (especially calcite, dolomite, magnesite, and aragonite), sulfates (anhydrite and gypsum), and chlorides (particularly halite, sylvite, and carnallite), as well as various borates, silicates, nitrates, and sulfocarbonates. Evaporite deposits occur in both marine and nonmarine sedimentary successions.

Minerals in evaporites

Though restricted in area, modern evaporites contribute to genetic models for explaining ancient evaporite deposits. Modern evaporites are limited to arid regions (those of high temperature and low rates of precipitation), for example, on the floors of semidry ephemeral playa lakes in the Great Basin of Nevada and California, across the coastal salt flats (sabkhas) of the Middle East, and in salt pans, estuaries, and lagoons around the Gulf of Suez. Ancient evaporates occur widely in the Phanerozoic geologic record, particularly in those of Cambrian (from 570 to 505 million years ago), Permian (from 286 to 245 million years ago), and Triassic (from 245 to 208 million years ago) age, but are rare in sedimentary sequences of Precambrian age. They tend to be closely associated with shallow marine shelf carbonates and fine (typically rich in iron oxide) mudrocks. Because evaporite sedimentation requires a specific climate and basin setting, their presence in time and space clearly constrains inferences of paleoclimatology and paleogeography. Evaporite beds tend to concentrate and facilitate major thrust fault horizons, so their presence is of particular interest to structural geologists. Evaporites also have economic significance as a source of salts and fertilizer.

All evaporite deposits result from the precipitation of brines generated by evaporation. Laboratory experiments can accurately trace the evolution of brines as various evaporite minerals crystallize. Normal seawater has a salinity of 3.5 percent (or 35,000 parts per million), with the most important dissolved constituents being sodium and chlorine. When seawater volume is reduced to one-fifth of the original, evaporite precipitation commences in an orderly fashion, with the more insoluble components (gypsum and anhydrite) forming first. When the solution reaches one-tenth the volume of the original, more soluble minerals like sylvite and halite form. Natural evaporite sequences show vertical changes in mineralogy that crudely correspond to the orderly appearance of mineralogy as a function of solubility but are less systematic.

Nonmarine environment. Evaporite deposition in the nonmarine environment occurs in closed lakes—*i.e.,* those without outlet—in arid and semiarid regions. Such lakes form in closed interior basins or shallow depressions on land where drainage is internal and runoff does not reach the sea. If water depths are shallow or, more typically, somewhat ephemeral, the term playa or playa lake is commonly used.

Water inflow into closed lakes consists principally of precipitation and surface runoff, both of which are small in amount and variable in occurrence in arid regions. Groundwater flow and discharge from springs may provide additional water input, but evaporation rates are always in excess of precipitation and surface runoff. Sporadic or seasonal storms may give rise to a sudden surge of water inflow. Because closed lakes lack outlets, they can respond to such circumstances only by deepening and expanding. Subsequent evaporation will reduce the volume of water present to prestorm or normal amount; fluctuation of closed lake levels therefore characterizes the environment.

Fluctuating lake levels

Such changing lake levels and water volumes lead to fluctuating salinity values. Variations in salinity effect equilibrium relations between the resulting brines and lead to much solution and subsequent reprecipitation of evaporites in the nonmarine environment. As a result of these complexities as well as the distinctive nature of dissolved constituents in closed lake settings, nonmarine evaporite deposits contain many minerals that are uncommon in marine evaporites—*e.g.,* borax, epsomite, trona, and mirabilite.

Shallow marine environment. Evaporite deposition in the shallow marine environment (sometimes termed the salina) occurs in desert coastal areas, particularly along the margins of such semi-restricted water bodies as the Red Sea, Persian Gulf, and Gulf of California. Restriction is, in general, one of the critical requirements for evaporite deposition, because free and unlimited mixing with the open sea would allow the bodies of water to easily overcome the high evaporation rates of arid areas and dilute these waters to near-normal salinity. This semi-restriction cannot, in fact, prevent a large amount of dilution by mixing; coastal physiography is the principal factor involved in brine production. Shallow-water evaporites, almost exclusively gypsum, anhydrite, and halite, typically interfinger with tidal flat limestone and dolomite and fine-grained mudrock.

Deep-basin environment. Most of the thick, laterally extensive evaporite deposits appear to have been produced in deep, isolated basins that developed during episodes of global aridity. The most crucial requirement for evaporite production is aridity; water must be evaporated more rapidly than it can be replenished by precipitation and inflow. In addition, the evaporite basin must somehow be isolated or at least partially isolated from the open ocean so that brines produced through evaporation are prevented from returning there. Restricting brines to such an isolated basin over a period of time enables them to be concentrated to the point where evaporite mineral precipitation occurs. Periodic breaching of the barrier, due either to crustal downwarping or to global sea-level changes, refills the basin from time to time, thereby replenishing the volume of seawater to be evaporated and making possible the inordinately thick, regionally extensive evaporite sequences visible in the geologic record.

Debate continues over the exact mechanisms for gener-

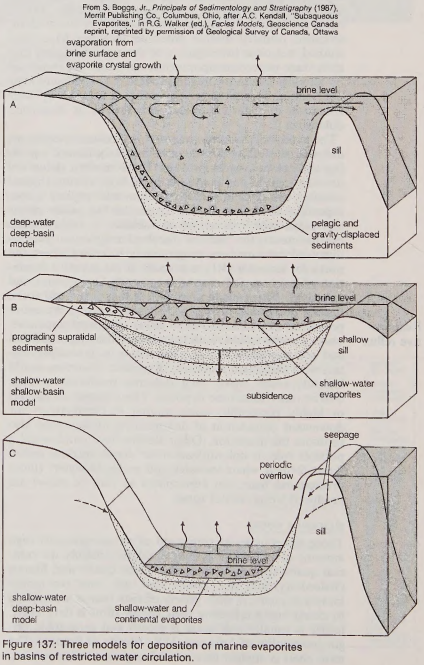


Figure 137: Three models for deposition of marine evaporites in basins of restricted water circulation.

ating thick evaporite deposits. Three possible models for restricting "barred" evaporite basins are shown in Figure 137. They differ in detail, and none has garnered a consensus of support. The deep-water, deep-basin model accounts for replenishment of the basin across the barrier or sill, with slow, continual buildup of thick evaporites made possible by the seaward escape of brine that allows a constant brine concentration to be maintained. The shallow-water, shallow-basin model produces thick evaporites by continual subsidence of the basin floor. The shallow-water, deep-basin model shows the brine level in the basin beneath the level of the sea as a result of evaporation; brines are replenished by groundwater recharge from the open ocean.

IRON-RICH SEDIMENTARY ROCKS

Almost all sedimentary rocks are iron-bearing in the sense that mudrocks, sandstones, and carbonates typically have an iron content of several percent. Nevertheless, sedimentary rocks in which the proportion of iron exceeds 15 percent are separately categorized as iron-rich. Two major types of iron-rich sedimentary rocks are recognized: (1) iron formation, or banded iron formation (BIF)—regionally extensive, locally thick sequences composed of alternating thin (millimetre to centimetre thick) layers of mainly crystalline-textured iron-rich minerals and chert—and (2) ironstone—noncherty, essentially clastic-textured, iron-rich minerals of local extent.

Banded iron formation

Banded iron formations are predominantly Precambrian in age; most are 1.8 to 2.2 billion years old; none are younger than Cambrian age. The most important iron-bearing minerals in iron formations are hematite, magnetite, and greenalite. These deposits constitute the world's major source of iron ore. Classic examples are found in the Mesabi Range of Minnesota, U.S., and the Kiruna ores of Sweden.

Ironstones are principally of Phanerozoic age, mainly Early Paleozoic (roughly 440 to 570 million years old) and Jurassic (about 144 to 208 million years old), but can be as old as Middle Precambrian age (about 1.6 to 3 billion years old). They appear to be restricted to basins no larger than 150 kilometres in any direction. Major iron minerals are goethite, hematite, and chamosite.

Origin of banded iron formation. The origin of banded iron formation is not clearly understood. Banded iron formation units are typically 50 to 600 metres thick. Their complex mineralogy includes various iron oxides, iron carbonates, iron silicates, and iron sulfides. The essentially crystalline texture of these minerals together with the definitive crystalline texture of the laminated chert bands with which the iron mineral layers alternate is perplexing. At present, iron is not easily dissolved, nor can it be readily transported in solution and subsequently precipitated as crystalline-textured, iron-rich minerals, because of the presence of free atmospheric oxygen. Many sedimentary petrologists consequently conclude that banded iron formation deposition is a uniquely Precambrian occurrence made possible by, and supporting the existence of, an earlier anaerobic Earth atmosphere (one lacking free oxygen) quite unlike that in existence today. Controversy also continues over the ultimate source of iron (weathering as opposed to magmatic iron escaping from the Earth's interior) and over the possible role of microorganisms such as bacteria and algae in the precipitation of the iron.

Origin of ironstones. The origin of ironstones also is not well understood, but most appear to be derived from the erosion and redeposition of lateritic (iron-rich, red) soils. Ironstones occur as thin (a few tens of metres at most) units interbedded with shallow marine and transitional carbonates, mudrocks, and sandstones. They generally have an oölitic texture. Cross-bedding, ripple marks, and small scour and fill channels are abundant. Slight uplift and erosion of reddish soils developed in coastal regions drained by rivers that transport and deposit such material in deltas and embayments along the coast is compatible with the features and fossils found in deposits of this sort. Classical ironstone deposits include the Ordovician Wabana Formation of Newfoundland and the Silurian Clinton Group of the central and southern Appalachians.

ORGANIC-RICH SEDIMENTARY DEPOSITS

Coal, oil shale, and petroleum are not sedimentary rocks per se; they represent accumulations of undecayed organic tissue that can either make up the bulk of the material (*e.g.*, coal), or be disseminated in the pores within mudrocks, sandstones, and carbonates (*e.g.*, oil shale and petroleum). Much of the undecomposed organic matter in sediment and sedimentary rocks is humus, plant matter that accumulates in soil. Other important organic constituents include peat, humic organic matter that collects in bogs and swamps where oxidation and bacterial decay is incomplete, and sapropel, fine-grained organic material—mainly the soft organic tissue of phytoplankton and zooplankton, along with bits and pieces of higher plants—that amass subaqueously in lakes and oceans.

Fossil fuels

Organic-rich sedimentary rock deposits are collectively referred to as fossil fuels because they consist of the undecayed organic tissue of plants and animals preserved in depositional settings characterized by a lack of free oxygen. Fossil fuels constitute the major sources of energy in the industrial world, and their unequal distribution in time (exclusively Phanerozoic) and space (more than half of the proved petroleum reserves are in the Persian Gulf region of the Middle East) has a significant effect on the world's political and economic stability.

Coal. Coals are the most abundant organic-rich sedimentary rock. They consist of undecayed organic matter that either accumulated in place or was transported from elsewhere to the depositional site. The most important organic component in coal is humus. The grade or rank of coal is determined by the percentage of carbon present. The term peat is used for the uncompacted plant matter that accumulates in bogs and brackish swamps. With increasing compaction and carbon content, peat can be transformed into the various kinds of coal: initially brown coal or lignite, then soft or bituminous coal, and finally, with metamorphism, hard or anthracite coal. In the geologic record, coal occurs in beds, called seams, which are blanketlike coal deposits a few centimetres to metres or hundreds of metres thick.

Many coal seams occur within cyclothems, rhythmic successions of sandstone, mudrock, and limestone in which nonmarine units are regularly and systematically overlain by an underclay, the coal seam itself, and then various marine lithologies. The nonmarine units are thought to constitute the floor of ancient forests and swamps developed in low-lying coastal regions; the underclay is a preserved relict of the soil in which the coal-producing vegetation was rooted; and the marine units overlying the coal record the rapid transgression of the sea inland that killed the vegetation by drowning it and preventing its decomposition by rapid burial. The exact mechanism responsible for generating the rapid episodes of marine transgression and regression necessary to generate coal-bearing cyclothems is not definitively known. A combination of episodic upwarping and downwarping of the continental blocks or global (eustatic) changes in sea level or both, coupled with normal changes in the rate of sediment supply that occurs along coasts traversed by major laterally meandering river systems, may have been the cause.

In any case, coal is a rare, though widely distributed, lithology. Extensive coal deposits overall occur mainly in rocks of Devonian age (those from 408 to 360 million years old) and younger because their existence is clearly contingent on the evolution of land plants. Nevertheless, small, scattered coal deposits as old as early Proterozoic have been described. Coal-bearing cyclothem deposits are especially abundant in the middle and late Paleozoic sequences of the Appalachians and central United States and in the Carboniferous of Great Britain, probably because during this time interval global climates were warm and humid and large portions of the continental blocks were low-lying platforms located only slightly above sea level.

Oil shale. Mudrock containing high amounts of organic matter in the form of kerogen is known as oil shale or kerogen shale. Kerogen is altered, undecayed, fatty organic matter, mainly sapropel, and is very fine-grained. It can be generated in place or transported. The most famous oil shale deposit in the world, located in the United States,

is the Green River Formation of Utah, Wyoming, and Colorado of Eocene age (*i.e.*, formed 57.8 to 36.6 million years ago). This vast deposit contains fossils and sedimentary structures, suggesting rapid deposition and burial of unoxidized organic matter in shallow lakes or marine embayments. The quantity of oil entrapped in the Green River Formation is significant. The cost of extracting the oil trapped in the mudrock by heating the oil shale, however, far exceeds the cost of extracting equivalent quantities of oil, natural gas, or coal. Also, the refractory process not only requires extensive strip mining and immense volumes of water but also results in a volume expansion of the original oil shale. Despite these considerable economic and technical problems, oil shales potentially represent a significant future energy resource.

Hydrocarbons

Oil and natural gas. Natural gas refers collectively to the various gaseous hydrocarbons generated below the Earth's surface and trapped in the pores of sedimentary rocks. Major natural gas varieties, include methane, ethane, propane, and butane. These natural gases are commonly, though not invariably, intimately associated with the various liquid hydrocarbons—mainly liquid paraffins, napthenes, and aromatics that collectively constitute oil.

The exact process by which oil and natural gas are produced is not precisely known, despite the extensive efforts made to determine the mode of petroleum genesis. Crude oil is thought to form from undecomposed organic matter, principally single-celled floating phytoplankton and zooplankton that settle to the bottom of marine basins and are rapidly buried within sequences of mudrock and limestone. Natural gas and oil are generated from such source rocks only after heating and compaction. Typical petroleum formation (maturation) temperatures do not exceed 100° C, meaning that the depth of burial of source rocks cannot be greater than a few kilometres. After their formation, oil and natural gas migrate from source rocks to reservoir rocks composed of sedimentary rocks largely as a consequence of the lower density of the hydrocarbon fluids and gases. Good reservoir rocks, by implication, must possess high porosity and permeability. A high proportion of open pore spaces enhances the capacity of a reservoir to store the migrating petroleum; the interconnectedness of the pores facilitates the withdrawal of the petroleum once the reservoir rock is penetrated by drill holes.

Secular trends in the sedimentary rock record

Reexamination of the sedimentary rock record preserved within the continental blocks suggests systematic changes through time in the relative proportions of the major sedimentary rock types deposited, as summarized in Figure 138. These changes can be linked to the evolution of the atmosphere and hydrosphere and to the changing global tectonic setting. Carbonates and quartz sands, for example, require long-term source area stability as well as the existence of broad, shallow-water epeiric seas that mantle continental blocks. Marine transgressions and regressions across broad stable continental cratons occurred only in

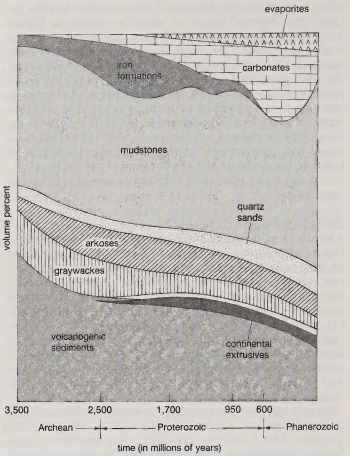


Figure 138: Changes in relative proportions of sedimentary rocks deposited on cratonic surfaces throughout geologic time.
From S.M. Stanley, *Earth and Life through Time* (1987), 2nd ed., W.H. Freeman and Co., New York

Proterozoic and Phanerozoic time; Archean continental blocks were smaller and tectonically unstable, and most likely less granitic than those of today. Consequently, the early Precambrian sedimentary rock record consists largely of volcanogenic sediments, wackes, and arkoses physically disintegrated from small, high-relief island arcs (the Archean greenstone belts of the various Precambrian shields) and microcontinental fragments. The fact that iron formations are restricted to rocks of Archean and Proterozoic time supports the conclusion that atmospheric oxygen levels in earlier stages of Earth history were lower, promoting the dissolution, transport, and precipitation of iron by chemical or biochemical means. The total lack of evaporites from the Archean record and their subsequent steady buildup probably reflects a number of factors. Such deposits can be easily destroyed by metamorphism, and presumably, given enough time, they will have been completely erased. Also, evaporite formation requires seawater with elevated salinity, a condition that is established with time. Finally, significant volumes of bedded evaporites can occur only once broad, stable continents have evolved, because the requisite restricted evaporite basins develop exclusively adjacent to cratons. (F.L.S.)

METAMORPHIC ROCKS

Metamorphic rocks are, as noted above, those rocks that have recrystallized in response to changes in pressure, temperature, and the composition of fluids percolating through them. The word metamorphism is taken from the Greek for "change of form"; metamorphic rocks are derived from igneous or sedimentary rocks that have altered their form (recrystallized) as a result of changes in their physical environment. Metamorphism comprises changes both in mineralogy and in the fabric of the original rock.

Sources of metamorphic changes

In general, these alterations are brought about either by the intrusion of hot magma into cooler surrounding rocks (contact metamorphism) or by large-scale tectonic movements of the Earth's lithospheric plates that alter the pressure-temperature conditions of the rocks (regional metamorphism; see also PLATE TECTONICS). Minerals within the original rock, or protolith, respond to the changing conditions by reacting with one another to produce a new mineral assemblage that is thermodynamically stable under the new pressure-temperature conditions. These reactions occur in the solid state but may be facilitated by the presence of a fluid phase lining the grain boundaries of the minerals. In contrast to the formation of igneous rocks, metamorphic rocks do not crystallize from a silicate melt, although high-temperature metamorphism can lead to partial melting of the host rock.

Because metamorphism represents a response to changing physical conditions, those regions of the Earth's surface where dynamic processes are most active will also be regions where metamorphic processes are most intense and easily observed. The vast region of the Pacific mar-

gin, for example, with its seismic and volcanic activity, is also an area in which materials are being buried and metamorphosed intensely. In general, the margins of continents and regions of mountain building are the regions where metamorphic processes proceed with intensity. But in relatively quiet places, where sediments accumulate at slow rates, less spectacular changes also occur in response to changes in pressure and temperature conditions. Metamorphic rocks are therefore distributed throughout the geologic column.

Because most of the Earth's mantle is solid, metamorphic processes may also occur there. Mantle rocks are seldom observed at the surface because they are too dense to rise, but occasionally a glimpse is presented by their inclusion in volcanic materials. Such rocks may represent samples from a depth of a few hundred kilometres, where pressures of about 100 kilobars (3,000,000 inches of mercury) may be operative. Experiments at high pressure have shown that few of the common minerals that occur at the surface will survive at depth within the mantle without changing to new high-density phases in which atoms are packed more closely together. Thus, the common form of SiO_2, quartz, with a density of 2.65 grams per cubic centimetre, transforms to a new phase, stishovite, with a density of 4.29 grams per cubic centimetre. Such changes are of critical significance in the geophysical interpretation of the Earth's interior.

Geotherms

In general, temperatures increase with depth within the Earth along curves referred to as geotherms. The specific shape of the geotherm beneath any location on Earth is a function of its corresponding local tectonic regime. Metamorphism can occur either when a rock moves from one position to another along a single geotherm or when the geotherm itself changes form (see Figure 139). The former can take place when a rock is buried or uplifted at a rate that permits it to maintain thermal equilibrium with its surroundings; this type of metamorphism occurs beneath slowly subsiding sedimentary basins and also in the descending oceanic plate in some subduction zones. The latter process occurs either when hot magma intrudes and alters the thermal state of a stationary rock or when the rock is rapidly transported by tectonic processes (*e.g.*, thrust faulting or large-scale folding) into a new depth-temperature regime in, for example, areas of collision between two continents. Regardless of which process occurs, the result is that a collection of minerals that are thermodynamically stable at the initial conditions are placed under a new set of conditions at which they may or may not be stable. If they are no longer in equilibrium with one another under the new conditions, the minerals will react in such a way as to approach a new equilibrium state. This may involve a complete change in mineral assemblage or simply a shift in the compositions of the preexisting mineral phases. The resultant mineral assemblage will reflect the chemical composition of the original rock and the new pressure-temperature conditions to which the rock was subjected.

After B. Yardley, *An Introduction to Metamorphic Petrology* (1989), Longman Earth Science Series, Longman Group Ltd., Essex, England

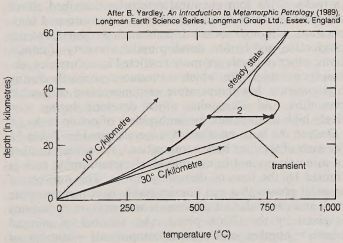


Figure 139: Depth-temperature diagram showing a typical steady-state geotherm through stable continental crust and a transient geotherm produced in response to magma intrusion at a depth of 30–40 kilometres. The heavier lines represent paths that show (1) metamorphism during burial along a single geotherm and (2) metamorphism as a result of a change in the geotherm at a fixed depth. Geothermal gradients of 10° C/km and 30° C/km are shown for reference.

Because protolith compositions and the pressure-temperature conditions under which they may be placed vary widely, the diversity of metamorphic rock types is large. Many of these varieties are repeatedly associated with one another in space and time, however, reflecting a uniformity of geologic processes over hundreds of millions of years. For example, the metamorphic rock associations that developed in the Appalachian Mountains of eastern North America in response to the collision between the North American and African lithospheric plates during the Paleozoic are very similar to those developed in the Alps of south-central Europe during the Mesozoic-Cenozoic collision between the European and African plates. Likewise, the metamorphic rocks exposed in the Alps are grossly similar to metamorphic rocks of the same age in the Himalayas of Asia, which formed during the continental collision between the Indian and Eurasian plates. Metamorphic rocks produced during collisions between oceanic and continental plates from different localities around the world also show striking similarities to each other (see below *Types of metamorphism and their associated facies: Regional metamorphism*) yet are markedly different from metamorphic rocks produced during continent-continent collisions. Thus, it is often possible to reconstruct tectonic events of the past on the basis of metamorphic rock associations currently exposed at the Earth's surface.

Metamorphic variables

Metamorphism results from a complex interplay between physical and chemical processes that operate on a scale ranging from micrometres (*e.g.*, fine mineral grain sizes, thickness of intergranular fluid, diffusion distances for chemical species) to tens or hundreds of kilometres (*e.g.*, crustal thickness, width of collision zone between lithospheric plates, depth to subducting plate). Despite this wide range and the many processes involved in the recrystallization of sedimentary and igneous protoliths into metamorphic rocks, there are relatively few variables that effect metamorphic changes. Those of greatest importance are temperature, pressure, and the original chemical composition of the protolith; each is briefly discussed below.

TEMPERATURE

Temperatures at which metamorphism occurs range from the conditions of diagenesis (approximately 150°–200° C) up to the onset of melting. Rocks of different compositions begin to melt at different temperatures, with initial melting occurring at roughly 650°–750° C in rocks of granitic or shaley composition and approximately 900°–1,200° C in rocks of basaltic composition. Above these temperatures, metamorphic processes gradually give way to igneous processes. Hence, the temperature realm of metamorphism spans an interval of about 150°–1,000° C and is strongly dependent on the composition of the protolith.

Geothermal gradient

The temperature at any point within the Earth's crust is controlled by the local heat-flow regime, which is a composite function of heat flow upward from the mantle into the crust, heat generated by radioactive decay in nearby regions of the crust, heat transported into the crust by silicate melts, and tectonic transport of hot or cold rocks at rates faster than those needed to maintain thermal equilibrium with the surrounding rocks. The temperature gradient at any location in the Earth, known as the geothermal gradient, is the increase in temperature per unit distance of depth; it is given by the tangent to the local geotherm. The magnitude of the geothermal gradient thus varies with the shape of the geotherm. In regions with high surface heat flow, such as areas of active volcanism or mantle upwelling beneath thinned continental crust, geothermal gradients of 40° to 100° C (104° to 212° F) per kilometre (0.6 mile) prevail, giving rise to high temperatures at relatively shallow levels of the crust. Within the stable interiors of old continents, geothermal gradients of 25° to 35° C per kilometre are more typical, and in zones of active subduction, where the relatively cold oceanic crust is rapidly transported to great depths,

geothermal gradients range from 10° to 20° C per kilometre. These large variations in geotherms and geothermal gradients give rise to different metamorphic regimes, or combinations of pressure-temperature conditions, associated with the different tectonic provinces.

In addition to the variation of geotherms as a function of position in the Earth, individual geotherms at a single location can vary with time. Geotherms are at steady state (*i.e.*, do not change with time) in tectonically quiescent areas of the Earth, such as the middle regions of large continents, and also in areas where tectonic processes like subduction have operated at similar rates over long periods. Transient geotherms, on the other hand, are generated in tectonically active regions, such as zones of continent-continent collision or rapid uplift and erosion, in which the tectonic processes are relatively short-lived; in these areas, the temperature at a given depth in the Earth is time-dependent, and individual geotherms can have very complex shapes that with time approach smooth curves (see Figure 139). These complex geotherms can produce wide temperature fluctuations at a given depth within the Earth; rocks metamorphosed in response to these variations may show considerable textural and chemical evidence of disequilibrium, reflecting the fact that temperatures changed at rates that were more rapid than reaction rates among the constituent minerals.

PRESSURE

The pressure experienced by a rock during metamorphism is due primarily to the weight of the overlying rocks (*i.e.*, lithostatic pressure) and is generally reported in units of bars or kilobars. For typical densities of crustal rocks of two to three grams per cubic centimetre, one kilobar of lithostatic pressure is generated by a column of overlying rocks approximately 3.5 kilometres high. Typical continental crustal thicknesses are on the order of 30–40 kilometres but can be as great as 60–80 kilometres in mountain belts such as the Alps and Himalayas. Hence, metamorphism of continental crust occurs at pressures from a few hundred bars (adjacent to shallow-level intrusions) to 10–20 kilobars at the base of the crust. Oceanic crust is generally 6–10 kilometres in thickness, and metamorphic pressures within the oceanic crust are therefore considerably less than in continental regions. In subduction zones, however, oceanic and, more rarely, continental crust may be carried down to depths exceeding 100 kilometres, and metamorphism at very high pressures may occur. Metamorphic recrystallization also occurs in the mantle at pressures up to hundreds of kilobars.

Burial and uplift

Changes in lithostatic pressure experienced by a rock during metamorphism are brought about by burial or uplift of the sample. Burial can occur in response either to ongoing deposition of sediments above the sample or tectonic loading brought about, for example, by thrust-faulting or large-scale folding of the region. Uplift, or more properly unroofing, takes place when overlying rocks are stripped off by erosional processes or when the overburden is tectonically thinned.

Fluids trapped in the pores of rocks during metamorphism exert pressure on the surrounding grains. At depths greater than a few kilometres within the Earth, the magnitude of the fluid pressure is equal to the lithostatic pressure, reflecting the fact that mineral grain boundaries recrystallize in such a way as to minimize pore space and to seal off the fluid channelways by which solutions rise from depth. At shallow depths, however, interconnected pore spaces can exist, and hence the pressure within a pore is related to the weight of an overlying column of fluid rather than rock. Because metamorphic fluids (dominantly composed of water and carbon dioxide) are less dense than rocks, the fluid pressure at these conditions is lower than the lithostatic pressure.

Deformation of rocks during metamorphism occurs when the rock experiences an anisotropic stress—*i.e.*, unequal pressures operating in different directions. Anisotropic stresses rarely exceed more than a few tens or hundreds of bars but have a profound influence on the textural development of metamorphic rocks (see below *Textural features; Structural features*).

ROCK COMPOSITION

Common metamorphic rock types have essentially the same chemical composition as what must be their equally common igneous or sedimentary precursors. Common greenschists have essentially the same compositions as basalts; marbles are like limestones; slates are similar to mudstones or shales; and many gneisses are like granodiorites. In general, then, the chemical composition of a metamorphic rock will closely reflect the primary nature of the material that has been metamorphosed. If there are significant differences, they tend to affect only the most mobile (soluble) or volatile elements; water and carbon dioxide contents can change significantly, for example.

Despite the wide variety of igneous and sedimentary rock types that can recrystallize into metamorphic rocks, most metamorphic rocks can be described with reference to only four chemical systems: pelitic, calcareous, felsic, and mafic. Pelitic rocks are derived from shale protoliths and are rich in potassium (K), aluminum (Al), silicon (Si), iron (Fe), magnesium (Mg), and water (H_2O), with lesser amounts of manganese (Mn), titanium (Ti), calcium (Ca), and other constituents. Calcareous rocks are formed from a variety of chemical and detrital sediments such as limestone, dolostone, or marl and are largely composed of calcium oxide (CaO), magnesium oxide (MgO), and carbon dioxide (CO_2), with varying amounts of aluminum, silicon, iron, and water. Felsic rocks can be produced by metamorphism of both igneous and sedimentary protoliths (*e.g.*, granite and arkose, respectively) and are rich in silicon, sodium (Na), potassium, calcium, aluminum, and lesser amounts of iron and magnesium. Mafic rocks derive from basalt protoliths and some volcanogenic sediments and contain an abundance of iron, magnesium, calcium, silicon, and aluminum. Ultramafic metamorphic rocks result from the metamorphism of mantle rocks and some oceanic crust and contain dominantly magnesium, silicon, and carbon dioxide, with smaller amounts of iron, calcium, and aluminum. For the purposes of this discussion, ultramafic rocks are considered to be a subset of the mafic category.

Mafic rocks

The particular metamorphic minerals that develop in each of these four rock categories are controlled above all by the protolith chemistry. The mineral calcite ($CaCO_3$), for example, can occur only in rocks that contain sufficient quantities of calcium. The specific pressure-temperature conditions to which the rock is subjected will further influence the minerals that are produced during recrystallization; for example, at high pressures calcite will be replaced by a denser polymorph of $CaCO_3$ called aragonite. In general, increasing pressure favours denser mineral structures, whereas increasing temperature favours anhydrous and less dense mineral phases. Many of the minerals developed during metamorphism, along with their chemical compositions, are given in alphabetical order in Table 55. The most common metamorphic minerals that form in rocks of the four chemical categories described above are listed in Table 56 as a function of pressure and temperature. Although some minerals, such as quartz, calcite, plagioclase, and biotite, develop under a variety of conditions, other minerals are more restricted in occurrence; examples are lawsonite, which is produced primarily during high-pressure, low-temperature metamorphism of basaltic protoliths, and sillimanite, which develops during relatively high-temperature metamorphism of pelitic rocks.

Despite the large number of minerals listed in Table 56 for each of the four bulk compositions, the actual number of minerals present in an individual metamorphic rock is limited by the laws of thermodynamics. The number of mineral phases that can coexist stably in a metamorphic rock at a particular set of pressure-temperature conditions is given by the Gibbs phase rule: number of mineral phases = number of chemical components − number of degrees of freedom + 2, where the 2 stands for the two variables of pressure and temperature. The degrees of freedom of the system are the parameters that can be independently varied without changing the mineral assemblage of the rock. For example, a rock with no degrees of freedom can only exist at a single set of pressure-temperature conditions; if either the pressure or the temperature is

Table 55: Common Minerals of Metamorphic Rocks

mineral	composition
Actinolite	$Ca_2(Mg, Fe)_5(Si_8O_{22})(OH)_2$
Adularia†	$KAlSi_3O_8$
Albite*	$NaAlSi_3O_8$
Andalusite†	Al_2SiO_5
Anorthite	$CaAl_2Si_2O_8$
Anthophyllite	$Mg_5Si_8O_{22}(OH)_2$
Aragonite†	$CaCO_3$
Biotite*	$K_2(Mg, Fe^{2+})_{6-4}Fe^{3+}, Al, Ti)_{0-2}(Si_{6-5}Al_{2-3}O_{20})(OH, F)_4$
Calcite*†	$CaCO_3$
Chlorite*	$(Mg, Al, Fe)_{12}[(Si, Al)_8O_{20}](OH)_{16}$
Chloritoid	$(Fe^{2+}, Mg, Mn)_2(Al, Fe^{3+})Al_3O_2(SiO_4)_2(OH)_4$
Cordierite	$Al_3(Mg, Fe^{2})_2(Si_4AlO_{18})$
Diopside	$CaMgSi_2O_6$
Dolomite*	$CaMg(CO_3)_2$
Enstatite	$MgSiO_3$
Epidote*	$Ca_2Fe^{3+}Al_2Si_3O_{13}(OH)$
Forsterite	Mg_2SiO_4
Garnet*	a complex solid solution of pyrope $Mg_3Al_2Si_3O_{12}$ almandine $Fe_3^{2+}Al_2Si_3O_{12}$ spessartine $Mn_3Al_2Si_3O_{12}$ grossular $Ca_3Al_2Si_3O_{12}$ andradite $Ca_3Fe_2^{3+}Si_3O_{12}$
Glaucophane	$Na_2Mg_3Al_2(Si_8O_{22})(OH, F)_2$
Hornblende*	$(Na, K)_{0-1}Ca_2(Mg, Fe^{2+}, Fe^{3+}, Al)_5(Si_{6-7}Al_{2-1}O_{22})(OH, F)_2$
Hypersthene	$(Mg, Fe)SiO_3$
Jadeite	$NaAlSi_2O_6$
Kaolinite	$Al_2Si_2O_5(OH)_8$
Kyanite†	Al_2SiO_5
Lawsonite	$CaAl_2(Si_2O_7)(OH)_2 \cdot H_2O$
Magnesite	$MgCO_3$
Microcline†	$KAlSi_3O_8$
Muscovite*	$KAl_2(AlSi_3O_{10})(OH)_2$
Omphacite*	a complex solid solution mainly of $NaAlSi_2O_6$-$CaMgSi_2O_6$-$NaFeSi_2O_6$
Orthociase†	$KAlSi_3O_8$
Plagioclase*	$NaAlSi_3O_8$; $CaAl_2Si_2O_8$
Prehnite	$Ca_2Al(AlSi_3O_{10})(OH)_2$
Pumpellyite	$Ca_4(Mg, Fe^{2+})(Al, Fe^{3+})_2O(OH)_3(Si_2O_7)_2(SiO_4)_2 \cdot 2H_2O$
Quartz*†	SiO_2
Sanidine†	$KAlSi_3O_8$
Scapolite	$(Na, Ca, K)_4[Al_3(Al, Si)Si_8O_{24}](Cl, SO_4, CO_3)$
Serpentine†	$Mg_3(Si_2O_5)(OH)_4$
Sillimanite†	Al_2SiO_5
Staurolite	$(Fe^{2+}, Mg)_2(Al, Fe^{3+})_9O_6(SiO_4)_4(O, OH)_2$
Stilpnomelane	$(K, Na, Ca)_{0-1}(Fe^{3+}, Fe^{2+}, Mg, Al, Mn)_{5.9-8.2}(Si_8O_{20})$ $(OH)_2(O, OH, H_2O)_{3.6-8.5}$
Talc	$Mg_3(Si_2O_5)_2(OH)_2$
Tremolite	$Ca_2Mg_5(Si_8O_{22})(OH)_2$
Wollastonite	$CaSiO_3$

*Indicates wide range of stability. †Indicates more than one form (polymorph) exists.

varied, the minerals will react with one another to change the assemblage. A rock with two degrees of freedom can undergo small changes in pressure or temperature or both without altering the assemblage. Most metamorphic rocks have mineral assemblages that reflect two or more degrees of freedom at the time the rock recrystallized. Thus, a typical pelitic rock made up of the six chemical components silica (SiO_2), aluminum oxide (Al_2O_3), ferrous oxide (FeO), magnesium oxide (MgO), potash (K_2O), and water would contain no more than six minerals; the identity of those minerals would be controlled by the pressure and temperature at which recrystallization occurred. In such a rock taken from the Earth's surface, the identity of the six minerals could be used to infer the approximate depth and temperature conditions that prevailed at the time of its recrystallization. Rocks that contain more mineral phases than would be predicted by the phase rule often preserve evidence of chemical disequilibrium in the form of reactions that did not go to completion. Careful examination of such samples under the microscope can often reveal the nature of these reactions and provide useful information on how pressure and temperature conditions changed during the burial and uplift history of the rock.

Metamorphic rocks only rarely exhibit a chemical composition that is characteristically "metamorphic." This statement is equivalent to saying that diffusion of materials in metamorphism is a slow process, and various chemical units do not mix on any large scale. But occasionally, particularly during contact metamorphism, diffusion may occur across a boundary of chemical dissimilarity, leading to rocks of unique composition. This process is referred to as metasomatism. If a granite is emplaced into a limestone, the contact region may be flooded with silica and other components, leading to the formation of a metasomatic rock. Often such contacts are chemically zoned. A simple example is provided by the metamorphism of magnesium-rich igneous rocks in contact with quartz-rich sediments. A zonation of the type serpentine-talc-quartz may be found such as:

$$Mg_6(Si_4O_{10})(OH)_8\text{-}Mg_3(Si_4O_{10})(OH)_2\text{-}SiO_2.$$

In this case the talc zone has grown by silica diffusion into the more silica-poor environment of the serpentine. Economic deposits are not uncommon in such situations—*e.g.*, the formation of the $CaWO_4$ (calcium tungstate) scheelite when tungstate in the form of WO_3 moves from a granite into a limestone contact. The reaction can be expressed as:

$$CaCO_3 + WO_3 \text{ (solution)} \rightarrow CaWO_4 + CO_2 \text{ (gas)}.$$

calcite scheelite

Metasomatism

Metamorphic reactions

A very simple mineralogical system and its response to changing pressure and temperature provide a good illustration of what occurs in metamorphism. An uncomplicated sediment at the Earth's surface, a mixture of the clay mineral kaolinite [$Al_4Si_4O_{10}(OH)_8$] and the mineral quartz (SiO_2), provides a good example. Most sediments have small crystals or grain sizes but great porosity and permeability, and the pores are filled with water. As time passes, more sediments are piled on top of the surface layer, and it becomes slowly buried. Accordingly, the pressure to which the layer is subjected increases because of the load on top, known as overburden. At the same time, the temperature will increase because of radioactive heating within the sediment and heat flow from deeper levels within the Earth.

In the first stages of incremental burial and heating, few chemical reactions will occur in the sediment layer, but the porosity decreases, and the low-density pore water is squeezed out. This process will be nearly complete by the time the layer is buried by five kilometres of overburden. There will be some increase in the size of crystals; small crystals with a large surface area are more soluble and less stable than large crystals, and throughout metamorphic processes there is a tendency for crystals to grow in size with time, particularly if the temperature is rising.

Eventually, when the rock is buried to a depth at which

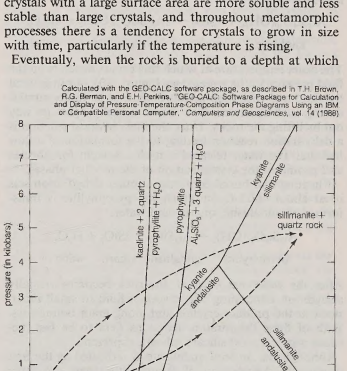


Figure 140: Pressure-temperature diagram showing the positions of the following reactions: kaolinite + 2 quartz = pyrophyllite + H_2O and pyrophyllite = Al_2SiO_5 + 3 quartz + H_2O, as well as the regions where the three polymorphs of Al_2SiO_5 are stable. Dashed lines show possible burial paths that would produce either kyanite or andalusite before sillimanite.

Table 56: Common Metamorphic Minerals as a Function of Pressure, Temperature, and Protolith Composition*

protolith	high P/low T	medium P and T	low P/high T
Shale, mudstone (*pelitic*)	paragonite, muscovite kyanite Mg-chloritoid Mg-carpholite jadeite chlorite pyrope garnet talc coesite	muscovite, paragonite chlorite biotite chloritoid garnet staurolite andalusite, kyanite, sillimanite plagioclase alkali feldspar cordierite orthopyroxene	muscovite biotite andalusite, sillimanite cordierite plagioclase orthopyroxene microcline, sanidine mullite spinel tridymite
Limestone, dolostone, marl (*calcareous*)	aragonite magnesite lawsonite zoisite jadeite talc	calcite dolomite tremolite diopside epidote, clinozoisite grossular garnet	wollastonite grossular garnet diopside plagioclase vesuvianite clinozoisite forsterite brucite talc
Granite, granodiorite, arkose (*felsic*)	jadeite paragonite	plagioclase alkali feldspar muscovite biotite garnet sillimanite	plagioclase alkali feldspar sillimanite cordierite
Basalt, andesite (*mafic*)	glaucophane lawsonite garnet omphacite epidote albite chlorite	plagioclase chlorite biotite garnet epidote actinolite hornblende diopside orthopyroxene	plagioclase biotite garnet hornblende diopside

*Quartz may be present in all categories. Minor phases such as oxides and sulfides have been omitted.

temperatures of about 300° C obtain, a chemical reaction sets in, and the kaolinite and quartz are transformed to pyrophyllite and water:

$$Al_4Si_4O_{10}(OH)_8 + 4SiO_2 \rightarrow 2Al_2Si_4O_{10}(OH)_2 + 2H_2O.$$

kaolinite quartz pyrophyllite water

The exact temperature at which this occurs depends on the fluid pressure in the system (see Figure 140), but in general the fluid and rock-load pressures tend to be rather similar during such reactions. The water virtually fights its way out by lifting the rocks. Thus, the first chemical reaction is a dehydration reaction leading to the formation of a new hydrate. The water released is itself a solvent for silicates and promotes the crystallization of the product phases.

A second dehydration reaction

If heating and burial continue, another dehydration sets in at about 400° C, in which the pyrophyllite is transformed to andalusite, quartz, and water:

$$Al_2Si_4O_{10}(OH)_2 \rightarrow Al_2SiO_5 + 3SiO_2 + H_2O.$$

pyrophyllite andalusite quartz water

After the water has escaped, the rock becomes virtually anhydrous, containing only traces of fluid in small inclusions in the product crystals and along grain boundaries. Both of these dehydration reactions tend to be fast, because water, a good silicate solvent, is present.

Although the mineral andalusite is indicated as the first product of dehydration of pyrophyllite, there are three minerals with the chemical composition Al_2SiO_5. Each has unique crystal structures, and each is stable under definite pressure-temperature conditions (Figure 140). Such differing forms with identical composition are called polymorphs. If pyrophyllite is dehydrated under high-pressure conditions, the polymorph of Al_2SiO_5 formed would be the mineral kyanite (the most dense polymorph). With continued heating, the original andalusite or kyanite will invert to sillimanite, the highest-temperature Al_2SiO_5 polymorph (see Figure 140):

$$Al_2SiO_5 \rightarrow Al_2SiO_5$$

andalusite or kyanite sillimanite

The kinetics of these polymorphic transformations are sufficiently sluggish, however, that kyanite or andalusite may persist well into the stability field of sillimanite.

Owing to the very simple bulk composition of the protolith in this example (a subset of the pelitic system containing only SiO_2-Al_2O_3-H_2O), no other mineralogical changes will occur with continued heating or burial. The original sediment composed of kaolinite, quartz, and water will thus have been metamorphosed into a rock composed of sillimanite and quartz, and perhaps some metastable andalusite or kyanite, depending on the details of the burial and heating history. In the case of a more typical pelite containing the additional chemical components potash, ferrous oxide, and magnesium oxide, the reaction history would be correspondingly more complex. A typical shale that undergoes burial and heating in response to continent-continent collision would develop the minerals muscovite, chlorite, biotite, garnet, staurolite, kyanite, sillimanite, and alkali feldspar, in approximately that order, before beginning to melt at about 700° C. Each of these minerals appears in response to a chemical reaction similar to those presented above. Most of these reactions are dehydration reactions, and the shale thus loses water progressively throughout the entire metamorphic event. As discussed above, the total number of minerals present in the rock is controlled by the Gibbs phase rule, and the addition of new minerals generally results from the breakdown of old minerals. For example, the following reaction,

$$\text{garnet} + \text{muscovite} + \text{chlorite} \rightarrow \text{staurolite} + \text{biotite} + \text{quartz} + \text{water},$$

occurs at temperatures of about 500°–550° C and typically consumes all the preexisting chlorite in the rock, introduces the new mineral staurolite, and adds more biotite and quartz to the biotite and quartz generated by earlier reactions. Some garnet and muscovite usually remain after the reaction, although examination of the sample under the microscope would probably reveal partial corrosion (wearing away due to chemical reactions) of the garnets resulting from their consumption.

Reactions that introduce new minerals in rocks of a specific bulk composition are referred to as mineral appearance isograds. Isograds can be mapped in the field as lines across which the metamorphic mineral assemblage changes. Caution must be exercised to note the approximate bulk composition of the rocks throughout the map area, however, because the same mineral can develop at quite different sets of pressure-temperature conditions in rocks of dissimilar chemical composition. For example, garnet generally appears at a lower temperature in pelitic rocks than it does in mafic rocks; hence, the garnet isograd in pelitic rocks will not be the same map line as that in metabasaltic (*i.e.*, metamorphosed basalt) compositions. Isograd patterns are discussed further in *Structural features* below.

Isograds

PRINCIPAL TYPES

Metamorphic reactions can be classified into two types that show different degrees of sensitivity to temperature and pressure changes: net-transfer reactions and exchange reactions. Net-transfer reactions involve the breakdown of preexisting mineral phases and corresponding nucleation and growth of new phases. (Nucleation is the process in which a crystal begins to grow from one or more points, or nuclei.) They can be either solid-solid reactions (mineral A + mineral B = mineral C + mineral D) or devolatilization reactions (hydrous mineral A = anhydrous mineral B + water), but in either case they require significant breaking of bonds and reorganization of material in the rock. They may depend most strongly on either temperature or pressure changes. In general, devolatilization reactions are temperature-sensitive, reflecting the large increase in entropy (disorder) that accompanies release of structurally bound hydroxyl groups (OH) from minerals to produce molecular water. Net-transfer reactions that

involve a significant change in density of the participating mineral phases are typically more sensitive to changes in pressure than in temperature. An example is the transformation of albite ($NaAlSi_3O_8$) to the sodic pyroxene jadeite ($NaAlSi_2O_6$) plus quartz (SiO_2); albite and quartz have similar densities of about 2.6 grams per cubic centimetre, whereas jadeite has a density of 3.3 grams per cubic centimetre. The increased density reflects the closer packing of atoms in the jadeite structure. Not surprisingly, the denser phase jadeite is produced during subduction zone (high-pressure) metamorphism. Net-transfer reactions always involve a change in mineral assemblage, and textural evidence of the reaction often remains in the sample (see below *Textural features*); isograd reactions are invariably net-transfer reactions.

Exchange reactions

In contrast to net-transfer reactions, exchange reactions involve redistribution of atoms between preexisting phases rather than nucleation and growth of new phases. The reactions result simply in compositional changes of minerals already present in the rock and do not modify the mineral assemblage. For example, the reaction

$$Fe_3Al_2Si_3O_{12} + KMg_3AlSi_3O_{10}(OH)_2 \rightarrow$$

almandine garnet magnesium-biotite

$$Mg_3Al_2Si_3O_{12} + KFe_3AlSi_3O_{10}(OH)_2$$

pyrope garnet iron-biotite

results in redistribution of iron and magnesium between garnet and biotite but creates no new phases. This reaction is limited by the rates at which iron and magnesium can diffuse through the garnet and biotite structures. Because diffusion processes are strongly controlled by temperature but are nearly unaffected by pressure, exchange reactions are typically sensitive to changes only in metamorphic temperature. Exchange reactions leave no textural record in the sample and can be determined only by detailed microanalysis of the constituent mineral phases. The compositions of minerals as controlled by exchange reactions can provide a useful record of the temperature history of a metamorphic sample.

The types of reactions cited here are typical of all metamorphic changes. Gases are lost (hydrates lose water, carbonates lose carbon dioxide), and mineral phases undergo polymorphic or other structural changes; low-volume, dense mineral species are formed by high pressures, and less dense phases are favoured by high temperatures. Considering the immense chemical and mineralogical complexity of the Earth's crust, it is clear that the number of possible reactions is vast. In any given complex column of crustal materials some chemical reaction is likely for almost any incremental change in pressure and temperature. This is a fact of immense importance in unraveling the history and mechanics of the Earth, for such changes constitute a vital record and are the primary reason for the study of metamorphic rocks.

RETROGRADE METAMORPHISM

In general, the changes in mineral assemblage and mineral composition that occur during burial and heating are referred to as prograde metamorphism, whereas those that occur during uplift and cooling of a rock represent retrograde metamorphism. If thermodynamic equilibrium were always maintained, one might expect all the reactions that occur during prograde metamorphism to be reversed during subsequent uplift of the rocks and reexposure at the Earth's surface; in this case, metamorphic rocks would never be seen in outcrop. Two factors mitigate against complete retrogression of metamorphic rocks, however, during their return to the Earth's surface. First is the efficient removal of the water and carbon dioxide released during prograde devolatilization reactions by upward migration of the fluid along grain boundaries and through fractures. Because almost all the water released during heating by reactions such as

$$Fe_5Al_6Si_3O_{20}(OH)_{16} + 4SiO_2 \rightarrow 3Fe_3Al_2Si_3O_{12} + 8H_2O$$

chlorite quartz garnet water

is removed from the site of reaction, the reaction cannot be reversed during cooling unless water is subsequently added to the rock. Thus, garnet can be preserved at the Earth's surface even though it is thermodynamically unstable at such low temperatures and pressures. The second reason that metamorphic reactions do not typically operate in reverse during cooling is that reaction rates are increased by rising temperatures. During cooling, reaction kinetics become sluggish, and metastable mineral assemblages and compositions can be preserved well outside their normal stability fields. Thus, prograde reactions are generally more efficient than retrograde reactions, and metamorphic assemblages indicative of even extremely high temperatures or pressures or both are found exposed throughout the world. It is common, however, to find at least some signs of retrogression in most metamorphic rocks. For example, garnets are often rimmed by small amounts of chlorite and quartz, indicating that limited quantities of water were available for the reverse of the reaction given above to proceed during cooling. Retrograde features such as these reaction rims can be mapped to yield information on pathways of fluid migration through the rocks during uplift and cooling. In other rocks, such as high-temperature gneisses, mineral compositions often reflect temperatures too low to be in equilibrium with the preserved mineral assemblage; in these samples, it is clear that certain exchange reactions operated in a retrograde sense even when the net-transfer reactions were frozen in during prograde metamorphism.

Reaction rims

Textural features

The fabric of a metamorphic rock results from the combined effects of mineral reactions and deformation throughout the metamorphic event and the subsequent return of the rock to the terrestrial surface. The study of metamorphic fabrics in outcrop and under the microscope has become a highly specialized subject aimed at revealing the nature and direction of the forces acting during dynamic processes within the Earth. Much of this work is an outgrowth of a classic investigation conducted in 1930 by the Austrian geologist Bruno Sander, coupled with more recent experimental work on the pressure-temperature stabilities of metamorphic minerals and their responses to deformation.

Observations show that pressure is only rarely hydrostatic (equal in all directions) at any point within the Earth's crust. In real cases, consequently, anisotropic stresses operate that may lead to flow or fracture of materials. Such occurrences produce certain characteristic fabrics or structures in metamorphic rocks that may be observed at the scale of the orientation of small crystals in a rock or as a pattern of folds in a mountain range. One of the principal characteristics of most metamorphic rocks is that the arrangement of crystals is not isotropic, or random, but that there is a strong preferred orientation related to the direction of stress components of pressure. Such preferred orientation of crystals and mineral grains is perhaps the most striking difference between metamorphic rocks and other rock types.

The most obvious features of metamorphic rocks are certain planar features that are often termed s-surfaces. The simplest planar features may be primary bedding (akin to the layering in sedimentary rocks). As the rock crystallizes or recrystallizes under directed pressure, new crystals may grow in some preferred direction, sometimes subparallel to the primary bedding but often at new angles defining new planar structures. At the same time, folding of layers may occur, leading to folds with amplitudes on scales of kilometres or millimetres. Fabric symmetry may be represented by the nature of deformed fossils, pebbles in a conglomerate, or any objects with a known shape prior to deformation (Figure 141).

A few terms that commonly are used to describe several types of preferred orientation in metamorphic rocks include foliation, a general term describing any type of s-surface, bedding, or crystal orientation; slaty cleavage, a planar structure leading to facile cleavage that is normally caused by the preferred orientation of mica crystals; schis-

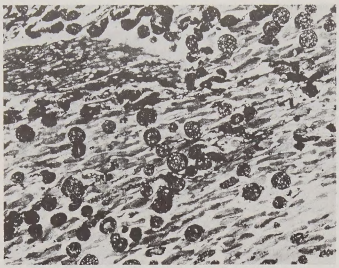


Figure 141: A deformed dolomite-calcite marble from Sardinia containing spherical fossil objects (oölites) about 3 millimetres (0.12 inch) in size. Oölites made of dolomite (black circles) are not deformed. Oölites made of calcite (gray), a weaker solid, are smeared out in S forms.

By courtesy of J. Ramsay, Imperial College, London

tosity, a term used to describe repetitive and pronounced foliation of the type that is present in schists; and lineation, which is any linear structure, such as the axis of the fold, grooves on a fault plane, or the direction of stretching of pebbles.

The various mineral phases of a metamorphic rock have different physical properties and symmetries. When a rock is subjected to recrystallization in a stress field, different substances will behave differently according to such physical properties and symmetries. Some minerals always tend to grow in better-formed crystals than others; rates of nucleation may differ, and this can lead to different patterns of growth of crystals—there may be a few large crystals or a mass of small crystals. Minerals can be arranged in order of their tendency to form crystals showing planar surfaces—namely, magnetite, garnet, epidote, mica, calcite, quartz, and feldspar. Minerals that have a tendency to form large single crystals (*e.g.*, garnet) are termed porphyroblasts.

Porphyroblasts

Porphyroblastic crystals may grow before, during, or after an episode of deformation (pre-, syn-, and postkinematic growth, respectively); the relative timing of mineral growth and deformation can often be determined by examining the sample under a microscope. Prekinematic porphyroblasts may be fractured by subsequent deformation; the orientation of the fractures and any offset of the grains along them provide information on the directed stresses responsible for the deformation. Prekinematic grains may also be surrounded by pressure shadows produced by minerals such as quartz that dissolve in zones of maximum compressive stress and reprecipitate in zones of lesser

By courtesy of J. Ramsay, Imperial College, London

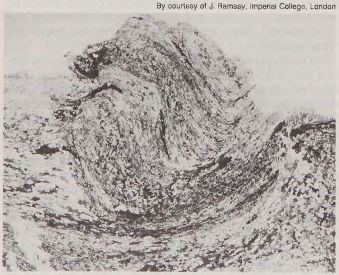


Figure 142: A large garnet crystal (enlarged; 1 centimetre [0.4 inch]) growing in a quartz-mica matrix. The garnet contains trails of inclusions and has rotated during growth in the flowing rock medium.

compressive stress adjacent to the rigid porphyroblasts. The texture of the shadows is different from that of the host rock. Samples exhibiting asymmetric pressure shadows around porphyroblasts can yield information on the orientation of shear stresses during deformation. A spectacular example of synkinematic prophyroblast growth is provided by the so-called snowball garnets, which have spiral trails of inclusions that indicate rotation of either the garnet or the matrix foliation during garnet growth (see Figure 142). Postkinematic porphyroblasts typically overgrow all previous fabrics in the rock and may contain trails of mineral inclusions that define microfolds or an earlier schistosity.

In some samples, it is possible to use the compositions of the porphyroblasts to calculate the depth and temperature conditions at which they grew and thereby constrain the conditions at which deformation occurred. Studies of this sort add immeasurably to the understanding of crustal rheologies and the response of rocks to large-scale orogenic events. Because a particular metamorphic event may be accompanied by either several isolated episodes of deformation or a single continuum of deformation, there may be many fabric generations recorded in one sample; individual minerals may be postkinematic with respect to the earliest deformation but prekinematic relative to younger deformation in the same rock. Thus, the study of porphyroblast fabrics in metamorphic rocks can be complex but has the potential to yield important information on the structural history of metamorphic regions (see below *Structural features*).

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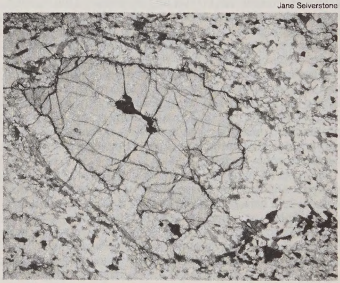


Figure 143: Photomicrograph showing corroded garnet (gray) surrounded by a corona of cordierite produced during uplift of the sample (see text). Other minerals present are biotite, plagioclase, sillimanite, alkali feldspar, and ilmenite. The garnet is two millimetres across.

Because changes in pressure and temperature often occur at faster rates than those of mineral reaction and recrystallization, metamorphic rocks may display fabrics that result from incomplete reactions. Such disequilibrium features provide a wealth of information on the reaction history of the sample and, by comparison with experimental studies of mineral stabilities, can also constrain the quantitative pressure-temperature history of the rock during metamorphism. An example of a reaction texture is shown in Figure 143, in which a corroded garnet is surrounded by a corona (reaction rim) of the mineral cordierite; other minerals present in the matrix include sillimanite, quartz, biotite, and alkali feldspar. The sample does not contain garnet in contact with sillimanite or quartz. These textural features suggest the following reaction relationship between garnet, sillimanite, quartz, and cordierite:

$$2Mg_3Al_2Si_3O_{12} + 4Al_2SiO_5 + 5SiO_2 \rightleftharpoons 3Mg_2Al_4Si_5O_{18}.$$

garnet sillimanite quartz cordierite

This reaction has been shown experimentally to occur at temperatures of approximately $725° \pm 50°$ C and to be very sensitive to pressure, with cordierite occurring under low-pressure conditions. The textural evidence that pre-

existing garnet was partially replaced by cordierite thus implies that the rock underwent decompression while still at high temperatures and that the decompression occurred too rapidly for the rock to recrystallize completely (*i.e.,* for garnet to be totally replaced by cordierite).

Lamination

There is also a tendency for many types of metamorphic rocks to become laminated, and the separate laminae may have distinct chemical compositions. A macroscopically rather homogeneous sediment may prove to be inhomogeneous on a minute scale. When graywackes are metamorphosed within the greenschist facies, for example, laminae rich in quartz and feldspar alternate with others rich in epidote, chlorite, and muscovite. The precise causes of this process are not well known, but it must result from a combination of extensive deformation accompanied by recrystallization. In a sense, it is a type of flow unmixing. It is important to recognize that this type of structure need have no relation to original bedding in the unmetamorphosed sediments.

Structural features

Metamorphic rocks are often intimately related to large-scale (kilometres of tens of kilometres) structural features of the Earth. Such features include folds, nappes, and faults with a wide variety of geometries. In many cases, the correlation of metamorphic isograds and their position in the structure implies a genetic relationship between the two. For example, one of the major structural features in the Himalayan mountain belt is the Main Central Thrust, a thrust fault that runs for hundreds of kilometres from east to west and was responsible for the transportation of rocks belonging to the Eurasian Plate southward over those of the Indian Plate. Along much of the length of this fault, the metamorphic rocks in the hanging wall (located above the fault) display a pattern of inverted isograds; *i.e.,* the rocks that reached the highest temperatures of metamorphism overlie rocks that record lower temperatures, implying that metamorphic temperatures decreased with depth to the fault. Several explanations have been proposed to account for this anomalous distribution of temperature with depth. One model suggests the fault transported hot Asian rocks over cooler Indian rocks, which caused cooling of the Asian rocks in the vicinity of the fault. Another model proposes that fluids circulating along the fault zone caused retrograde metamorphism and thus reset the rocks located nearest to the fault to lower temperatures. Although neither of these models provides an adequate explanation for the entire length of the Main Central Thrust, they both emphasize the significant control that structural features can exert on the development of metamorphic rocks.

Nappes

Metamorphism associated with nappes (large recumbent folds) in the Alps and the Appalachians provides strong evidence that the tectonic transport of rocks typically occurs at rates faster than those of thermal equilibration—in other words, that the nappes can transport hot rocks for large distances without significant cooling. Nappe formation is a major process of crustal thickening during continent-continent collision; emplacement of the nappes results in burial and heating of the underlying rocks. Isograd distributions associated with nappe structures can be either normal or inverted, depending on the relative rates of nappe emplacement and heat transfer.

Isograd maps can provide information on the relative timing of structural and metamorphic events in much the same way that fabric studies constrain the relative timing of deformation episodes and prophyroblast growth. For example, isograd patterns that are cut by faults clearly indicate that metamorphism predated fault displacement, whereas isograd sequences that overprint structural discontinuities imply the reverse. Isograds that parallel major structures suggest some cause-and-effect relationship between the structural and metamorphic development of the region. Since the 1980s, metamorphic petrologists and structural geologists have increasingly worked together to correlate metamorphic and tectonic events and thereby increase understanding of crustal dynamics in tectonically active regions of the Earth.

Metamorphic facies

Metamorphic petrologists studying contact metamorphism early in the 20th century introduced the idea of metamorphic facies to correlate metamorphic events. The concept was first defined in 1914 by a Finnish petrologist, Pentti Eelis Eskola, as any rock of a metamorphic formation that has attained chemical equilibrium through metamorphism at constant temperature and pressure conditions, with its mineral composition controlled only by the chemical composition. In current usage, a metamorphic facies (Figure 144) is a set of metamorphic mineral assemblages, repeatedly associated in space and time, such that there is a constant and therefore predictable relation between mineral composition and chemical composition.

The facies concept is more or less observation-based. In a single outcrop, for instance, layers of different chemical composition will display different mineral assemblages despite having all experienced the same pressure and temperature history. A pelitic layer might contain the assemblage garnet + chlorite + biotite + muscovite + quartz, whereas a basaltic horizon a few centimetres away would contain the assemblage chlorite + actinolite + albite. Both of these rocks belong to the same facies, meaning that, in another region, a geologist who observed the assemblage chlorite + actinolite + albite in a metabasalt could predict that associated pelitic rocks would contain the garnet + chlorite + biotite + muscovite + quartz assemblage.

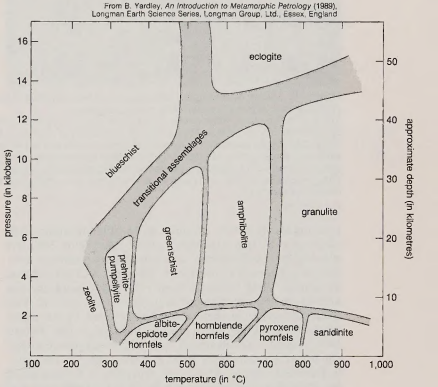


Figure 144: Approximate pressure-temperature regions of the major metamorphic facies (see text).

Experimental work on the relative stabilities of metamorphic minerals and assemblages has permitted correlation of the empirically derived facies with quantitative pressure and temperature conditions, as shown in Figure 144. The names of metamorphic facies in common usage are derived from the behaviour of a rock of basaltic bulk composition during metamorphism at various sets of pressure-temperature conditions. For example, a basalt metamorphosed during subduction to high pressures at low temperatures recrystallizes into a rock containing glaucophane, lawsonite, and albite; glaucophane is a sodic amphibole that is blue to black in hand sample and lavender to blue under the microscope (see Figure 145). Because of their distinctive bluish coloration, such samples are called blueschists. The same rock type metamorphosed at more moderate pressures and temperatures in the range of 400°–500° C would contain abundant chlorite and actinolite, minerals that are green both in hand sample and under the microscope, and would be referred to as a greenschist (see Figure 145). At somewhat higher temperatures, the rock would become an amphibolite, reflecting a mineralogy composed



Figure 145: *Mineral assemblages produced during metamorphism of rocks of basaltic composition at different pressure-temperature conditions.*
The four metamorphic facies shown in the figure owe their names to differences in their appearance. (Top left) Blueschist containing glaucophanitic amphibole (blue), epidote, and albite. (Top right) Greenschist composed of green chlorite and actinolitic amphibole with albite and some epidote. (Bottom left) Amphibolite containing the amphibole hornblende (green), garnet, and plagioclase. (Bottom right) Granulite consisting of equigranular plagioclase (gray), hypersthene (tan), and diopside (blue and red). Long dimension of all photos is four millimetres (see text).
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predominantly of the amphibole hornblende along with plagioclase and perhaps some garnet (see Figure 145). At still higher temperatures, a metabasalt recrystallizes into a rock containing hypersthene, diopside, and plagioclase; in general, these minerals form relatively equant crystals and hence do not develop a preferred orientation. The granular texture of these rocks has resulted in the name granulite for a high-temperature metabasalt (see Figure 145). A pelitic or calcareous rock will develop very different mineral assemblages from a metabasalt, yet the same facies names apply. Thus, one can refer to a greenschist facies pelitic schist, an amphibolite facies calcsilicate rock, or a granulite facies garnet gneiss.

Facies boundaries

The boundaries between the different facies are regions of pressure and temperature in which chemical reactions occur that would significantly alter the mineralogy of a rock of basaltic bulk composition. For example, the boundary between the greenschist and amphibolite facies marks a transition from amphibole of actinolitic composition to hornblende and of a sodic plagioclase into a more calcic plagioclase. The reactions that bring about these transformations depend on the specific composition of the rock and hence are denoted by broad bands rather than single lines on the pressure-temperature diagram in Figure 144.

FACIES SERIES

Different types of tectonic processes produce different associations of metamorphic facies in the field. For example, regions associated with subduction of oceanic material beneath either oceanic or continental crust are characterized by blueschist, greenschist, and eclogite facies rocks, whereas areas thought to reflect continent-continent collision are more typically distinguished by greenschist and amphibolite facies rocks. Still other regions, usually containing an abundance of intrusive igneous material, show associations of low-pressure greenschist, amphibolite, and granulite facies rocks. These observations led a Japanese petrologist, Akiho Miyashiro, working in the 1960s and '70s, to develop the concept of baric types, or metamorphic facies series. Miyashiro described the three facies associations given above as high-pressure, medium-pressure, and low-pressure facies series, respectively, and correlated the development of these characteristic series with the shape of the geotherm in different tectonic settings. Subsequent thermal modeling studies have shown that metamorphism generally occurs in response to tectonically induced perturbation of geotherms rather than along steady-state geotherms and, hence, that the facies series do not record metamorphic geotherms. Nonetheless, the concept of metamorphic facies series is a useful one in that it emphasizes the strong genetic relationship between metamorphic style and tectonic setting.

PRESSURE-TEMPERATURE-TIME PATHS

Interaction between metamorphic petrologists and geophysicists in the 1980s led to the realization that each metamorphic rock follows its own unique path through pressure- (depth-) temperature space during metamorphism and that these paths bear little or no resemblance to steady-state geotherms. The specific shape of a pressure-temperature-time (P-T-t) path depends on the tectonic setting in which the rock was metamorphosed, which in turn controls the relative rates at which burial or uplift and heating or cooling occur. For example, a rock that is uplifted rapidly from depth, perhaps in response to extensional faulting (that caused by the stretching of the Earth's crust), may transport heat with it to near-surface depths. Its P-T-t path would show a phase of nearly isothermal decompression (uplift at approximately constant temperature), reflecting the fact that uplift rates were more rapid

than those of heat transfer. In contrast, if the same rock remained at depth for a long period of time and then experienced very slow uplift, its P-T-t path would show cooling during uplift or even a phase of isobaric (constant-pressure) cooling. Rocks belonging to medium-pressure facies series generally follow P-T-t paths that are clockwise loops on a pressure-temperature diagram, reflecting rapid burial during a collisional event followed by heating and relatively rapid uplift. In contrast, low-pressure facies series rocks may follow counterclockwise P-T-t paths in response to rapid heating of the crust due to magma intrusion prior to uplift (Figure 146). P-T-t paths followed by rocks of a high-pressure facies series are less predictable and depend strongly on the mechanism by which the rocks are transferred from the subducting slab to the overlying continental crust. In general, the mineral assemblage preserved in a metamorphic rock is frozen at the highest temperature experienced during metamorphism (see above *Retrograde metamorphism*), and thus the facies and facies series to which the rock would be assigned reflect only a single point on its P-T-t path.

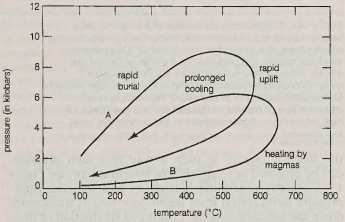


Figure 146: Examples of pressure-temperature-time paths that would be followed by rocks metamorphosed in different environments. (A) represents the rapid burial and uplift paths typical of areas of continental convergence. (B) represents heating and burial in response to regional-scale magma intrusion, followed by prolonged cooling and slow uplift.

Reconstruction of P-T-t paths

One of the principal goals of much of the work that is done on metamorphic rocks is the reconstruction of the P-T-t paths followed by rocks presently exposed at the Earth's surface. Because these paths are so strongly linked to dynamic processes, their reconstruction provides a means by which tectonic processes operative in the geologic past may be understood. Owing to the continuous recrystallization of rocks that occurs during progressive metamorphism, much of the early record of metamorphic changes within a sample is eradicated by later events. It is, therefore, not possible to determine the entire P-T-t path followed by an individual sample, but often enough disequilibrium features are preserved to permit reconstruction of a few thousand bars and a couple of hundred degrees of the path; such a portion may represent anywhere from a few million to a hundred million years of Earth history, as revealed by geochronologic determinations involving different minerals or fabric generations in the sample. Techniques for determining the pressure-temperature history of a metamorphic rock include using compositions of coexisting minerals to calculate pressures and temperatures of equilibration (geobarometry and geothermometry, respectively), comparing the mineral assemblage to experimentally determined stability fields for the phases, utilizing mineral inclusions enclosed within porphyroblasts to constrain assemblages present in the early history of the sample, and making use of the densities of small inclusions of fluids trapped within the minerals to determine possible pressures and temperatures experienced at different stages in the burial and uplift history.

Origin of metamorphic rocks: types of metamorphism

It is convenient to distinguish several general types of metamorphism in order to simplify the description of the various metamorphic phenomena. Recognized here are hydrothermal, dynamic, contact, and regional metamorphism, each of which will be described in turn.

Hydrothermal metamorphism. Changes that occur in rocks near the surface, where there is intense activity of hot water, are categorized as hydrothermal metamorphism. Such areas include Yellowstone National Park in the northwestern United States, the Salton Sea in California, and Wairakei in New Zealand. It is now generally recognized that the circulating groundwaters that often become heated by their proximity to igneous materials produce the metamorphism. Migration of chemical elements, vein formation, and other kinds of mineral concentration may be extreme on account of the large volumes of water circulated.

Dynamic metamorphism. When directed pressure or stress is the dominant agent of metamorphism, it is termed dynamic; other terms are dislocation, kinematic, and mechanical metamorphism. Mineralogical changes occurring on a fault plane provide an obvious example. In some such cases, the action may simply be a grinding up of existing grains or realignment of minerals that have nonequant crystals. If the action is intense, friction may even lead to melting.

Contact metamorphism. Whenever silicate melts (magmas, from which igneous rocks crystallize within the Earth) invade the crust at any level, they perturb the normal thermal regime and cause a heat increase in the vicinity. If a mass of basaltic liquid ascending from the upper mantle is trapped in the crust and crystallizes there, it will heat the surrounding area; the amount of heating and its duration will be a direct function of the mass and shape of the igneous material. Contact-metamorphic phenomena thus occur in the vicinity of hot igneous materials and at any depth. Under such circumstances, pressure and temperature are not simply correlated. Thermal gradients are often steep unless the igneous mass is extremely large.

Contact-aureole thickness

Contact aureoles—the surrounding zones of rock that become altered or metamorphosed—vary in thickness from several centimetres (around tabular bodies such as dikes and thin sills) to several kilometres (around large granitic intrusions). The contact metamorphic rocks of the aureole zone often lack any obvious schistosity or foliation.

The facies associated with contact metamorphism include the sanidinite, pyroxenite-hornfels, hornblende-hornfels, and albite-epidote-hornfels facies.

Sanidinite facies. Rocks of the sanidinite facies are represented by small fragments of aureole materials that have often been totally immersed in silicate liquids or by the aureole rocks surrounding volcanic pipes. Very high temperatures are attained, often at very low pressures. The dominant feature of the mineralogy of this facies is an almost complete lack of minerals containing water or carbon dioxide. Many of the minerals show similarity to those of igneous rocks themselves. If the duration of heating is short, adjustment to the imposed temperature is often imperfect.

Pelitic rocks (high in aluminum oxide) contain minerals such as mullite, sillimanite, sanidine, cordierite, spinel, hypersthene, anorthite, tridymite, and even glass. One of the classic localities of such rocks is the island of Mull, off the west coast of Scotland, but these rocks can be found in most regions of volcanism.

Calcareous rocks (originally impure limestones or dolomites) tend to lose nearly all their carbon dioxide, but pure calcite may survive. Typical metamorphic minerals are quartz, wollastonite, anorthite, diopside, periclase, and in some places (the classic is Scawt Hill in Northern Ireland) an array of complex calcium silicates such as spurrite, larnite, rankinite, melilite, merwinite, and monticellite. These minerals result from the addition of varying amounts of silica to impure mixtures of calcite and dolomite. In a general way the minerals of this facies are reminiscent of those of industrial slags.

Pyroxene-hornfels facies. Rocks of the pyroxene-hornfels facies are characteristically formed near larger granitic or gabbroic bodies at depths of a few kilometres or at pressures of a few hundred bars. The mineral assemblages are again largely anhydrous, but, unlike the sanidinite

facies, the minerals reflect distinctly lower temperatures. One of the classic descriptions of such rocks is from the Oslo district of Norway.

In pelitic rocks, minerals such as quartz, orthoclase, andalusite, sillimanite, cordierite, hypersthene, and plagioclase occur. Sometimes the hydrate biotite is developed. In calcareous rocks the minerals found include plagioclase, diopside, grossularite, vesuvianite (a hydrate), wollastonite, and sometimes the more complex calcium silicates monticellite, melilite, spurrite, tilleyite, and clinohumite.

Hornblende-hornfels facies. A generally deeper level of contact metamorphism where pressures of a few kilobars may be active is represented by the hornblende-hornfels facies. Hydrated phases become stable, and the transition to regional metamorphism becomes apparent. Because of the generally greater depth, this type of aureole is often superposed on a metamorphism at more normal pressure-temperature conditions, and the rocks may appear schistose and exhibit new thermally generated minerals on a preexisting assemblage. This type of metamorphism develops the classic "spotted" texture in which new porphyroblasts grow in slates and phyllites of a previous episode of metamorphism. Typically, such rocks are developed near most of the world's large granite batholiths, where these have moved to higher levels in the Earth's crust.

Typical minerals of pelitic assemblages include quartz, muscovite, biotite, andalusite, sillimanite, cordierite, plagioclase, microcline, and staurolite. Calcareous assemblages include calcite, quartz, diopside, grossularite, plagioclase, wollastonite, brucite, talc, forsterite, tremolite, and clinozoisite. Basaltic compositions include plagioclase, hornblende, diopside, quartz, biotite, and almandine garnet.

Formation of skarns

When rather pure limestone and dolomite come into direct contact with granitic rocks, elements such as silicon, iron, magnesium, and aluminum diffuse into the limestone, forming spectacular rocks termed skarns. These rocks often consist of large garnet crystals (grossularite) with green diopside and vesuvianite or epidote.

Albite-epidote-hornfels facies. Rocks of the albite-epidote-hornfels facies are characteristically found as the outer zones of contact aureoles where the thermal episode fades out and the rocks pass into their regional grade of metamorphism. The mineral assemblages are quite similar to those found in regional greenschist-facies metamorphism, except for the presence of low-pressure phases such as andalusite. Characteristic minerals include quartz, muscovite, biotite, chlorite, andalusite, actinolite, calcite, dolomite, albite, and epidote.

Regional metamorphism. Regional metamorphism is associated with the major events of Earth dynamics, and the vast majority of metamorphic rocks are so produced. They are the rocks involved in the cyclic processes of erosion, sedimentation, burial, metamorphism, and mountain building, events that are all related to major convective processes in the Earth's mantle.

Most regionally metamorphosed rocks develop primarily in response to continent-continent collision and to collision between oceanic and continental plates. As a result, young metamorphic belts aligned roughly parallel to the present-day continental margins (*e.g.*, the Pacific margin) as well as older metamorphic belts are used to infer the geometries of the continental margins at earlier periods in Earth history. Most of the world's mountain belts are at least partially composed of regionally metamorphosed rocks, with spectacular examples provided by the Alps, the Himalayas, the northern Appalachians, and the Highlands of Scotland. Although the processes that formed each of these mountain belts are broadly similar, in almost all such crustal events at different times and places, there is uniqueness as well as conformity to a general pattern. Metamorphic events in the Alps, the Urals, and the Himalayas all show specific differences: to unravel such differences and their significance is one of the major tasks of metamorphic petrology.

In areas of collision between oceanic and continental lithospheric plates such as the circum-Pacific region, the denser oceanic plate is subducted (carried into the Earth's mantle) beneath the more buoyant continental lithosphere. Rapid subduction of the cool oceanic lithosphere perturbs the thermal regime in such a way that high pressures can be obtained at relatively low temperatures (see Figure 147), thereby generating blueschists and eclogites (high-pressure facies series) from ocean-floor basalts transported down the subduction zone. Continued subduction of these rocks to great depth may eventually result in partial melting in response to rising temperatures; these melts contribute to the formation of the volcanoes that overlie subduction zones in areas such as the Andes of South America, Japan, and the Aleutian Islands. Upward migration of subduction-related magmas also contributes to the development of paired metamorphic belts, in which high-pressure, low-temperature metamorphic rocks are flanked on the continental side by a parallel belt of low-pressure, high-temperature rocks. The latter rocks are thought to reflect perturbation of the crustal thermal regime by the passage of silicate melts generated above the subducting slab. Continued intrusion of magma over a period of time would cause an increase in crustal temperatures at relatively shallow depths and produce the high-temperature rocks adjacent to the high-pressure rocks generated in the subduction zone (see Figure 147). Well-developed paired metamorphic belts are exposed in Japan, California, the Alps, and New Zealand.

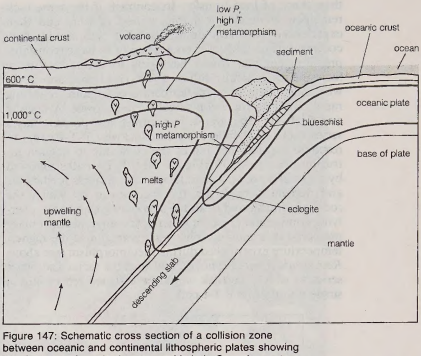


Figure 147: Schematic cross section of a collision zone between oceanic and continental lithospheric plates showing development of a paired metamorphic belt. Oceanic crust subducts rapidly and perturbs the thermal regime of the mantle. Rocks in the oceanic crust are progressively metamorphosed to blueschists and eclogites at high pressure. Subsequent melting in or above the descending crust causes a rise of magma to the surface and low-pressure, high-temperature metamorphism in the continental crust.
After A. Miyashiro, *Metamorphism and Metamorphic Belts* (1973), George Allen and Unwin, Ltd., London

Paired metamorphic belts

Data obtained from deep earthquakes in subduction zones indicate that a descending slab of oceanic lithosphere can remain intact to depths of several hundred kilometres before undergoing complete melting or fragmentation or both and being incorporated into the surrounding mantle. Clearly, the blueschists and eclogites exposed in orogenic belts around the world did not undergo such a process and were instead returned to the Earth's surface. Most of the high-pressure rocks that have been studied from Japan, California, New Caledonia, the Alps, and Scandinavia record maximum pressures of 10–20 kilobars, corresponding to subduction to depths of approximately 35–70 kilometres. A few samples have been discovered in Norway, the Alps, and China that contain the mineral coesite, a high-pressure polymorph of quartz. Experimental studies on the stability of coesite imply minimum pressures of 30 kilobars for these rocks, indicating burial or subduction to depths of approximately 100 kilometres. These pressures are particularly noteworthy in that they are recorded in rocks derived from sedimentary rather than basaltic protoliths. Because of the low density, and hence greater buoyancy, of sediments relative to basalts, many geologists have argued that sediment subduction must be

a rather limited process; the coesite-bearing metapelites (metamorphosed pelites) provide important evidence that sediment subduction can and does occur under certain circumstances.

The processes by which rocks that have been partially subducted are returned to the surface are not well understood. Models have been proposed to account for uplift and exposure of these high-pressure, high-density rocks; they include scraping material from the subducting plate against the overlying crustal lithosphere, upward flow of material in response to forced convection above the subducted slab, and removal of overlying thickened crust by low-angle extensional faulting. Testing these models requires considerable petrologic and structural work in areas where high-pressure rocks are exposed.

High-pressure rocks

Most of the high-pressure rocks that are currently displayed in metamorphic belts around the world were metamorphosed in Mesozoic or Cenozoic time (*e.g.*, the circum-Pacific belt, the Alps, the Greek Cyclades, and the Cordillera Betica in Spain). Older high-pressure rocks are known from only a few isolated occurrences in, for example, Wales, Bavaria, the Île de Groix off the coast of Brittany, and the Norwegian Caledonides (on the west coast of Norway). The general absence of high-pressure samples in the early rock record raises a number of interesting questions concerning Earth history. Some geologists have argued that the lack of well-developed Precambrian and Paleozoic high-pressure belts indicates that plate tectonic processes have changed significantly throughout geologic time. Specifically, they claim that greater heat production in Archean time (about 3.8 to 2.5 billion years ago) would have produced hotter crustal geotherms, resulting in thin, hot lithospheric plates whose mechanical behaviour may have been quite different from that of the present-day plates and hence may not have permitted formation of subduction zones. The increasing abundance of subduction-related metamorphic rocks with decreasing age in the rock record would thus reflect the gradual onset of plate tectonics as operative today. Others argue that the rock record is biased owing to preferential erosion or thermal overprinting (development of a new mineralogy that may obliterate the original one) of old blueschists and eclogites. Thermal modeling studies suggest that blueschists will generally undergo heating and be converted to greenschist assemblages if exposure at the Earth's surface does not occur within 100 million to 200 million years after high-pressure metamorphism. Early exposure at the surface also increases the chances for removal by erosion, however, resulting in a low probability for preserving blueschists greater than 100 million to 200 million years old. Geologists favouring generation of blueschists throughout Earth history but only selective preservation of these rocks also point to crustal rocks more than 2.5 billion years old that record metamorphism at depths of 25–40 kilometres; these medium-pressure facies series rocks imply that crustal thicknesses in the early Earth were similar to those of the present day and thus that modern plate tectonic processes may have operated from the early Precambrian to the present. This debate, though unresolved, emphasizes the substantial knowledge of the thermal structure of the Earth and plate tectonic processes that can be obtained from the study of metamorphic rocks.

Continent-continent collision

Depending on the original geometry of the Earth's lithospheric plates, subduction of oceanic crust beneath continental lithosphere may result in complete consumption of an ocean basin and subsequent collision between two continents. Collisions of this type have a long and complex history that may include initial formation of a paired metamorphic belt followed by extreme crustal thickening in response to the actual collision of the continents. The overthickened crust produced by the collision event will be gravitationally unstable and will undergo subsequent rapid erosion and possibly extensional faulting in order to return to a normal crustal thickness. Rocks metamorphosed in the early stages of collision may belong to a high-pressure facies series, reflecting the final stages of subduction of oceanic lithosphere, whereas the younger facies more typically belong to medium-pressure facies series. Metamorphic rocks exposed in former collision zones may thus have followed a variety of pressure-temperature-time paths, but paths showing rapid burial followed by heating and subsequent unroofing at moderate to high temperatures have been reported from many mountain belts around the world. Owing to the strong directed forces operative during collision, deformation typically accompanies metamorphism; rocks metamorphosed in response to continent-continent collision generally have fabrics showing a strong preferred orientation of mineral grains, folds on a variety of scales, and pre-, syn-, and postkinematic porphyroblasts. Examples of metamorphic belts produced in response to this type of collision include the Paleozoic Appalachian and Caledonides belts and the Mesozoic-Cenozoic Alpine and Himalayan belts.

Regionally metamorphosed rocks are also exposed in areas where the crust has been thinned by extensional faulting, such as the Basin and Range province of the western United States. In this type of occurrence, areas of medium- and low-pressure facies series rocks that measure a few tens of kilometres in diameter are juxtaposed against unmetamorphosed sediments or very low-grade metamorphic rocks along low-angle extensional faults. (Metamorphic grades refer to the degree and intensity of the metamorphism: they are determined by the pressure and temperatures to which the rock has been subjected.) Such areas are generally referred to as metamorphic core complexes. Metamorphism in these complexes may or may not be related to the extensional event. In some instances, metamorphic rocks produced during much earlier events are simply unroofed and exposed by the faulting but show little or no recrystallization related to extension. In other cases, prolonged extension has resulted in an increased crustal geotherm, and relatively high-temperature metamorphism and magmatism is thus directly related to the extensional event. Immediately adjacent to the faults, the rocks may also be affected by dynamic metamorphism.

The facies associated with regional metamorphism include, at low grade, the zeolite and prehnite-pumpellyite facies. In areas belonging to high-pressure facies series, the rocks are predominantly in the blueschist and eclogite facies. Medium- and low-pressure facies series are typified by rocks belonging to the greenschist, amphibolite, and granulite facies.

Zeolite facies. In the zeolite facies, sediments and volcanic debris show the first major response to burial. Reactions are often not complete, and typical metamorphic fabrics may be poorly developed or not developed at all. This is the facies of burial metamorphism.

The zeolite facies was first described from southern New Zealand, but similar rocks have now been described from many younger mountain regions of the Earth, particularly around the Pacific margin and the European Alps. Typically, the rocks are best developed where reactive volcanic materials (often partly glassy) are common and the characteristic minerals include zeolites, which are low-density, hydrated silicates, stable at temperatures rarely exceeding 300° C. Typical mineral assemblages include heulandite, analcite, quartz with complex clay minerals (montmorillonite), micaceous phases such as chlorite and celadonite, and the potassium feldspar, adularia. At higher grades of metamorphism, the zeolite laumonite and the feldspar albite dominate the mineral assemblage. In New Zealand these are developed in a rock column that is about 15 kilometres thick. Calcareous rocks (impure limestones) show very little response to this grade of metamorphism.

Prehnite-pumpellyite facies. Along with the zeolite facies, the prehnite-pumpellyite facies received little attention until about 1950. The first rocks of the facies were described in New Zealand and Celebes. The facies is transitional, bridging the path to the blueschist facies or the greenschist facies. It is particularly well developed in graywacke-type sediments. The two minerals prehnite and pumpellyite replace the zeolite minerals of the zeolite facies and are themselves replaced by epidote minerals in the greenschist facies and by lawsonite and pyroxenes in the blueschist facies. Typical minerals in this facies are quartz, albite, prehnite, pumpellyite, chlorite, stilpnomelane, muscovite, and actinolite. Almost all the minerals are hydrated, and, except for chlorite, they bear little re-

Transitional facies

semblance to the minerals of sediments. Again, the facies has been most described from younger mountain ranges of the Pacific margin.

Blueschist facies. Rocks of the blueschist facies represent deep metamorphism under conditions of a low thermal gradient. The characteristic locale for this type of metamorphism appears to be along a continental margin being underthrust by an oceanic plate. Regions in which blueschists are found are also regions of great seismic and volcanic activity, such as the Pacific margin. The best described examples of this class of metamorphism come from California, Japan, New Caledonia, Celebes, the Alps, and the Mediterranean region. At present there are no confirmed examples of glaucophane schists predating the Paleozoic Era. Because of the presence of the blue amphibole glaucophane and minerals such as garnet and jadeite, these schists are among the most attractive of metamorphic rocks.

Characteristic minerals of the facies include quartz, glaucophane, lawsonite, jadeite, omphacite, garnet, albite, chlorite, muscovite, paragonite, epidote, and kyanite. In calcareous rocks, calcite may be replaced by the high-pressure polymorph aragonite. In general, the facies is characterized by many high-density minerals reflecting a high pressure of formation.

Eclogite facies. The eclogite facies was initially recognized in rocks only of basaltic composition, which are transformed at the pressure-temperature conditions of the eclogite facies into spectacular red and green rocks composed of the anhydrous mineral assemblage garnet plus omphacite. The garnet is rich in the high-pressure species pyrope, and the omphacite is rich in the high-pressure pyroxene jadeite. Small amounts of minerals such as kyanite, the hydrate zoisite, and hornblende may be present. The rocks are of high density and frequently show little or no schistosity. It is now known that protoliths other than basalt also can be metamorphosed to pressures and temperatures characteristic of the eclogite facies, and a wide variety of mineral assemblages can be stable at these conditions, including several hydrous mineral phases. Minerals that have been observed in metapelites include magnesium-rich chloritoid and staurolite, kyanite, garnet, phengite (a muscovite mica with high magnesium and silicon and low aluminum content), chlorite, and talc. Experimental work shows that pelitic rocks composed primarily of talc and kyanite, which are referred to as whiteschists, can be stable from pressures of approximately 6 kilobars up to greater than 30 kilobars. Minerals observed in eclogite-facies calcareous rocks include magnesite, dolomite, zoisite or epidote, and omphacite.

Upper mantle as a source of eclogite

Because of the high density and composition, it was proposed long ago that part of the upper mantle might be made of eclogite. Such a view is supported by eclogitic intrusions in volcanic rocks and by eclogitic inclusions in diamond-bearing kimberlite, which must come from the upper mantle. Some workers also think that eclogites found in metamorphic terrains in Norway, California, U.S., and the European Alps could also come from the mantle by tectonic processes.

Early experimental work on eclogites of basaltic bulk composition suggested that eclogites could generally only be stable if water pressure was much lower than the lithostatic pressure, and the facies was thus thought to represent dry, high-pressure metamorphism of basaltic protoliths. Subsequent work on the more diverse protolith compositions reveals, however, that a wide range of water pressures are possible in the eclogite facies and that fluid compositions in equilibrium with the eclogite minerals also probably vary greatly. Indeed, fluid inclusions (tiny bubbles of fluid trapped within mineral grains) in eclogite samples provide evidence of fluids containing nitrogen, salts, and carbon dioxide in addition to water. Eclogite metamorphism is therefore not confined to dry environments but results instead from metamorphism of a variety of rock types at pressures above about 10 kilobars, corresponding to burial to approximately 35 kilometres, and at temperatures ranging from about 400° to 1,000° C. The temperatures of the eclogite facies overlap those of the greenschist, amphibolite, and granulite facies, but the higher pressures result in distinctly different mineral assemblages characterized by high-density mineral phases.

Greenschist facies. The greenschist facies was once considered the first major facies of metamorphism proper. The name comes from the abundance of the green mineral chlorite in such rocks. Because chlorite and muscovite are ubiquitous and because both exhibit a platy crystal habit, these rocks normally show a highly developed foliation and often exhibit strong metamorphic differentiation. They have been described from practically every metamorphic terrain on Earth, from earliest Precambrian to the young mountain regions. In fact, many of the Earth's oldest rocks (about three billion years old) of the continental-shield areas are in this facies, classic examples of which are in the Appalachians, the Highlands of Scotland, New Zealand, the European Alps, Japan, and Norway.

The dominant minerals of greenschists formed from silicate-rich sediments include quartz, albite, muscovite, chlorite, epidote, calcite, actinolite, magnetite, biotite, and paragonite. Minerals less common include the manganese-rich garnet spessartine, stilpnomelane, kyanite, rutile, sphene, pyrophyllite, and chloritoid. Calcareous rocks are dominated by calcite, dolomite, and quartz; the major carbonate minerals are thermally stable. It is only when large quantities of water flush away carbon dioxide or keep its partial pressure low that carbonate-silicate reactions take place and liberate carbon dioxide. The typical minerals of this facies have low water contents as compared to the zeolite facies minerals.

Amphibolite facies. The amphibolite facies is the common high-grade facies of regional metamorphism, and, like the greenschist facies, such rocks are present in all ages from all over the world. Their characteristic feature is the development of the most common amphibole, hornblende, in the presence of a plagioclase feldspar and garnet. The rocks are normally highly foliated or schistose. Many zones or isograds subdividing the facies have been recognized, and classic studies have been made in the Highlands of Scotland, New Hampshire and Vermont in the United States, Switzerland, and the Himalayas.

Hornblende, the most common amphibole

Characteristic minerals derived from pelitic rocks are quartz, muscovite, biotite, garnet, plagioclase, kyanite, sillimanite, staurolite, and orthoclase. Minerals derived from basaltic rocks include hornblende, plagioclase, garnet, epidote, and biotite. Those derived from calcareous rocks are calcite, diopside, grossularite (garnet), zoisite, actinolite (hornblende), scapolite, and phlogopite. Minerals from magnesium-rich ultrabasic rocks are chlorite, anthophyllite, and talc. In most common types, water is present in minerals only of the mica and amphibole families, and, with their water contents of only about 1 to 3 percent, dehydration is nearing its metamorphic climax.

Granulite facies. In rocks of basaltic composition, the granulite facies is an anhydrous facies that results from progressive dehydration of amphibolites at high temperature. Rocks of other bulk compositions may retain some hydrous minerals, such as biotite and hornblende, but it is likely that water pressure is lower than lithostatic pressure during most granulite facies metamorphism. Evidence for relatively low water pressures comes from fluid inclusion data indicating carbon dioxide-rich fluid compositions and from preservation of some bulk compositions that should have undergone nearly total melting at granulite temperatures if water pressure had been equal to lithostatic pressure.

Rocks of this facies frequently have a granular texture quite similar to plutonic igneous rocks. Schistosity is only weakly developed. Typical minerals of the facies are quartz, alkali feldspar, garnet, plagioclase, cordierite, sillimanite, and hypersthene. In calcareous members, dolomite, calcite, diopside, and forsterite occur; and it is in this facies that minerals of the scapolite family are best developed. Small amounts of hornblende are often present. A rare mineral occurring in this facies is sapphirine. The rock type charnockite (from Tamil Nādu, India), essentially a hypersthene granite, is normally included in this facies.

It appears from experimental studies that during ultrametamorphism, when melting starts, the basic reactions which take place are of the type

biotite + other minerals → melt + residue
hornblende + other minerals → melt + residue.

The first melts to form are partly wet granitic or granodioritic melts, and phases such as biotite and hornblende break down by producing a partly wet melt from the least refractory phases in the rocks. They would persist to much higher temperatures in other systems of their own composition. The residue in the above equations is a granulite-facies metamorphic rock containing phases such as pyroxene and sillimanite. Thus it is probable but certainly not universally proved that many granulites are formed only in the presence of a silicate liquid. This liquid may, of course, move to higher crustal levels.

The probable process of granulite formation

Large areas of granulite facies rocks are confined almost entirely to Precambrian areas of the continents (those areas that were formed more than 570 million years ago), with well-developed areas exposed in Canada, India, Africa, Antarctica, Greenland, and the Adirondack Mountains of New York in the northeastern United States. Smaller areas of granulite facies rocks occur in younger mountain belts, with Paleozoic examples in New England (U.S.) and Brittany and Tertiary examples (those formed between 66.4 and 1.6 million years ago) in British Columbia (Can.) and Timor. The apparent decrease in the volume of granulite facies rocks with decreasing age of metamorphism has led some geologists to postulate, as mentioned above, that plate tectonic processes might have changed significantly with time—specifically that steady-state continental geotherms were hotter in the Precambrian than at the present time. Some work on pressure-temperature-time paths in granulites also suggests that Precambrian granulites were metamorphosed along distinctly different paths than younger granulites, lending credence to models invoking changes in tectonic processes. An alternative hypothesis is that large volumes of granulites have been formed throughout Earth history but that they have not yet been exposed by erosion. Pressures calculated from fragments of granulite-facies metamorphic rocks carried to the surface in young volcanic eruptions suggest that the fragments were derived from the lower crust. It is likely that the lower crust is currently composed largely of granulite-facies rocks that may be exposed by future episodes of mountain building, but it is also possible that these granulites will prove to be different from their Precambrian counterparts. In order to resolve some of the controversies surrounding the origin and composition of granulites, it is necessary that considerable studies of these rocks be conducted in the future.

Distribution of metamorphic rocks

A high-grade metamorphic rock is one that formed at a depth of tens of kilometres and later returned to the surface. Hence, metamorphic regions are also regions of former or recent intense orogeny. More stable regions of the Earth's crust tend to be covered with sediments, and only deep drilling will reveal the metamorphic rocks below.

The Earth's crust is made up of two basic units, the continents and ocean basins. Exploration of ocean floors has revealed that old, thick sedimentary piles are missing. Doubtless this is related to the processes of continental drift or seafloor spreading; sediments are continuously swept up by continental motion and are added to the continents or returned to the upper mantle (see also PLATE TECTONICS). Nearly all studies of metamorphic rocks have concentrated on the continents for this reason.

There are few large areas of the Earth's crust that are not affected by some type of igneous event from time to time. Although the intensity of volcanism may be focused in certain geographic regions (*e.g.*, the Pacific margin), volcanism appears to be a rather random phenomenon, at times even occurring in the stable shield areas of the continents. In this sense, contact-metamorphic events may be found almost everywhere at almost any time on Earth. But these metamorphic events are of trivial volumetric significance compared to those of regional metamorphism.

During the past 500 million years or so of Earth history, major tectonic, seismic, igneous, and metamorphic events have been concentrated on continental margins (Figure 148). This has been a period of depression and uplift of the Earth's crust associated with the formation of the present continental distribution. The processes are still going on at dramatic rates in ocean trench environments. These modern regions of activity form immense linear belts. One such belt runs around virtually the entire Pacific margin and another through the Mediterranean and southern Asia to fuse with the circum-Pacific belt. It is in these belts that the spectacular development of zeolite facies, prehnite-pumpellyite facies, blueschist facies, and, occasionally, eclogite facies, as well as the more universal facies of regional metamorphism, have occurred. The granulite facies is almost missing.

Belts of mountain building and shield areas

The central and often dominant feature of most continents is their vast Precambrian-shield area; examples include the Canadian Shield, Brazilian Shield, African Shield, and Australian Shield. In these rocks, dating reveals ages of 1 to 3.5 billion years, and they have been little affected by tectonic events postdating the Cambrian. But

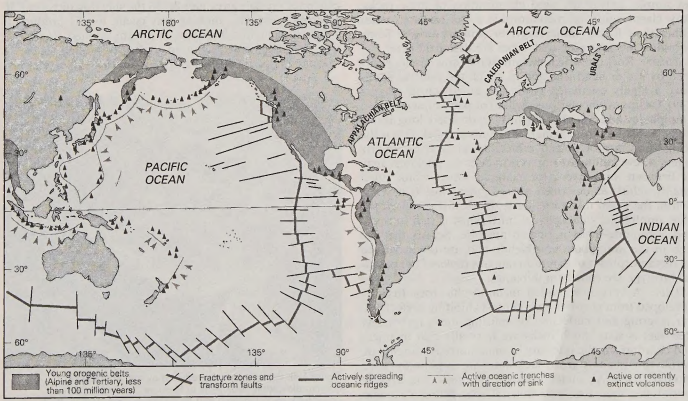


Figure 148: Tectonic units of the continents: shields and the present-day configuration of the continents and the Earth's major lithospheric plates (see text).

these shield areas are themselves complex. They consist of vast areas of granitic or granodioritic gneisses. Inside them, between them, and overlapping onto them are belts of sedimentary rocks quite like those in modern sedimentary belts of the Pacific margin or European Alps. These rocks are frequently metamorphosed in the greenschist, amphibolite, and granulite facies. Low-temperature facies and, in particular, low-temperature–high-pressure facies are missing—or have not yet been found. From marginal areas of these stable shield areas, a complex array of processes has been documented covering the past few hundred million years. The Caledonian orogeny (at the close of the Silurian Period) produced tectonic-metamorphic events along the east coast of North America, Greenland, the British Isles, Fennoscandia, Central Asia, and Australia. The Hercynian, or Variscan, orogeny followed about 300 million years ago, affecting subparallel regions and the Urals and European Alps. In fact, the shield margins appear to have been subjected to a more or less constant battering by forces both destroying and rebuilding the margins of these protocontinents. As geologists study Precambrian areas in greater detail, the number of metamorphic and orogenic events recognized on a global scale increases.

Tectonic-metamorphic events associated with the Caledonian orogeny

It is the great task and problem of those who study metamorphic rocks to deduce the record of Earth dynamics and thermal history from metamorphic rocks. Among the questions to be answered are (1) whether the pattern of facies development through time—*e.g.*, the granulite facies in the Archean to blueschist facies in the Tertiary—is a reflection of a cooling Earth and the decline of radioactivity in the crust, and (2) whether the increase in size of global tectonic-metamorphic belts through time reflects changes in convective patterns in the mantle.

As understanding of the pressure-temperature regimes of metamorphism increases, and as knowledge of rock mechanics and fluid motion during metamorphism also increases through field and laboratory studies, it may become possible to understand the details of the motion of the chemical elements during such processes and hence much of the subject of economic geology, or the search for man's essential raw materials.

Classification of metamorphic rocks

Because of the diverse chemistry, mineralogy, and primary origin of metamorphic rocks and because of the diverse fabrics or textures that may develop depending on the stresses that may operate during their formation, there is no simple, universally used classification of these rocks. Any classification of metamorphic rocks tends to stress either their fabric, mineralogy, or primary origin. Some common metamorphic rock types are described here.

Schist. Rocks in which metamorphic minerals are easily seen by eye or hand lens and in which the mineral grains have a highly orientated fabric are called schists (Figure 149). Grains of acicular (needlelike) or platy minerals (*e.g.*, amphiboles and micas) tend to lie with their long directions parallel or their planar directions parallel. Often the rocks show a pronounced mineralogical layering; quartz layers a few millimetres or centimetres in thickness may lie between mica layers, for example. Other words often qualify schist: as described above, greenschist is a schist rich in the green mineral chlorite; blueschist is rich in the blue amphibole, glaucophane; mica-schist is rich in mica; and a graphite-schist is rich in graphite. Schists that are rich in the amphibole hornblende and are often derived by metamorphism of common igneous rocks of the basalt-gabbro type are called amphibolites.

Pronounced mineralogical layering in schists

Slate. A very fine-grained metamorphic rock (usually developed from clay-rich sediments) exhibiting perfect planar layering and perfection of splitting into layers (slaty cleavage) is slate. Such rocks are normally rich in micas and chlorites. As the intensity of metamorphism increases, porphyroblasts may grow; such slates are sometimes called spotted slates. As metamorphism proceeds, the average crystal size increases, and mineral segregation develops; the rock then may be termed a phyllite.

Gneiss. A gneiss is produced by intense metamorphism,

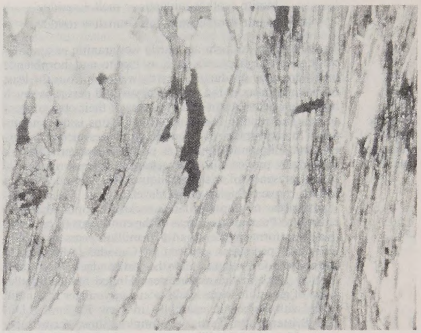


Figure 149: Photomicrograph of a staurolite-biotite schist from Scotland showing strong orientation of biotite crystals (dark) in a matrix of quartz and feldspars (magnification 50×).
By courtesy of W.S. Fyfe

at high temperature and pressure. The grain size is coarser than that in schists, and layering is often well developed (see Figure 150); mineral orientation is less perfect than in schists, however. Very common granitic gneisses of Precambrian areas have been derived from metamorphism of granitic igneous rocks.

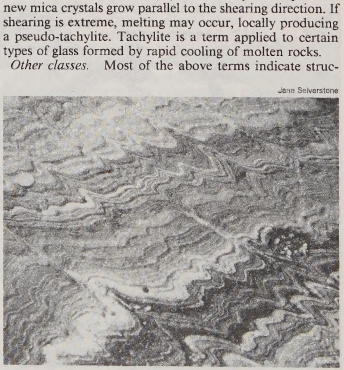
Hornfels. The hornfels are formed by contact metamorphism and typically show little sign of the action of directed pressure. They are fine-grained rocks in which crystals display little orientation.

Hornfels as a product of contact metamorphism

Marble. Rocks derived from the metamorphism of carbonate sediments containing calcite or dolomite are marbles. The main result of metamorphism is an increase in grain size. Because of the rather equidimensional habit of calcite and dolomite crystals, they rarely appear schistose unless they contain other minerals such as mica.

Mylonites and cataclastites. These are rocks in which the texture is the result of ductile shearing or mechanical shattering of grains. They often show only slight, if any, development of new minerals. They form on fault planes or in zones of intense shearing. If the crustal rocks have an appropriate composition, phyllonites may develop where new mica crystals grow parallel to the shearing direction. If shearing is extreme, melting may occur, locally producing a pseudo-tachylite. Tachylite is a term applied to certain types of glass formed by rapid cooling of molten rocks.

Other classes. Most of the above terms indicate struc-



Jann Selverstone

Figure 150: Banded gneiss produced by metamorphism of quartzofeldspathic sediments in Scotland. White bands have undergone partial melting and recrystallized into granite. Dark bands represent material composed predominantly of biotite and minor hornblende.

tural or fabric classification of metamorphic rocks. Sometimes terms are used to indicate chemical features. Several types of schists, for example, include the following: pelitic schists contain much aluminum oxide and often are derivatives of clay-rich sediments; quartzofeldspathic schists are high in quartz and feldspars and often are derivatives of sandstones or quartz-rich igneous rocks; calcareous schists have a high content of lime (CaO) and often are derivatives of impure limestones, dolomites, or calcareous muds; and basic schists contain the elements of basic igneous rocks—namely, calcium, magnesium, and iron.

(W.S.F./Ja.Se.)

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(R.V.Di.)

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(Ja.Se.)

Modernization and Industrialization

Modern society is industrial society. To modernize a society is, first of all, to industrialize it. Historically, the rise of modern society has been inextricably linked with the emergence of industrial society. All the features that are associated with modernity can be shown to be related to the set of changes that, no more than two centuries ago, brought into being the industrial type of society. This suggests that the terms industrialism and industrial society imply far more than the economic and technological components that make up their core. Industrialism is a way of life that encompasses profound economic, social, political, and cultural changes. It is by undergoing the comprehensive transformation of industrialization that societies become modern.

Modernization is a continuous and open-ended process. Historically, the span of time over which it has occurred must be measured in centuries, although there are examples of accelerated modernization. In either case, modernization is not a once-and-for-all-time achievement. There seems to be a dynamic principle built into the very fabric of modern societies that does not allow them to settle, or to achieve equilibrium. Their development is always irregular and uneven. Whatever the level of development, there are always "backward" regions and "peripheral" groups. This is a persistent source of strain and conflict in modern societies. Such a condition is not confined to the internal development of individual states. It can be seen on a global scale, as modernization extends outward from its original Western base to take in the whole world. The existence of unevenly and unequally developed nations introduces a fundamental element of instability into the world system of states.

Modernization seems to have two main phases. Up to a certain point in its course, it carries the institutions and values of society along with it, in what is generally regarded as a progressive, upward movement. Initial resistance to modernization may be sharp and prolonged, but it is generally doomed to failure. Beyond some point, however, modernization begins to breed discontent on an increasing scale. This is due in part to rising expectations provoked by the early successes and dynamism of modern society. Groups tend to make escalating demands on the community, and these demands become increasingly difficult to meet. More seriously, modernization on an intensified level and on a world scale brings new social and material strains that may threaten the very growth and expansion on which modern society is founded. In this second phase, modern societies find themselves faced with an array of new problems whose solutions often seem beyond the competence of the traditional nation-state. At the same time, the world remains dominated by a system of just such sovereign nation-states of unequal strengths and conflicting interests.

Yet challenge and response are the essence of modern society. In considering its nature and development, what stands out initially at least is not so much the difficulties and dangers as the extraordinary success with which modern society has mastered the most profound and far-reaching revolution in human history.

This article discusses the processes of modernization and industrialization from a very general and primarily sociological point of view. It does so also, it should be remembered, from a position within the very processes it describes. The phenomena of industrialization and modernization that are taken to have begun some two centuries ago and that were not until much later identified as distinct and novel concepts have not yet arrived at any recognizable closure. The end of the story, if there is one, is thus not in sight, and the question of an ultimate judgment on the nature and value of this vast historical movement is unanswerable.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, sections 521, 524, and 712.

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Becoming modern

THE REVOLUTION OF MODERNITY

If one imagines all of human social evolution charted on a 12-hour clock, then the modern industrial epoch represents the last five minutes, no more. For more than half a million years, small bands of what we may agree were human beings roamed the earth as hunters and gatherers. With simple stone tools and a social order based on kinship ties they successfully preserved the human species against predators and natural calamities. In observing contemporary Australian Aborigines, the San (Bushmen) of southern Africa, the Eskimo, the Negritos in Malaysia and the Philippines, and Pygmy groups in Africa, a glimpse may be had of the social life of the Paleolithic period (Old Stone Age)—the oldest and most enduring type of human society.

About 10,000 BC some of these hunters and gatherers took to cultivating the earth and domesticating animals. It is this process that is somewhat misleadingly called the Neolithic revolution, implying that new stone tools were at the root of this vast change. It is now generally accepted that the new technology was not the principal factor. Nevertheless what took place was undoubtedly a revolution. Mobile bands became settled village communities. The development of the plow raised the productivity of the land a thousandfold, and in response the human population of the planet increased dramatically. More significantly, herding and agriculture for the first time created a surplus of food. This allowed some members of the population to abandon subsistence activities and become artisans, merchants, priests, and bureaucrats. This division of labour took place in a newly concentrated physical environment. In the 4th millennium BC cities arose, and with them trade, markets, government, laws, and armies.

The agricultural revolution

The technology and social organization of the Neolithic revolution remained the basis of all civilization until the coming of industrialism. With remarkably few additions—the invention of the stirrup was an important one—what served ancient Mesopotamia and ancient Egypt of the

third and second millennia BC served as the foundation of all the states and empires of the ancient world, from China and India to Greece and Rome. And it served equally the European Middle Ages, which in some respects, notably in technology, actually fell back from the achievements of the ancient world. Not until the 17th and 18th centuries in Europe did humankind make another leap comparable to that of the Neolithic revolution.

It is against this very slowly evolutionary background that the revolution that underlay modernity must be seen. It is one of just two quantum jumps that human social evolution has made since the primal hunting and gathering stage of early *Homo sapiens*. The Neolithic or agricultural revolution produced, paradoxically, urban civilization; the Industrial Revolution lifted humankind onto a new plane of technological development that vastly increased the scope for transforming the material environment. In its speed and scale the change brought about by the Industrial Revolution has had, indeed, a greater impact on human life than the Neolithic revolution. Neolithic civilization remained throughout confined by a sharply limited technical and economic base; industrial civilization knows no such limits. Nevertheless, an understanding of agrarian society is essential to the analysis of industrial society, for it is largely through the contrast with its agrarian past that modern society stands out. The meaning of the modern is to be found as much in what it renounces as in what it aspires to.

THE WEST AND THE WORLD

It is not fully understood what produced the leap into modernity and why, just as some groups of hunters and gatherers gave rise to agrarian society, some agrarian societies gave rise to industrial society. What is clear is that it took place between the 16th and 18th centuries and that it began in the countries of northwestern Europe—especially England, the Netherlands, northern France, and northern Germany.

This could not have been expected. Compared to the Mediterranean, not to mention Arabic and Chinese civilizations, northwestern Europe early in the 16th century was backward, technically and culturally. In the 16th and 17th centuries it was still absorbing the commercial and artistic innovations of the Italian city-states of the Renaissance and making piratical raids, where it could, on the wealthy Spanish empire. It seemed an unlikely candidate for future economic leadership of Europe. Yet it was there that the changes took place that propelled those particular societies into the forefront of world development.

One reason advanced for this is that northwestern Europe was the origin and heartland of the Protestant Reformation of the 16th century. In his great work *The Protestant Ethic and the Spirit of Capitalism* (1904), the German sociologist Max Weber suggested that Roman Catholicism and to an even greater extent such Eastern religions as Hinduism and Buddhism were essentially otherworldly religions. They placed doctrinal emphasis on religious contemplation and the life hereafter. Protestantism, on the other hand, was predominantly a "this-worldly" religion. It broke down the distinction between the church and the world, between the monastery and the marketplace. Every man was a priest; everything he did, at work or at play, he did 'in the sight of God. Weber sought to show that Protestantism, and especially its Puritan variety, developed a particular type of character that valued frugality and hard work. Protestantism particularly promoted a work ethic. For the Protestant, all work, all occupations, were in a sense a religious vocation. Work was to be pursued with a fitting seriousness and order, in a spirit of rational enterprise that eschewed waste and frivolous adventurism. Such an attitude was admirably suited—though not intentionally—to the development of industrial capitalism. The Protestant nations, therefore, according to Weber, invented modern capitalism and so launched the world on a course that it still follows. Some later historians have disputed Weber's thesis and have adduced evidence that the early development of capitalism and of industrial organization preceded the rise of Protestantism. In either case, their mutual accommodation remains striking.

Weber's thesis

In a similarly persuasive way, the rationality of the Protestant work ethic has seemed linked to the development of modern science. This, too, took place largely in northwestern Europe in the course of the 17th century. In no other place, at no other time, was there anything like the scientific revolution of these years in England, France, and the Netherlands. It is true that the Industrial Revolution, in its early phases at least, did not depend on the theoretical science of Isaac Newton, Robert Boyle, or others of the period. What was crucial was the rationalist culture and the scientific habits of mind that this culture nurtured. Moreover, the scientific method of observation, hypothesis, experimentation, and verification could be applied not only to nature but also to society. Eventually, toward the end of the 18th century, what would later be called social science—economics and sociology especially—began to find a place alongside natural science. The scientific outlook—skeptical, autonomous, applying fixed standards of observation to continually changing phenomena, to reach conclusions that were never to be considered more than provisional—became the hallmark of modern society.

The scientific temper

Already, by the 17th century, western Europe had embarked on the course of transoceanic expansion that was to become one of its most notable features in the succeeding centuries. The colonization of America, although uneven, added a vast new domain to the West. In wealth, resources, and physical power, the West took a commanding lead over the rest of the world. From the enormous potentialities of science and industry, it acquired a momentum and a dynamism that pointed to a future immeasurably grander than anything previously achieved. For the first time, moralists and philosophers began to conceive of the possibility that the modern world might come to be the equal and even the superior of the ancient world of Greece and Rome. The idea of progress, and with it that of modernism, was born. The world was growing in power and enlightenment and, so far as anyone could see, would continue indefinitely to do so. Western society was not merely plunging ahead on its own; it was paving the way for the rest of the world. As Karl Marx said, albeit two centuries later, "The country that is more developed industrially only shows, to the less developed, the image of its own future."

THE DUAL REVOLUTION

Modern society owes its origin to two great upheavals in the 18th century, one political, the other economic. Both were part of a broader pattern of change that, since the Renaissance and Reformation, had set the West on a different path of development from that of the rest of the world. This pattern included the individualism and, in the end, the secularism, that was the Protestant legacy. It also included the rise of science, as a method and as a practice. Both of these culminated in explosive events toward the end of the 18th century. The first helped provoke political revolutions in America and France. The second, in creating an atmosphere conducive to technological innovation, was one of the chief elements in the emergence of the Industrial Revolution in Great Britain.

The American and French revolutions established the political character of modern society as constitutional and democratic, meaning not necessarily that every government thenceforward was of such character but that even those most conspicuously not so frequently claimed to be. From the time of those revolutions it became clear to practically all thinkers that no political system could now claim legitimacy that was not in some sense based on "the will of the people," constitutionally expressed. It was this message that was so brilliantly spelled out by the clear-sighted French aristocrat Alexis de Tocqueville in his works, *The Ancien Régime and the Revolution* (1856) and *Democracy in America* (1835–40).

Political origins of modern society

That the new democratic legitimation could be, and would be, claimed by popular or constitutional dictatorships such as those of Napoleon III in France or Adolf Hitler in Germany only showed how central the double ideal of democracy and constitutional justification had become. But they were not infinitely malleable. The idea

of tacit or implicit popular consent, resorted to by several old-fashioned monarchies and empires, fell before the march of modern democratic theory as developed from the American and French revolutions. In the United Kingdom this was done through a gradual extension of the franchise in the 19th century. In Russia and in eastern and central Europe, violent revolution, defeat in war, and centrifugal nationalist tendencies turned out to be the means by which autocratic intransigence was overcome.

The democratic constitutional state

But however accomplished—whether grudgingly conceded, seized in popular revolution, or imposed by modernizing elites—the democratic constitutional state has come to be accepted as in principle the only fully legitimate polity of modern society. States that deviate from the norm, as, for instance, the communist states of eastern Europe or the military dictatorships of Africa and Latin America, feel compelled to offer elaborate justifications of their conduct. These are sometimes outright denials that the regime in question is the antithesis of a constitutional democracy; generally, however, they take the form of pleading special or emergency conditions. Full democracy, at some time in the future, remains the professed goal. The doggedness with which most of this casuistry is advanced, often in the teeth of observable evidence to the contrary, is the clearest testimony to the normative strength of the democratic ideal in modern society.

Self-determination

The American Revolution added a further ingredient to the political form of modern society. It asserted the principle of self-determination. Only those states were legitimate in which a people of common culture ruled for themselves a common territory. Foreign rule, or rule by an alien elite, as in the Ottoman and Habsburg empires, was unnatural. Only nation-states were natural political entities; only they were legitimate. "National self-determination" became one of the most powerful catchphrases of the liberal and radical ideologies that largely shaped the modern states of the 19th and 20th centuries.

That self-determination could be a highly ambiguous demand, as with democracy, was shown especially in the experience of central and eastern Europe, where the question of whose presumed nationality should be the basis of the state divided ethnic groups bitterly and murderously. Who, in the extremely mixed domains of what was Austria-Hungary before 1918, was to constitute an autonomous national group—Magyars, Slovaks, Croats, Serbs, Romanians? Only force would resolve the issue, so that modern Romania ended up with substantial Magyar and Saxon minorities inside its national boundaries while Yugoslavia contained a number of ethnic groups not much less various than those of the Austro-Hungarian monarchy which in part it was created to replace. But, once again, it was not the practical difficulties that mattered. As with democracy, it was the pure ideal of nationalism that became the irresistible force. And, once invented by the West, it could not be contained there. Along with democracy, it was one of the ideals absorbed by the colonies of the Western powers, and it became a powerful factor in the dissolution of Europe's overseas empires.

If the American and French revolutions laid down the political pattern of the modern world, the Industrial Revolution in Great Britain laid down the economic pattern. The changes that took place in Britain during the 19th century became almost a prototype of industrialization. To choose to industrialize—and not so to choose meant risking backwardness and dependence—was to imitate consciously the British Industrial Revolution. Great Britain was the pioneer industrial nation of the world; there simply was no other model to fix on. Even later, when it was clear that the British method of industrialization might not be exclusively valid or universally applicable, the general form of society that emerged in the course of the Industrial Revolution was widely regarded as typical.

Industrial revolution in Britain

Certain episodes and tendencies in the British case were pointed to as characterizing industrial development as such. These included the movement from the land to the cities, the massing of workers in the new industrial towns and factories, and the rise of new distinctions between family life and work life, and between work and leisure as notions meaningful to large classes of persons. Such features, with various others, were compounded into a powerful image of industrialism as a whole and wholly new social system and way of life.

The British themselves, it should be noted, did not contribute much to the promulgation of this image of industrialism, at least insofar as it was turned into a systematic account of society. Certain powerful symbols and images of urban and industrial life were indeed picked up from such English novelists as Charles Dickens and Elizabeth Gaskell. But it was left to others, from societies only just beginning to industrialize, to blend these artistic impressions (many of them not at all celebratory) into a systematic analysis of the new society. Foreigners such as Alexis de Tocqueville, Friedrich Engels, and Karl Marx observed and reflected on the changes they saw in England. They were convinced that what was happening in Britain would be repeated, more or less exactly, in other societies as they underwent industrialization. Industrial Britain could be seen, therefore, as a social laboratory of inestimable value to those other societies. In works such as Engels' *The Condition of the Working Class in England in 1844* (1845), and Marx's *Das Kapital* (1867–1894), British experience was examined for the light it shed on the general process of industrialization and for what it suggested of future developments, there and elsewhere. Through such works, the British Industrial Revolution became the property not just of the British nation but of the whole world. All societies, it was felt, would have their "Coketowns," the generic industrial town of Dickens' *Hard Times* (1854); all would have industrializing ideologies and institutions of the kind—referred to by Germans as *Manchestertum*—that 19th-century observers came to associate with the world's leading industrial city. Manchester was indeed the symbol of the new industrial society, and hence the image of the world's future. "The age of ruins is past," declared the British politician and novelist Benjamin Disraeli in his novel *Coningsby* (1844). "Have you seen Manchester?"

Industrialization as symbol

One consequence of this tendency to generalize the British experience was that the idea of industrialism itself grew in scope and significance. It came to symbolize and to embody not just the economic and technological changes that lay at its heart, but other political, social, and cultural changes that appeared to be organically connected with it, whether as causes, concomitants, or consequences. Thus, the democratic movement triggered by the American and French revolutions was seen as the necessary political transformation that, sooner or later, must accompany all movement toward an industrial society. Similarly, changes in urban life, in family form, in individual and social values, and in intellectual outlook, were all seen as linked to industrialism. Industrial society came to stand as the epitome of modern society. And through the lens provided by industrialism, earlier developments, such as Protestant individualism and the scientific revolution, came to be seen as preconditions or presentiments of industrialism, elements incorporated into a systematic and more comprehensive movement that had its own compelling logic and momentum. Industrialism, it came to be agreed, was a package and had to be purchased as such.

The nature of modern society

GENERAL FEATURES

Modernity must be understood, in part at least, against the background of what went before. Industrial society emerged only patchily and unevenly out of agrarian society, a system that had endured 5,000 years. Industrial structures thus took much of their characteristic form and colour from the rejection, conscious or unconscious, of preindustrial ways. Industrialism certainly contained much that was new, but it remained always at least partly an idea that in both its theory and its practice was to be understood as much by what it denied as by what it affirmed. The force of the modern has always been partly a reactive force, a force that derived meaning and momentum by a comparison or contrast with, and by rejection or negation of, what went before.

Considered at the most general level, this point suggests a view of modernization as a process of individualiza-

tion, differentiation or specialization, and abstraction. Put more concretely: first, the structures of modern society take as their basic unit the individual rather than, as with agrarian or peasant society, the group or community. Second, modern institutions are assigned the performance of specific, specialized tasks in a social system with a highly developed and complex division of labour; in this they stand in the sharpest possible contrast with, for instance, the family in peasant society, which is at once the unit of production, consumption, socialization, and authoritative decision-making. Third, rather than attaching rights and prerogatives to particular groups and persons, or being guided by custom or tradition, modern institutions tend to be governed and guided by general rules and regulations that derive their legitimacy from the methods and findings of science. In principle at least, they are not the agents of particular individuals, such as a king or priest, endowed with divine or prescriptive authority, but act according to the rational and impersonal precepts formulated by "experts."

Contrasts with traditional society

These contrasts by no means complete the characterization of modern society, nor are they the only ones that might be drawn. Nevertheless, they do illustrate the dependence of the concept of modernity on past structures that form the basis of comparison and exclusion. Indeed, it is such a set of contrasts, not necessarily carefully distinguished, that most people have in mind when they speak of modern as opposed to traditional society.

With regard to the more positive features of industrialism, industrial society can best be thought of as consisting of an economic core around which other, noneconomic structures crystallize. In Marxist terminology, this is rendered in the more deterministic form of an economic base conditioning a noneconomic "superstructure." This seems unnecessarily rigid and misleading. The relation of the economic to the noneconomic realm is mutual and interactive, as can be seen by considering the impact of scientific ideas on economic and technological development. Still, it is true to say that, fundamentally, it is the economic changes that most dramatically affect industrial society.

ECONOMIC CHANGE

Economic historians and theorists have been inclined to stress economic growth as the central defining feature of an industrial as opposed to a nonindustrial economy. Thus, the British historian Edward Anthony Wrigley (b. 1931) declared that "industrialization is said to occur in a given country when real incomes per head begin to rise steadily and without apparent limit." The American economic historian W.W. Rostow (b. 1916) popularized a similar conception in suggesting that with industrialization, the economy at a certain point "takes off" into "self-sustained growth"; all the relevant statistical indexes of the economy—investment, output, growth rate, and so on—take sudden, sharp, almost vertical upward turns.

Underlying this phenomenon of growth are certain core components of the industrial system. These include technological change, whereby work is increasingly done by machines rather than by hand; the supplementing or replacement of human and animal power by inanimate sources of energy, such as coal and oil; the freeing of the labourer from feudal and customary ties and obligations, and the consequent creation of a free market in labour; the concentration of workers in single, comprehensive enterprises (the factory system); and a pivotal role for a specific social type, the entrepreneur.

Core components of the industrial system

It would be easy to vary and extend this list. Not all components are of equal importance, nor are all equally indispensable to the industrial economy. They are drawn largely from the experience of the first industrializing nations, in western Europe and North America. Later industrializers were able to dispense with some of them, or at least to try to do so. The Soviet Union, for instance, industrialized on the basis largely of forced rather than free labour and made a point of doing away with entrepreneurs, while in Japan the entrepreneur was throughout stimulated and sustained by strong state involvement in industrialization. Moreover, it should be remembered that states—as, for instance, Denmark and New Zealand—can industrialize largely through the commercialization and mechanization of agriculture. Agriculture simply becomes another industry; farms are simply rural factories.

Even in this latter case, there is no place for a distinctively rural way of life in industrial society. Mechanization brings an increase in productivity that renders a large portion of the rural labour force superfluous. Even where agriculture remains an important part of the industrial economy, the proportion of the labour force employed in agriculture drops steadily with industrialization. This is the "sectoral transformation" that is one of industrialization's clearest and most obvious effects. A majority of the work force comes to be employed in the production of manufactured goods and in services rather than in the primary sector of agriculture. In both the United Kingdom and the United States, for instance, by the mid-1970s more than 95 percent of the employed population were in manufacturing and services and less than 5 percent in agriculture. Japan, as an example of a late developer, shows the same pattern: in 1970, more than 80 percent of the employed population were in manufacturing and services, and less than 20 percent in agriculture. These figures should be compared with the normal condition of preindustrial agrarian societies, where typically 90 percent of the adult population are peasant farmers or farm workers.

Agricultural productivity and labour

The vast increase in agricultural productivity which this sectoral change in employment signals is characteristic of industrialism. Industrial society breaks through the historic limits of scarcity. In the past, the potential for economic growth was always cut short by Malthusian checks on population, by limitations of food supply, or by the shortage of easily available raw materials such as wood. Industrialization permits the creation of large food surpluses that can feed a largely urban population. The entire world, both on land and in the sea, is scoured for raw materials and further energy sources to supply industry. Science has so far proved remarkably effective at finding substitutes for those sources that have dried up and those materials that have become dangerously scarce. The British economist John Maynard Keynes suggested that, for the first time in human history, "the economic problem may be solved," and that "the economic problem is not the permanent problem of the human race." In the mid-1980s it still seemed reasonable to believe that industrialism promised growth for the foreseeable future, even that it might bring abundance to all.

POPULATION CHANGE

There have been two major population explosions in the course of human social evolution. By the end of the Paleolithic period the world's human population is estimated to have been between five and six million (an average of 0.1 person per square mile [0.04 person per square kilometre] of the Earth's land area). Following the Neolithic or agricultural revolution, the population made its first major leap, reaching over the short span of 8,000 years around 150 million by the year 1000 BC (2.6 persons per square mile). For the next two and a half thousand years there was relatively little change. World population had reached about 500 million by the middle of the 17th century. During this time any tendency for population to grow was punished by the Malthusian checks of starvation and pestilence. Only with the Industrial Revolution of the 18th century did population break out again from its Malthusian fetters.

From about 1700 there was a second and far more rapid population explosion. Since the late 1600s the world's population has increased more than eightfold, reaching 4.8 billion by the mid-1980s. On current projections it is expected to reach more than six billion by the year 2000 (which will mean an average of 42 persons per square kilometre of the Earth's land area). This gives some measure of the difference between the two population revolutions of human history: there has been a dramatic acceleration not simply in population but in the rate of increase of population since industrialization took hold. Between 1650 and 1850 the average annual rate of increase of the world's population doubled; it doubled again by the

Industrial revolution and population

1920s, and more than doubled, once more, by the 1970s.

If the time taken to double the world's population over the past 350 years is taken as a measure, then the doubling time is seen to have been shrinking fast. It took 200 years, to 1825, to double the world's population from 500 million to one billion. It took only 100 years to achieve the next doubling, bringing the total to two billion by 1930; and only 45 years to achieve yet another doubling, to four billion by 1975. There were signs of slowing in the last part of the 20th century, and clearly this accelerating pace could not last indefinitely. Even so, many experts predicted eight billion by early in the 21st century, a reduction in the doubling time to about 40 years.

It was in western Europe, with the Industrial Revolution, that the second population revolution began. Europe's population doubled during the 18th century, from roughly 100 million to almost 200 million, and doubled again during the 19th century, to about 400 million. It was in Europe, too, that the pattern first emerged that has come to be known as the "demographic transition" (see POPULATION). The populations of nonindustrial countries are normally stable (and low) because high birth rates are matched by high death rates. With industrialization, improvements in medical knowledge and public health, together with a more regular food supply, bring about a drastic reduction in the death rate but no corresponding decline in the birth rate. The result is a population explosion, as experienced in 19th-century Europe. In time, however, as European societies showed in the early 20th century, the urbanized populations of industrial societies voluntarily lower their birth rates and population growth flattens out. A new population plateau is reached. Japan, industrializing some 50 years later than the West, provided an almost textbook demonstration of the pattern of the demographic transition. Its population grew rapidly after 1870, during its industrializing phase, and leveled off equally rapidly after World War II. In an even more speeded-up form, the Soviet Union in its century of industrialization that began in the 1880s illustrated the link between industrialization and population.

Demographic transition

Does the demographic transition hold good for the developing societies known as the Third World? Nearly all of these countries experienced rapid population growth after World War II, at rates greater than had ever occurred anywhere in the West. Western aid and medical science spectacularly reduced the high death rates, often by more than 50 percent. But, unlike those in the West, the high birth rates showed little tendency to fall. Determined efforts in a few countries, such as Singapore, Sri Lanka, and China, were beginning to yield some results by the 1980s. But on the whole the attempts by national governments and international agencies to persuade non-Westerners to have smaller families had failed. One result was the persistence of predominantly youthful populations in societies that could least afford the burden of feeding and educating their nonproductive young. People under 15 made up more than 40 percent of the populations of the Third World, as compared with between 20 and 30 percent in the industrialized world.

Third World demographics

It was argued that the birth rate remained stubbornly high in these societies partly because industrialization was so slow and fragmentary in the Third World. In addition, where any significant development had taken place, as in Brazil or Malaysia, it had only really affected a small elite; the mass of the people were untouched. Thus, the reasons people in the industrialized West chose to have fewer children lacked cogency in underdeveloped countries. It remained rational for the bulk of the population to continue to have large families both to share in manual labour and to provide security for parents in their old age. Lower fertility would come, it was argued, when wealth was more evenly distributed and social security systems well established.

URBANISM AS A WAY OF LIFE

Industrialism does not simply increase numbers; it distributes them in particular ways, concentrating mass populations in cities. Modern life is unquestionably urban life.

It may be argued that it was in the cities of ancient Mesopotamia, Egypt, Greece, and Rome that a distinctively urban existence was first brought to that pitch of refinement that signifies an advanced civilization. Certainly for those fortunates who were free citizens the Athens of Pericles provided an agreeable existence. The Italian cities of the Renaissance, too, provided a distinctly urban culture.

Industrial urbanism differs from preindustrial urbanism in two ways. The first is in its quantitative reach and intensity; the second is in the new qualitative relationship it sets up between the city and society.

For all the culture and sophistication of the preindustrial city, it remained a minority experience. Full participation in urban life was available to no more than the 3 or 4 percent of the population who were city dwellers in 3rd-millennium-BC Egypt and Mesopotamia and to the 10 to 15 percent of Romans who lived in cities at the zenith of imperial Rome (but who were heavily dependent on food supplies from North Africa). These latter represent a high point of preindustrial urbanism.

Industrialization brings a growth in trade and manufactures. To serve these activities it requires centralized sites of production, distribution, exchange, and credit. It demands a regular system of communications and transport. It multiplies the demand that political authorities establish a dependable coinage, a standard system of weights and measures, a reasonable degree of protection and safety on the roads, and regular enforcement of the laws. All these developments conduce to a vast increase in urbanization. Whereas in typical agrarian societies 90 percent or more of the population are rural, in industrial societies it is not uncommon for 90 percent or more to be urban.

Demands of industrialization

The growth of cities with industrialization can be illustrated by the example of the United Kingdom. In 1801 about a fifth of its population lived in towns and cities of 10,000 or more inhabitants. By 1851 two fifths were so urbanized; and if smaller towns of 5,000 or more are included, as they were in the census of that year, more than half the population could be counted as urbanized. The world's first industrial society had become its first truly urban society as well. By 1901, the year of Queen Victoria's death, the census recorded three-quarters of the population as urban (two-thirds in cities of 10,000 or more and half in cities of 20,000 or more). In the span of a century a largely rural society had become a largely urban one.

The pattern was repeated on a European and then a world scale as industrialization proceeded. At the beginning of the 19th century, continental Europe (excluding Russia) was less than 10 percent urbanized, with respect to cities of 10,000 or more; by the end of the century it was about 30 percent urbanized (10 percent in cities with 100,000 or more), and by the mid-1980s, the urban population was more than 70 percent. In the United States in 1800, only 6 percent of the population lived in towns of 2,500 or more; in 1920 the census reported that for the first time more than half of the American people lived in cities. By the mid-1980s this had risen to nearly 75 percent—about the same as Japan's urban population—and more than two-fifths of the population lived in metropolitan areas of one million or more. Taking the world as a whole, in 1800 no more than 2.5 percent of the population lived in cities of 20,000 or more; by 1965 this had increased to 25 percent, and by 1980 to 40 percent. It is estimated that by the year 2000 about half the world's population will be urban, by this measure. At the same time there has been a great growth of very large cities, of a type virtually unknown in the preindustrial world. Cities of more than one million inhabitants numbered 16 in 1900, 67 in 1950, and 250 in 1985.

Western urbanization

As with population growth, it was in the underdeveloped nations that the fastest rates of urban growth were to be found. The rapidly expanding population of a countryside unable to support it sought the city for both escape and opportunity, though in many cases it was a perilous choice. Between 1900 and 1950, while the world's population as a whole grew by 50 percent, the urban population grew by 254 percent; but in Asia urban growth was 444 percent and in Africa 629 percent. By the mid-1980s, Africa and Asia were about 30 percent urbanized, and Latin America

Third World urbanization

nearly 70 percent so. Cities such as São Paulo (15 million), Mexico City (17 million), and Calcutta (10 million), had mushroomed to rival and even overtake in size the large cities of the developed West and Japan.

But while urbanization in the underdeveloped nations repeats some of the more distressing features of its Western counterpart—overcrowding, unsanitary conditions, and unemployment—the compensation and eventual remedy of economic growth has been largely lacking. With some partial exceptions, such as Brazil, Mexico, Singapore, and Hong Kong, the underdeveloped world has known urbanization without industrialization. The result has been the rapid growth of shantytowns on the edges of the big cities. It has been estimated that about four or five million families in Latin America live in shantytowns.

Urbanism cannot be understood simply by statistics of urban growth. It is a matter, too, of a distinctive culture and consciousness. Urbanism is a way of life, as classically analyzed by the German sociologist Georg Simmel and the American sociologist Louis Wirth. City life, with its tendency to nervous overstimulation, may lead to a bored and blasé attitude to life. It may encourage frivolous and fleeting cults and fashions. It can detach people from their traditional communal moorings, leaving them morally stranded and so inclined to harbour unreal expectations and feverish dreams. In the very number of social contacts it necessarily generates, it may compel individuals to erect barriers to protect their privacy. Individuals may be forced into an attitude of reserve and isolation. Hence, as Simmel noted, the superficial paradox that "one nowhere feels as lonely and lost as in the metropolitan crowd."

Urban culture

At the same time, cities promote diversity and creativity. They attract the best and the brightest. If anything is to be accomplished in modern society, it almost certainly will be in the city. Karl Marx spoke of "the idiocy of rural life." Only in cities, many sociologists have felt, are human beings able to realize to the full all their potentialities. Cities are the forcing house of change and growth. "Great cities," declared the French sociologist Émile Durkheim, "are the uncontested homes of progress; it is in them that ideas, fashions, customs, new needs are elaborated and then spread over the rest of the country. . . . Minds naturally are there oriented to the future."

But whether they deplored or praised urban life, most commentators have agreed that, with industrialism, the city moved into a pivotal new relation with society as a whole. Preindustrial cities were islands in an agrarian sea. They hailed each other across vast alien tracts of nonurban life, which remained largely indifferent to and unaffected by their practices. Essentially they were parasitic on the countryside and on the peasant masses whose agricultural labour sustained them. Their disappearance not only would not have mattered to the peasants but would in most cases have been welcomed.

With industrial urbanism, this relationship was reversed. The countryside now became dependent on the city. It became an integral but peripheral part of a single economic system that was centred on the cities. Largely emptied of people, the countryside was now in effect simply another theatre of industrial operations for city merchants and bankers. Political and economic power resided in the city; industrial and financial corporations became the dominant landowners, replacing individual proprietors. Except in pockets largely maintained as quaint retreats for tourists, rustic life virtually disappeared; certainly it no longer significantly affected the values and practices of the larger society. What remained of "country life" was often little more than a persuasive and nostalgic motif in the hands of advertising copywriters, preying on the fantasies of city dwellers.

The city became both the symbol and the reality of industrial society as a whole. No longer, as in the past, standing in a merely mechanical relation to other parts of society, the city took its place at the centre of an increasingly organic whole. Industrialism created a centralized web of social relationships, and the city was the node. It dictated the style and set the standard for the whole society, imposing on all its own economic, political, and cultural framework.

WORK AND THE FAMILY

In preindustrial or nonindustrial society the family is the basic unit of production. All its members engage in a cooperative set of subsistence activities. In a typical example from early 18th-century England, the man might be a weaver and his wife a spinner, with the younger children acting as assistants in the joint domestic enterprise. Mixed in with this wage or piece labour would probably be the cultivation of a small plot of land, together with access to common land to forage for fuel and to hunt small game. The family need not necessarily be very large—in northwestern Europe and North America it seems to have been relatively small—but on the whole additional members are an economic asset as the value of extra hands to work outweighs the cost of extra mouths to feed. The family is a collective enterprise; all its members regard themselves as part of that collectivity and their contributions as adding to a common store; servants or other nonfamily members, such as apprentices, are "adopted" or treated as family members, for no other binding personal relationships but family ones are recognized. The family and its members are society in miniature.

The family as the unit of production

Industrialization radically disrupts this more or less autonomous family economy. It takes away the economic function of the family, and reduces it to a unit of consumption and socialization. Production moves away from the household to the factory. The commons are enclosed, and the land commercially exploited for national and international markets. Some individuals become the owners and the managers of the new system. But the bulk of family members must become either landless agricultural labourers or, increasingly, workers in the factories of the new industrial towns. In either case, the family becomes immediately dependent for its livelihood on structures and processes external to itself. It lives by the jobs and wages of its members, and these are affected by forces which it barely comprehends, still less controls.

In the early stages of industrialization, the family will likely struggle to maintain its traditional collective unity. Its members, whether employed as farm workers in the country, industrial workers in the towns, or domestic servants in well-to-do urban homes, continue to pool their resources. They make regular visits home and continue to think of themselves as a collectivity. Their wages still contribute to a common family fund, which is used to support the nonworking young as well as temporarily unemployed members and to provide for members in sickness and old age. In the absence of a comprehensive system of social security, the family itself continues to fulfill the role. In these circumstances, as in the past, a large family can be as much an asset as a burden. For a considerable time, therefore, large families, especially among the working classes, continue to be the norm in industrializing society.

Eventually the forces of individualization, whose gross effects on the industrial economy and the society at large are so striking, also affect the family. Its members, male and female, increasingly come to think of their wages as their own, to be disposed of as they individually see fit. This attitude is encouraged by the increasing availability of attractive consumer goods. At some point it becomes economically and politically necessary for the state to step in to provide for those members unable to earn their own living, either because they are chronically unemployed, or because they are too young, too sick, or too old. The family role thus shrinks further to little more than child-rearing, and even here it has to compete with the school, peer groups, and child-care agencies. For its older members, the family becomes merely the domicile and the locus of recreation and a certain amount of sociability. Its members may spend a good deal of time at home, but their minds are formed more by influences operating outside it. Their lives are led largely outside the family, in their work and in association with nonfamily friends and colleagues. They no longer find their identity within a collective family identity. Hence the tendency of young adults to marry young, to break away from their families of origin, and to set up their own independent families.

Fragmentation of the family

Shorn of so many traditional functions, the family becomes almost exclusively the sphere of private life. It

attends to the needs of children and the emotional and sexual satisfaction of the spouses. A small unit is best suited to these tasks. The extended families of the preindustrial and early industrial periods, which sometimes included grandparents and married offspring to three or more generations, give way to the small, two-generation nuclear family of parents and dependent children only. Whether or not the nuclear family precedes industrialization—as, for instance, it seems to have done in England—in industrial society it certainly becomes the norm.

With the shrinking and privatization of the family, the importance of work grows correspondingly. It becomes the principal source of individual identity. In preindustrial society, the question of who one is is likely to be answered in terms of place of origin or family membership: I am John of Winchester, or John, Robert's son. In industrial society the question is typically answered in terms of one's occupation in the formal economy. The occupational role, as miner or machinist, clerk or cleaner, becomes the determining and defining role. It is the source of one's identity, status, and income. Work, throwing off its religious justifications, itself becomes a religion. Not to work, to be unemployed, is to be stigmatized as much in one's own eyes as in the eyes of society.

Work as identity

Work is redefined as applying almost exclusively to formal employment in the industrial economy. All other kinds of work—unpaid domestic work, voluntary work, work done for friends or family, child-rearing—are devalued and treated as marginal or "unproductive." The paradox is that the elevation of employed work is accompanied by a decisive fragmentation of work as an activity. Industrialization brings about a massive increase in the division of labour. But this involves not just, as in preindustrial urban life, a specialization of crafts and the rise of new occupations. More significant is a new kind of division of labour, what Adam Smith and Karl Marx called the "detailed" division of labour, in the work task itself. The set of tasks involved in the making of a whole product, which was previously performed by a single artisan or worker, is now broken apart and allocated to a number of different individuals. In his famous example of a pin manufactory, Adam Smith showed how, by dividing the task of pin-making into some 18 distinct operations, each performed by "distinct hands," productivity could be increased more than a thousandfold. It was this form of the division of labour that became the source of the fantastic productivity of the industrial system, especially once Henry Ford had organized it around the continuously moving assembly line and the American pioneer in scientific management Frederick W. Taylor had supplied an engineering method for the splitting of any task into its simplest operations.

Division of labour

The English social critic John Ruskin pointed to one consequence of this new division of labour when he said that "it is not, truly speaking, the labour that is divided, but the men." The problem of motivating the work force, of providing sufficient inducement to work discipline and performance when the tasks themselves were so intrinsically uninteresting, haunted all industrial societies. But the new division of labour itself pointed, rather ominously, to the likely resolution of this problem. Once tasks had been so minutely subdivided that the least skilled worker could do them, the next step was to mechanize the tasks and dispense with the human worker altogether. Full automation was in some sense implicit in the principle of the division of labour from the very start. It is ironic that a social process that had in its early stages put work at its very centre should also, in its further evolution, threaten to take it away altogether from its citizens.

SOCIAL STRUCTURE

Given the importance of economic institutions in general, and of employment in particular, it is not surprising to find that industrial society tends to produce a new principle in the ordering and ranking of individuals. Economic position and relationships become the key to social position and class membership. This is new, at least in its extent. While wealth or the lack of it were always important in determining social position, they were not usually the sole or even the central determinant. In all nonindustrial societies, attributes of tribal membership, race, religion, age, and gender are of equal and often greater importance in assigning individuals to a position in the social hierarchy. In the traditional Indian caste system, for instance, the religious eminence of even the poorest Brahman marks him out as a member of the highest and most esteemed caste.

Industrial society tends to subordinate all these preindustrial principles of ranking to the economic one. One's position in the system of production or, more generally, in the marketplace assigns one to a particular class or group. Ownership of property, level of education, and type and degree of training all affect one's market position. Karl Marx was convinced that in the course of its development capitalism—the only form of industrialism he considered—would eventually throw up only two main economic classes, the propertyless workers, or proletariat, and the capitalist owners, or bourgeoisie.

Primacy of economic status

One reason why Marx's prediction has not come to pass in any developed society is that, though perhaps dominant in the long run, economic relationships have not so sweepingly eliminated other noneconomic considerations. Older sources of identity have continued to exert considerable power. Groups based on ethnic, religious, and regional ties have overlapped with and occasionally submerged those based solely on the tie of economic interest. Thus, the working class of Northern Ireland has preferred to stress its Protestant identification over its proletarian one. Workers and capitalists in the Basque and Catalan regions of Spain have united in a long, drawn-out opposition to the central government in Madrid. In the United States, racial identity has continued to override any other based on income or occupation.

This is one way in which it is brought home that even radical changes do not necessarily disrupt all continuities. There are gainers and losers in the process of change, and the losers are apt to hark back to past ways and values. Industrialization, while making a fundamental break with earlier forms of society, does not abolish all the elements of traditional society.

SECULARIZATION AND RATIONALIZATION

At the most abstract level of analysis, modernization leads to what Max Weber called "the disenchantment of the world." It eliminates all the superhuman and supernatural forces, the gods and spirits, with which nonindustrial cultures populate the universe and to which they attribute responsibility for the phenomena of the natural and social worlds. In their place it substitutes as the sole cosmology the modern scientific interpretation of nature. Only the laws and regularities discovered by the scientific method are admitted as valid explanations of phenomena. If it rains, or does not rain, it is not because the gods are angry but because of atmospheric conditions, as measured by the barometer and photographed by satellites.

Specifically, modernization involves a process of secularization; that is, it systematically displaces religious institutions, beliefs, and practices, substituting for them those of reason and science. This process was first observable in Christian Europe toward the end of the 17th century. (It is possible that there is something inherently secularizing about Christianity, for no other religion seems to give rise spontaneously to secular beliefs.) At any rate, once invented in Europe, especially Protestant Europe, secularization was carried as part of the "package" of industrialism that was exported to the non-European world. Wherever modern European cultures have impinged, they have diffused secularizing currents into traditional religions and nonrational ideologies.

Although secularization is a general tendency or principle of development in modern societies, this does not imply that religion is driven out altogether from society. Against a deep background of tradition, it inevitably leaves many religious practices in place and may even stimulate new ones. Religious rituals, such as Christian baptism and church weddings, persist in all industrial societies; the church may, as in England and Italy, continue to play an important moral and social role. The majority of the population may hold, however insecurely, traditional religious beliefs alongside more scientific ones. There may even

Persistence of religious practice

be, as in the United States, waves of religious revivalism, involving large sections of the population.

It is nonetheless true that all such religious phenomena, real as they may be in the lives of believers, lose their centrality in the life of the society as a whole. As compared with their place in traditional society, they increasingly take on the character of marginal, even leisure-time, activities. They no longer embody that crucial legitimating power that religious activities have in all nonindustrial societies. The religious establishment is aware that to confront the modern state too openly is to risk disestablishment, as in France, or even, as in communist societies, dissolution. Baptisms and church weddings persist as much for social reasons as from belief in their religious significance.

Secularization is but one manifestation of a larger cultural process that affects all modern societies: the process of rationalization. While this process is epitomized by the rise of the scientific worldview, it encompasses many more areas than are usually associated with science. It applies, for instance, to the capitalist economy, with its rational organization of labour and its rational calculation of profit and loss. It applies also to artistic developments, such as the rational application of the geometry of perspective in painting and the development of a rational system of notation and rational harmonic principles in music. For Max Weber, the most careful student of the process, it referred above all to the establishment of a rational system of laws and administration in modern society. It was in the system of bureaucracy, seen as the impersonal and impartial rule of rationally constituted laws and formal procedures, that Weber saw the highest development of the rational principle. Bureaucracy meant a principled hostility to all traditional and "irrational" considerations of person or place, kinship or culture. It expressed the triumph of the scientific method and scientific expertise in social life. The trained official, said Weber, is "the pillar both of the modern state and of the economic life of the West."

The role of bureaucracy

Weber was aware that bureaucracy has two faces. It can also be despotic and irrational in actual operation. The triumph of the principle does not guarantee its strict performance in practice. Rationalization is a process that operates at the highest, most general level of social development. It would be surprising if its effects were to be found in every nook and cranny of modern society. Everywhere one should expect to find the persistence of nonrational and even antirational attitudes and behaviour. Superstition is one example; the occasional rise of personal, charismatic leadership breaking through the rationalized routines of bureaucracy is another. These should not be thought of simply as vestiges of traditional society. They are also the expressions of essential needs, emotional and cultural, that are in danger of being stifled in a scientific and unillusioned environment.

Weber stressed another significant point. Rationalization does not connote that the populations of modern societies are, as individuals, any more reasonable or knowledgeable than those of nonindustrial societies. What it means is that there is, in principle, scientifically validated knowledge available to modern populations, by which they may, if they choose, enlighten themselves about their world and govern their behaviour. In practice, as Weber knew, such knowledge tends to be restricted to scientifically trained elites. The mass of the population of a modern society might in their daily lives be relatively more ignorant than the most primitive savage, for the savage usually has a comprehensive and working knowledge of the tools he uses and the food he consumes, whereas modern man may well use an elevator without the slightest idea of its working principle or eat food manufactured in ways and with materials of which he is totally unaware.

SOCIAL PROBLEMS

Two faces of modernity

As with bureaucracy, so with most other features: they show the two faces of modernity. One is dynamic, forward-looking, progressive, promising unprecedented abundance, freedom, and fulfillment. The other shows the dark side of modernity, the new problems that modernity brings in its wake by virtue of the very scale and novelty of its achievements. Social progress is matched by social pathology.

Thus, the historic achievement of becoming able to feed a large population brings with it crowding, pollution, and environmental destruction. Quiet, privacy, and space become scarce and increasingly treasured commodities. Massed together in cities, seeking rest and recreation, the populations of industrial societies force open the whole world to tourism. Soon every rural haven, every sunswept coast, is turned into an administered holiday camp, each a uniform replica of the rest. The industrial principle of mass production and distribution can readily be turned from the production of goods to that of services, including those of leisure and entertainment.

Urban-industrial life offers unprecedented opportunities for individual mobility and personal freedom. It also promises the attainment of dazzling prizes, in wealth and honours, for those with the enterprise and talent to reach for them. The other side of the coin is the loneliness of the city dweller and the desolation of failure for those many who cannot win any of the prizes. As Durkheim analyzed it, the individual is placed in the pathological condition of anomie. He experiences "the malady of infinite aspirations." The decline of religion and community removes the traditional restraints on appetite, allowing it to grow morbidly and without limit. At the same time the competitive modern order that stimulates these unreal expectations provides insufficient and unequal means for their realization. The result is an increase in suicide, crime, and mental disorder.

Anomie and alienation

Industrial work, too, exacts a high price for the enormous increase in productivity brought about by the intensified division of labour. Karl Marx offered the most systematic analysis of this price under the heading of "alienation." The industrial worker feels estranged from the activity of work because his task is so fragmented, undemanding, and meaningless. He does not realize himself, his human potential, in his work. Unlike traditional craft work, for instance, it does not call on his constructive and creative faculties. The industrial worker also feels alienated from the product of his work, for he has no control over its manufacture, nor over the terms and conditions of its disposal. As the dynamic sum of its parts, the industrial system of production is phenomenally powerful; but this power is achieved at the cost of reducing one class of those parts, the human workers, to mere "hands," mere semblances of humanity. Eventually, Marx hoped, the surplus wealth produced by the industrial system would free workers altogether from the necessity of work; but until that time the degraded condition of the worker would be the most eloquent testimony to the dehumanization wrought by the system.

Marx's optimism about the future was perhaps as excessive as his pessimism about his present. But he was by no means the only one who felt that industrial society demanded too high a price of many of its members. Repeatedly, industrialism was found to have created new and apparently ineradicable pockets of poverty. Despite steady economic growth, it was the persistent finding throughout the industrial world that between 15 and 20 percent of the population remained permanently below officially defined levels of poverty. It appeared that industrialism by its very mechanism of growth created a "new poor," who for whatever reason—deprived backgrounds, low enterprise, low intelligence—were unable to compete according to the rules of the industrial order. The communal and kinship supports of the past having withered away, there was no alternative for the failed and the rejected but to become claimants and pensioners of the state.

There were other victims, too. The small nuclear family offered, to a greater extent than ever before, the opportunity for intense privacy and emotional fulfillment. But the very intensity of these relationships seemed to put an intolerable burden on it. Added to that, the family survived as the only remaining primary group in society, the only social unit where relationships remained primarily personal and face-to-face. Elsewhere bureaucratic or commercial relationships prevailed. The nuclear family was called upon to do all the work of restoration and repair of its members on their return from the impersonal, large-scale, bureaucratic world of work and, increasingly, play.

Stress of the nuclear family

Under this unprecedented pressure it began to show all the classic symptoms of distress. Adolescent alienation and teenage rebellion became accepted features of modern family life. Divorce rates soared; and when people sought to remarry—"the triumph of hope over experience"—their second marriages proved even less stable than their first. There was a steady increase in the incidence of one-parent families, usually headed by a woman.

Societal costs of modernization

Modernization, finally, put a number of new political and cultural problems on the agenda. The decline of local communities, and the great growth in the scale of all social institutions and especially the acceleration of political centralization, put a strain on civic loyalties and the willingness of people to participate in political life. As mass political parties came to monopolize civic life, individual citizens retreated increasingly into private life. Political apathy and low turnouts at elections became matters of serious concern, calling into question the democratic claims of modern liberal societies. A similar concern centred on the spread of mass communications, which in the 20th century came to dominate the cultural life of modern societies. The uniformity and conformity bred by the press, radio, and television threatened—albeit passively rather than directly—the pluralism and diversity on which liberal society prided itself and which it regarded as its chief security against totalitarian challenge.

Together, political and cultural centralization and uniformity were interpreted as evidence of the creation of a "mass society." Tocqueville had warned that individuals lacking strong intermediate institutions with which to identify would become atomized and in their anonymity and powerlessness might look to the protection of strong men and strong governments. Once more, this outcome had to be seen as a possibility, not an inevitability. Pluralism remained strong in many societies. But the rise and success of totalitarian movements in some industrial societies showed that the tendencies were real and suggested that they were present in some degree in all modern societies.

Modern society and world society

WESTERN AND NON-WESTERN ROUTES TO MODERNITY

The Western experience of industrialization was the model for world industrialization. To become modern was to become something like Western industrial society. Non-Western societies were not always given much choice in the matter. As formal colonies or informal clients of Western powers, they often found themselves being "developed" in a Western direction before they were permitted to take political control of their own destinies. Once on the way, there was no turning back. But, even where an element of choice existed, it remained the consensus that the only viable form of society in the modern world was industrial society. Only industrial societies could be active agents in the world system. All others must remain clients or dependents. Japan demonstrated this better than any other nation. From a poor nation humiliated at the hands of the West in the mid-19th century, Japan rose through industrialization to become one of the most powerful societies in the world. More pointedly, Japan showed that, by meeting the challenge of industrialization, a non-Western society could become not merely the equal but the superior of some of the strongest Western powers.

Japan confirmed what Western experience had already made clear: There are several routes to modernity. In the 19th century Britain, Belgium, France, and the United States industrialized largely on the basis of the individual entrepreneur and the free market economy. In Germany, and even more in Japan, the state and political elites played a major role, organizing credit, coordinating and planning development, and restricting foreign access to home markets in the interests of native industry. Later still came the even more centralized authoritarian model of modernization under the aegis of the one-party state. Taking their lead from the Soviet Union following the Russian Revolution of 1917, many developing countries in Asia, Africa, and Latin America sought to industrialize according to economic plans drawn up by political elites and stringently imposed on their populations. Even where, as in India, formal liberal democracy was instituted, industrialization was largely guided by a single national party—usually the one identified with the struggle for independence from colonial rule, as was the Indian National Congress party. In any case, there were plenty of socialisms to choose from. There were the African socialisms of Kwame Nkrumah's Ghana and Julius Nyerere's Tanzania, the Chinese socialism of Mao Zedong, the Cuban socialism of Fidel Castro, or the Yugoslav socialism of Josip Broz Tito. All could aspire to be models of development to Third World societies.

Socialist paths to development

Japan and the Soviet Union (until its dissolution in 1991) suggested, in their different ways, that there was a general pattern of late development appropriate to all those nations that attempted to industrialize in the shadow of already formidable industrial powers. This pattern variously involved strong protectionism, directed labour, control of unions, and central supervision of banking and credit. It also meant circumventing the sharp division between management and workers that hampered most early Western industrializers and that continued to worry them in their later industrial history. Above all, late developers put the power of the state at the centre of the modernizing effort. The state was the prime mover and guardian of the whole enterprise. Unlike Britain or the United States, where the state—at any rate in the early stage—encouraged development more or less passively, keeping the peace and enforcing the laws and perhaps arranging for some free land (as for the railroads in the United States), in countries such as Japan, the former Soviet Union, and China the state directed the industrializing process from the start and supervised it closely throughout. The state made the major decisions about investment, transport and communications, and education. It developed the media of mass communications as agencies of mass socialization. Therefore, whether or not the economy was formally nationalized, in practice economic development was placed firmly under national auspices and directed to nationalist ends.

ONE WORLD OR MANY

Japan has been, so far, the only non-Western country in the world to become fully industrialized. It may be significant that it began its industrialization in the 19th century, while the West was still itself industrializing and before it had built up a truly commanding lead. The same is true of Russia, the only other major case of industrialization outside western Europe and North America (taking South Africa and Australia as "European"). In the 20th century it has become increasingly clear that industrialization is not something that nations can decide to do or how to do entirely by themselves. They operate within a context of world industrialization, in a world system of states of decidedly unequal wealth and power.

Throughout most of the 20th century the nations of this world system were categorized according to political or economic criteria. Applying the former resulted in the familiar "West–East" divide. This was primarily an ideological division between the developed capitalist nations, such as the United States, Germany, and Japan (counted ideologically as Western), and the developed communist or state-socialist nations, such as the countries of the former East European bloc. Attached to these were, respectively, underdeveloped capitalist nations, such as Bolivia and Bangladesh, and underdeveloped communist nations, such as China and Cuba. The West–East distinction became obsolete in the early 1990s with the collapse of the Soviet Union and of communist regimes throughout Eastern Europe.

West–East and North–South

A more significant and in many ways more interesting division arises from placing primary emphasis on the level of economic development, with political or ideological differences as subsidiary matters. This approach yields the "North–South" divide. With some anomalies—South Africa, Australia—the world is seen as divided essentially between the wealthy and powerful countries of the Northern Hemisphere and the poor, less-developed countries of the Southern Hemisphere. But the North–South dichotomy, though useful in debate, is inaccurate

and misleading. A more precise economic model of the world system distinguishes among the superpowers, solely the United States at the end of the 20th century; other developed countries, such as Japan, Germany, and Britain; and the underdeveloped countries, such as China and Bolivia. We then have First, Second, and Third Worlds.

For most of the 20th century, when the U.S.S.R. was still a superpower, this model illustrated the interconnections and flow of power in the world system. It showed the global dominance of the superpowers, which, despite their usually conflicting ideological and strategic interests, shared a common interest in maintaining their world political and economic leadership. In competing with each other, the superpowers drew into their respective spheres of influence the less powerful countries of the Second and Third Worlds; but, in order to maintain the balance of power, they could in effect collude, choosing on occasion to ignore opportunities to gain at each other's expense in order to stifle political movements that sought too independent a third way.

A further refinement of the economic model looks past the level of three worlds of development to a single underlying and developing world system. Based on a historical perspective, this view, advanced especially by the American theorist Immanuel Wallerstein (b. 1930), argues that there is but a single world economy, the capitalist

The world economy

world economy, which has been expanding since the 17th century. This economy has, over the centuries, been expanding outward from its northwestern European base to take in an increasingly large portion of the globe. Even under the communist regimes, the Eastern European societies were seen as full participants in this system and were accordingly regarded not as aberrant socialist economies but as "collective capitalist firms." In this model, countries are classified according to their nearness to the centre of the system. There are "core countries," such as the United States and Japan; "semi-peripheral countries," such as Brazil, most eastern European states, and China; and "peripheral countries," such as Cuba and most of the poor countries of Africa and Asia. Depending on economic fortunes and fluctuations, as well as the logic of the developing system itself, countries can move in and out of these categories.

The plausibility and appeal of this model lie in its recognition of the growing internationalization of the industrial economy. Nation-states, whether capitalist or communist, are becoming increasingly subordinate to world economic developments. The politics of energy—oil, gas, nuclear power—are world politics (just as, for some considerable time, military strategy has been world strategy). Decisions about capital investment and growth are made in a world context and on a global scale. The giant multinational corporations are the most significant new actors on the

The role of multinationals

world stage. They have been establishing a new international division of labour. From their point of view, it makes more sense to manufacture goods in South Korea or Taiwan, where labour is still cheap and governments compliant, than in the United States or Britain, where labour is expensive and regulation stringent. Such high-level functions as central planning and research and development can be retained in their Western homelands, where there are the necessary reserves of highly trained professional and scientific personnel. Profits can be declared in those countries where taxes are lowest. In such a way do the multinationals illustrate, even embody, the interdependence of core and periphery nations.

Postmodern and postindustrial society

NEW DEVELOPMENTS IN ECONOMIC AND SOCIAL STRUCTURE

Industrialism, at least within our experience of it for more than 200 years, never reaches a point of equilibrium or a level plateau. By its very principle of operation, it ceaselessly innovates and changes. Having largely eliminated the agricultural work force, it moves on manufacturing employment by creating new automated technology that increases manufacturing productivity while displacing workers. Manufacturing, from accounting for a half or more of the employed population of industrial societies, shrinks to between a quarter and a third. Its place is filled by the service sector, which in fully industrial societies comes to employ between a half and two-thirds of the work force and to account for more than half of the gross national product. Most service occupations—in government, health, education, finance, leisure and entertainment—are white-collar. The typical industrial worker is now not the blue-collar worker but the white-collar worker.

The service economy

The move to a service society is marked by a great expansion in education, health, and other private and public welfare services. The population typically becomes not just healthier, better housed, and better fed but also better educated. Most young people complete secondary- or high-school education; between a quarter and a half of them go on to full-time higher education. Professional and scientific knowledge becomes the most marketable commodity. The "knowledge class" of professional, scientific, and technical workers becomes the fastest-growing occupational group. The link between pure science and technology, loose and uncertain in the early stages of industrialization, becomes pivotal. New industries, starting with chemicals and pharmaceuticals and later including the aeronautical, space, and nuclear industries, are created by developments in pure science and depend largely on theoretical research. Theoretical knowledge in the social sciences also comes to be widely applied, as in Keynesian management of the national economy and in complex models of technological and economic forecasting.

Struck by these changes, as compared with the classic forms of industrial society of the 19th and early 20th centuries, some theorists, notably the American sociologist Daniel Bell, have discerned a movement to a new postmodern or postindustrial society. Such conclusions may be premature. Most of the changes characterizing late industrialism can be seen as the results of long-term developments implicit in the process of industrialization from the start. The rise of service industries has emerged in part from the increase in leisure and in disposable wealth and in part from the continuing process of mechanization and technical innovation, which constantly raises manufacturing productivity by replacing human labour with machines. It can also be seen as the consequence of the growth of multinational corporations; this, too, is the result of the increase in scale and complexity of industrial organization, a clear tendency from the very start. The growth of knowledge-based industries, finally, represents no break with the past. Science has always been at the base of industrialism, and its closer union with industry and society in the 20th century is simply the fulfillment of modernization's rationalizing drive.

But, while there may be no new society, these changes do add a new dimension to modern societies. Beyond a certain point in economic development, new values and problems emerge. The activities of the multinationals seem to encourage a process of "de-industrialization" in many modern societies, a drastic decline in manufacturing output and employment as these functions shift to the Third World. While services have for the time being filled the breach, it cannot be assumed that such a balancing will continue, at least as far as employment is concerned. The new microelectronic technology, itself simply the latest wave of industrial tools, has made inroads into service employment faster than more traditional industrial machines displaced manufacturing workers. The application

Effects of the computer

of computers to information processing in a wide range of service work may threaten in turn to displace the vast mass of routine white-collar workers. Nor are the jobs of the more skilled workers necessarily much safer: Computer-aided design may take over much of the draftsman's and architect's work as computer-aided manufacturing equipment displaces skilled machinists; electronic audio-visual equipment may to a large extent take the place of the classroom teacher; and self-service diagnostic software may eliminate many tasks of the nurse and doctor.

NEW PATTERNS OF URBAN LIFE

Many features of modernity, intensified beyond a certain level, produce a reactive response. Urbanization, having

reached some practical saturation point, leads to suburbanization, the desire to live in neighbourhoods with green spaces and at least a breath of country air. As the suburbs fill up, the more prosperous citizens become exurban: they colonize the villages and small towns of the countryside within commuting distance of their work in the city. Aiding this trend is the industrial decentralization and depopulation of many cities as old manufacturing industries decline and new service industries move out to the suburbs and small towns. For the first time since the onset of industrialization, the countryside begins to gain population and the cities begin to lose it. According to the 1980 U.S. census, cities such as St. Louis, Buffalo, and Detroit lost between 35 and 47 percent of their populations over a 30-year period. London lost almost 15 percent of the population of its inner boroughs between 1961 and 1971, and Liverpool almost 25 percent of its population in the 20-year period to 1971.

But there is a deceptive aspect to this movement. The familiar forces of industrialism, here as elsewhere, continue to dominate the process. Suburbanization and exurbanization do not mean deurbanization. On the contrary, they amount to a spreading of urban life over greater and greater areas. They are simply the filling up, at lesser but still urban densities, of larger areas and regions. From the old city develops the metropolitan area, comprising a large city of about 10 million people together with a surrounding community socially and economically dependent on it. The metropolitan areas themselves tend to merge into even larger urban agglomerations, the megalopolises, which serve populations of 40 million or more. The biggest of these is "Boswash," the chain of contiguous cities and surrounding regions that stretches from Boston to Washington, D.C., along the northeastern seaboard of the United States. Others in the United States include the Chicago–Pittsburgh area around the Great Lakes and the San Francisco–San Diego region along the California coast. There are emerging megalopolises in Britain in the region between London and the Midland cities, in Germany in the industrial basin of the Ruhr, and in Japan in the Tokyo–Osaka–Kyōto complex.

The megalopolis

The Greek architect and city planner Constantinos Apostolos Doxiadis argued that this process is part of a long-term evolution that must eventually culminate in the world-city, or "Ecumenopolis." This remarkable object will incorporate areas reserved for recreation and agriculture as well as desert and wilderness conservation areas, but essentially it will be a web of interconnected cities throughout the world, all closely linked by rapid transport and electronic communication, and all contributing to a single functional unity. In Ecumenopolis the entire land surface of the globe will have become recognizably the dwelling place of urbanized humanity.

Embedded in this process is a contradictory pattern typical of late industrial life. Subjectively, individuals wish to escape from the city. They leave the congested and declining older urban centres only to find themselves cocooned by larger urban structures in the region at large. The objective structural forces of industrialism have in no way abated. But increasingly they give rise to reactions and behaviour that have a de-modernizing character.

Thus there is reaction against large-scale bureaucratic organization. "Small is beautiful," declare the protesters as they seek to reestablish communal and craft environments characteristic of the preindustrial period. Parallel with this is a movement to promote "alternative" and "intermediate" technology, which aims to design tools that restore to the human worker the potential to use and express skill and creativity.

At the political level, too, there is reaction against large scale and centralization. In many industrial societies, such as those of Britain, France, and Canada, there have been strong regional movements demanding autonomy or outright independence. Often these are areas, such as Scotland in Britain, where at least substantial minorities wish to restore historic nations that have been incorporated into larger, more centralized states. Such movements derive momentum from the internationalization of the world economy and polity, which, over the world generally, gives rise to wholly new nationalisms as well. Lacking economic and often genuine political self-government, small societies assert their cultural identity and clamour—and sometimes fight—for autonomy. This was particularly evident in the 1990s with the dissolution of the Soviet Union, the breakup of Yugoslavia, and other nationalist movements in Africa and throughout the world. In less extreme cases, new nations may emerge, although their main symbols of independence may be no more than a national anthem and an international airport.

The rise of new nationalisms

The assertion of cultural values opposed to modernity is a general characteristic of late industrialism. This may take the form of a revival of ethnicity, a claim for a culture and way of life that often harks back to older communal traditions and which denies the legitimacy of any uniform culture propagated by the large nation-state. Thus in the United States blacks, Hispanics, American Indians, and many other groups have made strong claims on behalf of a distinctive ethnic way of life that they variously seek to defend against the encroachments of the national culture. Protests against rationality and uniformity are seen, as well, in the successive waves of youth cultures and religious revivals that have marked late industrial society. Objectively, it is clear that the large-scale bureaucratic institutions of society continue to give the main direction to national life. All revolts break against their indispensability to modern society. But subjectively these institutions are incapable of satisfying the emotional and social needs of individuals. The consequence is the repeated rise of subcultures, often of bizarre mystical or hedonistic kinds, which aim in their practice to reverse the main features of modernity and which give their members a sense of participation and belonging of an almost tribal nature. Central to most of these antinomian movements and ideologies is a wholesale rejection of the scientific worldview, which is depicted as alienating and dehumanizing.

The role of subcultures

To embark on modernization is to be caught up in a whirligig. Once started, the ceaselessly spinning motion seemingly cannot be stopped or even slowed for long. A nation that modernizes is set upon a path of development that carries its own logic and an inseparable mixture of good and bad. Without question, modern society brings progress in the form of material abundance. Less certainly, it brings increasing control of the natural and social environment. But its scientific and technological achievements are bought at some cost to spiritual and emotional life. In unifying the world, modernization establishes uniform standards, albeit higher ones in many cases than previously prevailed. At the same time, it ensures that failures and disasters will also be magnified globally. There are no retreats and escape routes, except those that modern society itself invents as pastimes. The world becomes one and its fate that of all its inhabitants.

To measure the balance of gains and losses in modernity and to increase the former against the latter require forms of social accounting and social engineering that have so far largely defied the efforts of social science and government. But in practice this does not matter. No one can wait for that problem to be solved, if it ever can be. To modernize is to take everything, the bad with the good, and not to modernize is to play no part in the life of contemporary humanity. One of the unusual, and historically unprecedented, aspects of modernization is that it leaves no choice in the matter.

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(Kr.K.)

Molière

Although the sacred and secular authorities of 17th-century France often combined against him, the comic genius of Jean-Baptiste Poquelin, known as Molière, emerged finally to win him eventual acclaim as the greatest of all French writers. Comedy had a long history before Molière, who employed most of its traditional forms, but he succeeded in inventing a new style that was based on a double vision of normal and abnormal seen in relation to each other—the comedy of the true opposed to the specious, the intelligent seen alongside the pedantic. An actor himself, Molière seems to have been incapable of visualizing any situation without animating and dramatizing it, often beyond the limits of probability; though living in an age of reason, his own good sense led him not to proselytize but rather to animate the absurd, as in such masterpieces as *Tartuffe, L'École des femmes, Le Misanthrope,* and many others. It is testimony to the freshness of his vision that the greatest comic artists working centuries later in other media, such as Charlie Chaplin, are still compared to Molière.

Beginnings in theatre. Molière was born (and died) in the heart of Paris. The registers showed that he was baptized on January 15, 1622, as Jean-Baptiste Poquelin. His mother died when he was 10 years old; his father, one of the appointed furnishers of the royal household, gave him a good education at the Collège de Clermont (the school that, as the Lycée Louis-le-Grand, was to train so many brilliant Frenchmen, including Voltaire). Although his father clearly intended him to take over his royal appointment, the young man renounced it in 1643, apparently determined to break with tradition and seek a living on the stage. That year he joined with nine others to produce and play comedy as a company under the name of the Illustre-Théâtre. His stage name, Molière, is first found in a document dated June 28, 1644. He was to give himself entirely to the theatre for 30 years and to die exhausted at the age of 51.

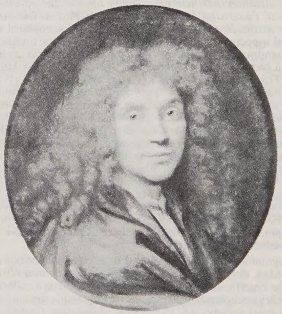
A talented actress, Madeleine Béjart, persuaded Molière to establish a theatre, but she could not keep the young company alive and solvent. In 1645 Molière was twice sent to prison for debts on the building and properties. The number of theatregoers in 17th-century Paris was small, and the city already had two established theatres, so that a continued existence must have seemed impossible to a young company. From the end of 1645, for no fewer than 13 years, the troupe sought a living touring the provinces. No history of these years is possible, though municipal registers and church records show the company emerging here and there: in Nantes in 1648, in Toulouse in 1649, and so on. They were in Lyon intermittently from the end of 1652 to the summer of 1655 and again in 1657, at Montpellier in 1654 and 1655, and at Béziers in 1656. Clearly they had their ups as well as downs. These unchronicled years must have been of crucial importance to Molière's career, forming as they did a rigorous apprenticeship to his later work as actor-manager and teaching him how to deal with authors, colleagues, audiences, and authorities. His rapid success and persistence against opposition when he finally got back to Paris is inexplicable without these years of training. His first two known plays date from this time: *L'Étourdi ou les contretemps* (*The Blunderer,* 1762), performed at Lyon in 1655, and *Le Dépit amoureux* (*The Amorous Quarrel,* 1762), performed at Béziers in 1656.

First success

The path to fame opened for him on the afternoon of October 24, 1658, when, in the guardroom of the Louvre and on an improvised stage, the company presented Corneille's *Nicomède* before the king, Louis XIV, and followed it with what Molière described as one of those little entertainments which had won him some reputation with provincial audiences. This was *Le Docteur amoureux* ("The Amorous Doctor"); whether it was in the form still extant is doubtful. It apparently was a success and secured the favour of the King's brother Philippe, duc d'Orléans. It is difficult to know the extent of the Duc's patronage, which lasted seven years, until the King himself took over the company known as "Troupe du roi." No doubt the company gained a certain celebrity and prestige, invitations to great houses, and subsidies (usually unpaid) to actors, but not much more.

From the time of his return to Paris in 1658, all the reliable facts about Molière's life have to do with his activity as author, actor, and manager. Some French biographers have done their best to read his personal life into his works, but at the cost of misconstruing what might have happened as what did happen. The truth is that there is little information except legend and satire. The fact that authors like Montaigne, Plutarch, Julius Caesar, and Seneca may have been in his library (according to a legal inventory of 1708), for example, does not mean that his plays should be read with the doctrines of such authors in mind.

Although unquestionably a great writer, Molière was not an author in the usual sense: he wrote little that could be called literature or even that was meant to be published—some poems and a translation of the ancient Latin writings of Lucretius, incomplete. His plays were made for the stage, and his early prefaces complain that he had to publish to avoid exploitation. (Two of them were in fact pirated.) He left seven of his plays unpublished, never issued any collected edition, and never (so far as is known) read proofs or took care with his text. Comedies, in his view, were made to be acted. This fact was forgotten in the 19th century. It took such 20th-century actors as Louis Jouvet, Charles Dullin, Jean-Louis Barrault, and Jean Vilar to present a new and exact sense of his dramatic genius.



"Molière," oil painting by Pierre Mignard. In the Musée Condé, Chantilly, France.

By courtesy of the Musee Conde, Chantilly, France; photograph, Giraudon—Art Resource

Nor was he at all a classical author, with leisure to plan and write as he would. Competition, the fight for existence, was the keynote of Molière's whole career. To keep his actors and his audiences was an unremitting struggle against other theatres. He won this contest almost single-handed. He held his company together by his technical competence and force of personality.

Molière's first Paris play, *Les Précieuses ridicules* (*The Affected Young Ladies*), prefigured what was to come. It centres on two provincial girls who are exposed by valets masquerading as masters in scenes that contrast, on the

one hand, the girls' desire for elegance coupled with a lack of common sense and, on the other, the valets' plain speech seasoned with cultural clichés. The girls' fatuities, which they consider the height of wit, suggest their warped view of culture in which material things are of no account. The fun at the expense of these affected people is still refreshing and must have been even more so for the first spectators.

Molière's Paris theatres

Les Précieuses, as well as *Sganarelle* (first performed in October, 1660), probably had its premiere at the Théâtre du Petit-Bourbon, a great house adjacent to the Louvre. The Petit-Bourbon was demolished (apparently without notice), and the company moved early in 1661 to a hall in the Palais-Royal, built as a theatre by Richelieu. Here it was that all Molière's "Paris" plays were staged, starting with *Dom Garcie de Navarre, ou le prince jaloux* in February 1661, a heroic comedy of which much was hoped; it failed on the stage and succeeded only in inspiring Molière to work on *Le Misanthrope*. Such failures were rare and eclipsed by successes greater than the Paris theatre had known.

Scandals and successes. The first night of *L'École des femmes* (*The School for Wives*), December 26, 1662, caused a scandal as if people suspected that here was an emergence of a comic genius that regarded nothing as sacrosanct. Some good judges have thought this to be Molière's masterpiece, as pure comedy as he ever attained. Based on Paul Scarron's version (*La Précaution inutile*, 1655) of a Spanish story, it presents a pedant, Arnolphe, who is so frightened of femininity that he decides to marry a girl entirely unacquainted with the ways of the world. The delicate portrayal in this girl of an awakening temperament, all the stronger for its absence of convention, is a marvel of comedy. Molière crowns his fantasy by showing his pedant falling in love with her, and his elephantine gropings toward lovers' talk are both his punishment and the audience's delight.

From 1662 onward the Palais-Royal theatre was shared by Italian actors, each company taking three playing days in each week. Molière also wrote plays that were privately commissioned and thus first performed elsewhere: *Les Fâcheux* (*The Impertinents*, 1732) at Vaux in August 1661; the first version of *Tartuffe* at Versailles in 1664; *Le Bourgeois Gentilhomme* at Chambord in 1670; and *Psyché* in the Tuileries Palace in 1671.

Marriage to Armande Béjart

On February 20, 1662, Molière married Armande Béjart. It is not certain whether she was Madeleine's sister, as the documents state, or her daughter, as some contemporaries suggest. There were three children of the marriage; only a daughter survived to maturity. It was not a happy marriage; flirtations of Armande are indicated in hostile pamphlets, but there is almost no reliable information.

Molière cleverly turned the outcry produced by *L'École des femmes* to the credit of the company by replying to his critics on the stage. *La Critique de L'École des femmes* in June 1663 and *L'Impromptu de Versailles* in October were both single-act discussion plays. In *La Critique* Molière allowed himself to express some principles of his new style of comedy, and in the other play he made theatre history by reproducing with astonishing realism the actual greenroom, or actors' lounge, of the company and the backchat involved in rehearsal.

The quarrel of *L'École des femmes* was itself outrun in violence and scandal by the presentation of the first version of *Tartuffe* in May 1664. The history of this great play sheds much light on the conditions in which Molière had to work and bears a quite remarkable testimony to his persistence and capacity to show fight. He had to wait five years and risk the livelihood of his actors before his reward, which proved to be the greatest success of his career. Most men would surely have given up the struggle: from the time of the first performance of what was probably the first three acts of the play as it is now known, many must have feared that the Roman Catholic Church would never allow its public performance.

Undeterred, Molière made matters worse by staging a version of *Dom Juan, ou le festin de Pierre* with a spectacular ending in which an atheist is committed to hell—but only after he had amused and scandalized the audience. *Dom Juan* was meant to be a quick money raiser, but it was a costly failure, mysteriously removed after 15 performances and never performed again or published by Molière. It is a priceless example of his art. The central character, Dom Juan, carries the aristocratic principle to its extreme by disclaiming all types of obligation, either to parents or doctors or tradesmen or God. Yet he assumes that others will fulfill their obligations to him. His servant, Sganarelle, is imagined as his opposite in every point, earthy, timorous, superstitious. These two form the perfect French counterpart to Don Quixote and Sancho.

Setbacks and harassment by the authorities

While engaged in his battles against the authorities, Molière continued to hold his company together single-handedly. He made up for lack of authors by writing more plays himself. He could never be sure either of actors or authors. In 1664 he put on the first play of Jean Racine, *La Thébaïde*, but the next year Racine transferred his second play, *Alexandre le Grand*, to a longer established theatre while Molière's actors were actually performing it. He was constantly harassed by the authorities. These setbacks may have been offset in part by the royal favour conferred upon Molière, but royal favour was capricious. Pensions were often promised and not paid. The court wanted more light plays than great works. The receipts of his theatre were uncertain and fluctuating. In his 14 years in Paris, Molière wrote 31 of the 95 plays that were presented on his stage. To meet the cumulative misfortunes of his own illness, the closing of the theatre for seven weeks upon the death of the Queen Mother, and the proscription of *Tartuffe* and *Dom Juan*, he wrote five plays in one season (1666–67). Of the five, only one, *Le Médecin malgré lui* (*The Doctor in Spite of Himself*, 1914), was a success.

In the preceding season, however, *Le Misanthrope*, almost from the start, was treated as a masterpiece by discerning playgoers, if not by the entire public. It is a drawing-room comedy, without known sources, constructed from the elements of Molière's own company. Molière himself played the role of Alceste, a fool of a new kind, with high principles and rigid standards, yet by nature a blind critic of everybody else. Alceste is in love with Célimène (played by Molière's wife, Armande), a superb comic creation, equal to any and every occasion, the incarnate spirit of society. The structure of the play is as simple as it is poetic. Alceste storms moodily through the play, finding no "honest" men to agree with him, always ready to see the mote in another's eye, blind to the beam in his own, as ignorant of his real nature as a Tartuffe.

The church nearly won its battle against Molière: it prevented public performance, both of *Tartuffe* for five years and of *Dom Juan* for the whole of Molière's life. A five-act version of *Tartuffe* was played in 1667, but once only: it was banned by the President of Police and by the Archbishop on pain of excommunication. Molière's reply was to lobby the King repeatedly, even in a military camp, and to publish a defense of his play called *Lettre sur la comédie de l'Imposteur*. He kept his company together through 1668 with *Amphitryon* (January 13), *George Dandin* (Versailles, July 18), and *L'Avare* (September 9). Sooner or later so original an author of comedy as Molière was bound to attempt a modern sketch of the ancient comic figure of the miser. The last of his three 1668 plays, *L'Avare*, is composed in prose that reads like verse; the stock situations are all recast, but the spirit is different from Molière's other works and not to everyone's taste. His miser is a living paradox, inhuman in his worship of money, all too human in his need of respect and affection. In breathtaking scenes his mania is made to suggest cruelty, pathological loneliness, even insanity. The play is too stark for those who expect laughter from comedy; Goethe started the dubious fashion of calling it tragic. Yet, as before, forces of mind and will are made to serve inhuman ends and are opposed by instinct and a very "human" nature. The basic comic suggestion is one of absurdity and incongruity rather than of gaiety.

His second play of 1668, *George Dandin*, often dismissed as a farce, may be one of Molière's greatest creations. It centres on a fool, who admits his folly while suggesting that wisdom would not help him because, if things in fact go against us, it is pointless to be wise. As it happens he

is in the right, but he can never prove it. The subject of the play is trivial, the suggestion is limitless; it sketches a new range of comedy altogether. In 1669, permission was somehow obtained, and the long run of *Tartuffe* at last began. More than 60 performances were given that year alone. The theme for this play, which brought Molière more trouble than any other, may have come to him when a local hypocrite seduced his landlady. Of the three versions of the play, only the last has survived; the first (presented in three acts played before the King in 1664) probably portrayed a pious crook so firmly established in a bourgeois household that the master promises him his daughter and disinherits his son. At the time it was common for lay directors of conscience to be placed in families to reprove and reform conduct. When this "holy" man is caught making love to his employer's wife, he recovers by masterly self-reproach and persuades the master not only to pardon him but also to urge him to see as much of his wife as possible. Molière must have seen even greater comic possibilities in this theme, for he made five acts out of it. The final version contains two seduction scenes and a shift of interest to the comic paradox in Tartuffe himself, posing as an inhuman ascetic while by nature he is an all-too-human lecher. It is difficult to think of a theme more likely to offend pious minds. Like Arnolphe in *L'École des femmes,* Tartuffe seems to have come to grief because he trusted in wit and forgot instinct.

The long run of *Tartuffe*

Last plays. The struggle over *Tartuffe* probably exhausted Molière to the point that he was unable to stave off repeated illness and supply new plays; he had, in fact, just four years more to live. Yet he produced in 1669 *Monsieur de Pourceaugnac* for the King at Chambord and in 1670 *Le Bourgeois Gentilhomme.*

Le Bourgeois Gentilhomme treated a contemporary theme—social climbing among the bourgeois, or upper middle class—but it is perhaps the least dated of all his comedies. The protagonist Jourdain, rather than being an unpleasant sycophant, is as delightful as he is fatuous, as genuine as he is naïve; his folly is embedded in a bountiful disposition, which he of course despises. This is comedy in Molière's happiest vein: the fatuity of the masculine master is offset by the common sense of wife and servant.

Continuing to write despite his illness, he produced *Psyché* and *Les Fourberies de Scapin* (*The Cheats of Scapin,* 1677) in 1671. *Les Femmes savantes* (*The Blue-Stockings,* 1927) followed in 1672; in rougher hands this subject would have been (as some have thought it) a satire on bluestockings, but Molière has imagined a sensible bourgeois who goes in fear of his masterful and learned wife. *Le Malade imaginaire* (first performed 1673; Eng. trans., *The Imaginary Invalid*), about a hypochondriac who fears death and doctors, was Molière's last play. It is a powerful play in its delineation of medical jargon and professionalism, in the fatuity of a would-be doctor with learning and no sense, in the normality of the young and sensible lovers, as opposed to the superstition, greed, and charlatanry of other characters. During the fourth performance of the play, on February 17, 1673, Molière collapsed on stage and was carried back to his house in the rue de Richelieu to die. As he had not been given the sacraments or the opportunity of formally renouncing the actor's profession, he was buried without ceremony and after sunset on February 21.

Molière's collapse on stage and death

Molière as actor and as playwright. Molière's acting had been both his disappointment and his glory. He aspired to be a tragic actor, but contemporary taste was against him. His public seemed to favour a tragic style that was pompous, with ranting and roaring, strutting and chanting. Molière had the build, the elasticity, the india-rubber face, as it has been called, of the born comedian. Offstage he was neither a great talker nor particularly merry, but he would mime and copy speech to the life. He had the tireless energy of the actor. He was always ready to make a scene out of an incident, to put himself on a stage. He gave one of his characters his own cough and another his own moods, and he made a play out of actual rehearsals. The characters of his greatest plays are like the members of his company. It was quite appropriate that he should die while playing the part of the sick man that he really was.

The actor in him influenced his writing, since he wrote (at speed) what he could most naturally act. He gave himself choleric parts, servants' parts, a henpecked husband, a foolish bourgeois, and a superstitious old man who cursed "that fellow Molière." (The comparison with Charlie Chaplin recurs constantly.) Something more than animal energy and a talent for mime was at work in him, a quality that can only be called intensity of dramatic vision. Here again actors have helped to recover an aspect of his genius that the scholars had missed, his stage violence. To take his plays as arguments in favour of reason is to miss their vitality. His sense of reason leads him to animate the absurd. His characters are imagined as excitable and excited to the point of incoherence. He sacrifices plot to drama, vivacity, a sense of life. He is a classical writer, yet he is ready to defy all rules of writing.

To think of Molière as a cool apostle of reason, sharing the views of the more rational men of his plays, is a heresy that dies hard; but careful scrutiny of the milieu in which Molière had to work makes it impossible to believe. The comedies are not sermons; such doctrine as may be extracted from them is incidental and at the opposite pole from didacticism. Ideas are expressed to please a public, not to propagate the author's view. If asked what he thought of hypocrisy or atheism, he would have marvelled at the question and evaded it with the observation that the theatre is not the place for "views." There is no documentary evidence that Molière ever tried to convey his own opinions on marriage, on the church, on hell, or on class distinctions. Strictly speaking, his views of these things are unknown. All that is known is that he worked for and in the theatre and used his amazing power of dramatic suggestion to vivify any imagined scene. If he has left a sympathetic picture of an atheist, it was not to recommend free thought: his picture of the earthy serving man is no less vivid, no less sympathetic. Scholars who have tried to make his plays prove things or to convey lessons have made little sense of his work and have been blind to its inherent fantasy and imaginative power.

The heresy of Molière as a propagandist

Since the power of Molière's writing seems to lie in its creative vigour of language, the traditional divisions of his works into comedies of manners, comedies of character, and farce are not helpful: he does not appear to have set out in any instance to write a certain kind of play. He starts from an occasion in *Le Mariage forcé* (1664; *The Forced Marriage,* 1762) from doubts about marriage expressed by Rabelais's character Panurge, and in *Le Médecin malgré lui* he starts from a medieval fable, or *fabliau,* of a woodcutter who, to avoid a beating, pretends he is a doctor. On such skeleton themes Molière animates figures or arranges discussion in which one character exposes another or the roles are first expressed and then reversed. It is intellectual rhythm rather than what happens, the discussion more than the story, that conveys the charm, so that to recount the plot may be to omit the essential.

His unique sense of the comic. The attacks on Molière gave him the chance in his responses to state some aesthetic home truths. Thus, in *La Critique de L'École des femmes,* he states that tragedy might be heroic, but comedy must hold the mirror up to nature: "You haven't achieved anything in comedy unless your portraits can be seen to be living types . . . making decent people laugh is a strange business." And as for the rules that some were anxious to impose on writers: "I wonder if the golden rule is not to give pleasure and if a successful play is not on the right track."

The attacks on *L'École des femmes* were child's play in comparison with the storm raised by *Tartuffe* and *Dom Juan.* The attacks on them also drew from the poet a valuable statement of artistic principle. On *Dom Juan* he made no public reply since it was never officially condemned. The documents in defense of *Tartuffe* are two placets, or petitions, to the King, the preface to the first edition of 1669 (all these published over Molière's own name), and the *Lettre sur la comédie de l'Imposteur* of 1667. The placets and preface are aesthetically disappointing, since Molière was forced to fight on ground chosen by

Concept of comedy

his opponents and to admit that comedy must be didactic. (There is no other evidence that Molière thought this, so it is not unfair to assume that he used the argument only when forced.) The *Lettre* is much more important. It expresses in a few pregnant lines the aesthetic basis not only of *Tartuffe* but of Molière's new concept of comedy:

> The comic is the outward and visible form that nature's bounty has attached to everything unreasonable, so that we should see, and avoid, it. To know the comic we must know the rational, of which it denotes the absence and we must see wherein the rational consists . . . incongruity is the heart of the comic . . . it follows that all lying, disguise, cheating, dissimulation, all outward show different from the reality, all contradiction in fact between actions that proceed from a single source, all this is in essence comic.

Molière seems here to put his finger on what was new in his notion of what is comic: a comedy, only incidentally funny, that is based on a constant double vision of wise and foolish, right and wrong seen together, side by side. This is his invention and his glory.

A main feature of Molière's technique is a mixing of registers, or of contexts. Characters are made to play a part, then forget it, speak out of turn, overplay their role, so that those who watch this byplay constantly have the suggestion of mixed registers. The starting point of *Le Médecin malgré lui,* the idea of beating a man to make him pretend he is a doctor, is certainly not subtle, but Molière plays with the idea, makes his woodcutter enjoy his new experience, master the jargon, and then not know what to do with it. He utters inanities about Hippocrates, is overjoyed to find a patient ignorant of Latin, so that he need not bother about meaning. He looks for the heart on the wrong side and, undeterred by having his error recognized, sweeps aside the protest with the immortal: "We have changed all that." The miser robbed of his money is pathetic, but he does not arouse emotions because his language leads him to the absurd " . . . it's all over . . . I'm dying, I'm dead, I'm buried." He demands justice with such intemperance that his language exceeds all reason and he threatens to put the courts in the court. Molière's *Misanthrope* is even more suggestive in his confusion of justice as an ideal and as a social institution: "I have justice on my side and I lose my case!" What to him is a scandal of world order is to others just proof that he is wrongheaded. Such concision does Molière's dramatic speech achieve.

A French genius. When Voltaire described Molière as "the painter of France," he suggested the range of French attitudes found in the plays, and this may explain why the French have developed a proprietary interest in a writer whom they seem to regard in a special sense as their own. They stress aspects of his work that others tend to overlook. Three of these are noteworthy.

First, formality permeates all his works. He never gives realism—life as it is—alone, but always within a pattern and a form that fuse light and movement, music and dance and speech. Modern productions that omit the interludes in his plays stray far from the original effect. Characters are grouped, scenes and even speeches are arranged, comic repartee is rounded off in defiance of realism.

Second, the French stress the poetry where foreigners see psychology. They take the plays not as studies of social mania but as patterns of fantasy that take up ideas, only to drop them when a point has been made. *Le Misanthrope* is not considered as a case study or a French *Hamlet* but as a subtly arranged chorus of voices and attitudes that convey a critique of individualism. The play charms by its successive evocations of its central theme. The tendency to speak one's mind is seen to be many things: idealistic or backbiting or rude or spiteful or just fatuous. It is in this fantasy playing on the mystery of self-centredness in society that Molière is in the eyes of his own people unsurpassed.

A third quality admired in France is his intellectual penetration in distinguishing the parts of a man from the whole man. Montaigne, the 16th-century essayist who deeply influenced Molière, divided qualities that are acquired, such as learning or politeness or skills, from those that are natural, such as humanity or animality, what might be called "human nature" without other attributes. Molière delighted in opposing his characters in this way; often in his plays a social veneer peels off, revealing a real man. Many of his dialogues start with politeness and end in open insults.

Molière opposed wit to nature in many forms. His comedy embraces things within the mind and beyond it; reason and fact seldom meet. As the beaten servant in *Amphitryon* observes: "That conflicts with common sense. But it is so, for all that." (W.G.Mo./Ed.)

MAJOR WORKS

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Mollusks

The phylum Mollusca (mollusks) is one of the most numerous groups in the animal kingdom after the insects and vertebrates. Each class includes an ecologically and structurally immense variety of forms (Figure 1): the shell-less Caudofoveata; the narrow-footed gliders (Solenogastres); the serially valved chitons (Placophora or Polyplacophora); the cap-shaped neopilinids (Tryblidia); the limpets, snails, and slugs (Gastropoda); the clams, mussels, scallops, oysters, and cockles (Bivalvia); the tubiform to barrel-shaped tusk shells (Scaphopoda); and the nautiluses, cuttlefishes, squids, and octopuses (Cephalopoda).

In this article the biology and classification of mollusks are first considered in general terms; more detailed information on the three major classes (Gastropoda, Bivalvia, and Cephalopoda) follows.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, section 313, and the *Index*.

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MOLLUSKS: THE PHYLUM MOLLUSCA

GENERAL FEATURES

Size range and diversity of structure. The range in size and structure is an adaptation to the environment. Typical molluscan features may be altered, or even lost, depending on the subgroup. Among the cephalopods the giant squids (*Architeuthis*), the largest living invertebrates, attain a body length of eight metres (more than 26 feet); with the tentacle arms extended, the total length reaches to 22 metres. Other cephalopods exceed a length of one metre. Many of the remaining molluscan classes show a large variation in size: among bivalves the giant clam (*Tridacna*) ranges up to 135 centimetres (four feet) and the pen shell (*Pinna*) from 40 to 80 centimetres; among gastropods the sea hares (*Aplysia*) grow from 40 to 100 centimetres and the Australian trumpet, or baler (*Syrinx*), up to 60 centimetres; among placophores the gumshoe, or gumboot chiton (*Cryptochiton*), achieves a length up to 30 to 43 centimetres; and, among solenogasters, *Epimenia* reaches a length of 15 to 30 centimetres. Finally, gastropods of the family Entoconchidae, which are parasitic in echinoderm sea cucumbers, may reach a size of almost 1.3 metres. In contrast, there are minute members, less than one millimetre (0.04 inch) in size, among the solenogasters and gastropods.

Adaptations

Distribution and abundance. The mollusks have adapted to all habitats except air. Although basically marine, bivalves and gastropods include freshwater species. Gastropods have also adapted to land, where the almost 17,500 species occupy most existing niches. Found on rocky, sandy, and muddy bottoms or substrates, mollusks burrow, become cemented to the surface, or are free-swimming.

Mollusks are of worldwide distribution, but there is a preponderance of some groups in certain areas of the world. The close association of many molluscan groups with their food source—whether by direct dependence on a specific food supply (*e.g.*, plant-eating, or herbivores) or by involvement in food chains—limits their geographic distribution; for example, bivalves of the family Teredinidae (shipworms) are associated with driftwood. In general, cold-water regions support fewer species.

Importance to humans. Mollusks are of general importance within food chains and as members of ecosystems. Certain species are of direct or indirect commercial and even medical importance to humans. Most bivalves contribute to the organic turnover in the intertidal (littoral) zones of marine and fresh water because, as filter feeders, they filter up to 40 litres (10 gallons) of water per hour. This filtering activity, however, may also seriously interfere with the various populations of invertebrate larvae (plankton) found suspended and free-swimming in the water.

Conchifera (a subphylum including the tryblids, gastropods, scaphopods, bivalves, and cephalopods) are a source of food for many cultures and therefore play an important role in the fishing industries of many countries. Conchifera also are used in the fabrication of ornaments and in pearl and mother-of-pearl industries.

NATURAL HISTORY

Reproduction and life cycles. Mollusks are primarily of separate sexes, and the reproductive organs (gonads) are simple. Reproduction via an unfertilized gamete (parthenogenesis) is also found among gastropods of the subclass Prosobranchia. Most reproduction is by sexual means: eggs and sperm are released into the water, where fertilization takes place; in prosobranch gastropods, water currents may cause a simple internal fertilization within the mantle cavity. Both male and female reproductive organs may be present in one individual (hermaphroditism) in some classes, and various groups exhibit different adaptations to this body form. For example, in bivalves and prosobranch gastropods, male and female gonads are functional at separate times and in rhythmic and consecutive patterns (successive hermaphroditism). Conversely, male and female gonads are functional at the same time

Methods of reproduction

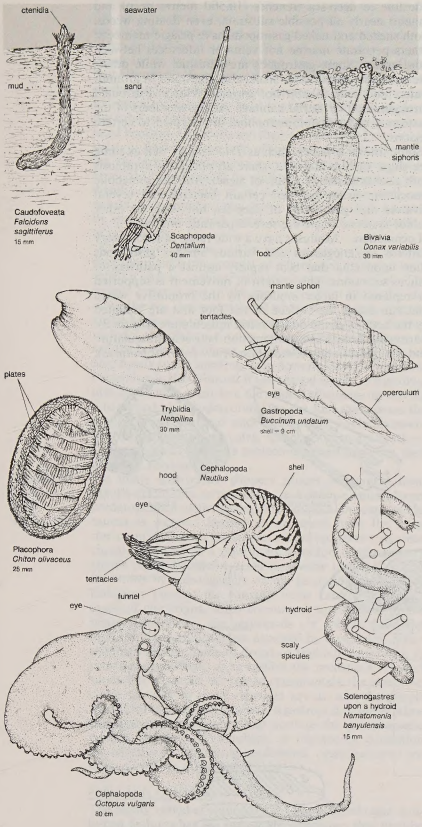


Figure 1: Body plans of mollusks.
From (*Falcidens, Nematomenia*) L.v. Salvini-Plawen in *Die Neue Brehm: Bucherei* (1971), A. Ziemsen Verlag, Wittenberg; (*Dentalium, Nautilus*) T.I. Storer and R.L. Usinger, *General Zoology* (1965), McGraw-Hill, New York; (*Donax*) R. Barnes, *Invertebrate Zoology* (1974), W.B. Saunders, Philadelphia; (*Chiton*) L.v. Salvini-Plawen in K.M. Wilbur (ed.), *The Mollusca*, vol 10 (1985), Academic Press, London; (*Buccinum*) adapted from K.-J. Gotting, *Malakozoologie* (1974), G. Fischer Verlag, Stuttgart; (*Octopus*) L.v. Salvini-Plawen in R. Reid (ed.), *Fauna und Flora des Mittelmeeres* (1983), Paul Parey Scientific Publishers, Hamburg and Berlin

(simultaneous hermaphroditism) in solenogasters and the gastropod subclass Euthyneura.

Fertilization by transfer of capsules containing sperm (spermatophores) typically occurs in cephalopods and some gastropods. In cephalopods, transfer of spermatophores is usually combined with copulation by a modified arm, or hectocotylus. Copulation in solenogasters, often by means of a special genital cone, may be supported by copulatory stylets. Various penis formations, in part with copulatory stylets, or darts, are widely found in gastropods.

Eggs are laid singly, in heaps, or as spawn, generally on some hard surface and often within capsules. Squids of the suborder Oegopsida and some gastropods have eggs that are suspended in the water. Fertilized eggs commonly undergo spiral cleavage. The eggs of cephalopods, on the other hand, possess a large amount of yolk, which displaces the dividing cells and causes a characteristic type of development.

Larvae (Figure 2) are originally free-swimming and lecithotrophic. The resulting larva in primitive forms is a pericalymma (test cell) larva in which the embryo is protected below a covering (test) of cells provided with one to four girdles of cilia, at the apex of which is a sensory plate of ciliated cells. After the developing juvenile has grown out apically of the test (which then is lost), the animal settles and develops into an adult. The test in other lecithotrophic larvae is restricted to a preoral girdle of ciliated cells (the prototrochus) and is called the pseudotrochophore larva. In more advanced mollusks the pseudotrochophore larva develops into a veliger larva (in marine gastropods) or into a rotiger larva (in bivalves). In these planktotrophic larvae, the girdle of ciliated cells widens to form a velum that entraps food. As the larva continues to develop, the shell, mantle cavity, and foot begin to appear; in case of planktotrophy, a characteristic larval shell interconnects the embryonic and adult shells. After a specific amount of time, the larva metamorphoses into an adult.

Development

Secondary (newly evolved) larvae are developed among freshwater bivalves and in some cephalopods. Maternal protection of the developing eggs (brood) is not unexceptional behaviour in solenogasters, bivalves, and certain gastropod adults. Direct development without a larval stage or the bearing of live young from a yolky egg, or both, are typical in cephalopods and most nonmarine gastropods. Many species go through two breeding seasons per year, whereas in cephalopods mating or egg laying appears to be rapidly followed by death effected by hormones.

Habitats, feeding habits, and associations. Caudofoveates burrow in muddy sediments at depths of 10 to more than 7,000 metres (33 to 23,000 feet) and consume microorganisms and loose organic material (detritus). In contrast, solenogasters prey on some members of the class Cnidaria (*e.g.,* hydroids and corals) in five to 6,850 metres of water, on clay or muddy sand, or directly upon hydroid or coral colonies. Placophores cling to hard bottoms of the intertidal zone, scraping algae from the rock surfaces by using their strong rasping teeth (radula); several members of the placophore family Lepidopleuridae

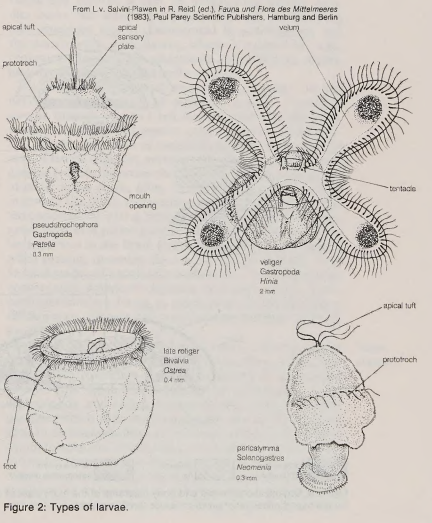


Figure 2: Types of larvae.

consume detritus found at depths down to 7,000 metres, and Hanleyidae as well as Hopaliidae even depend on animal food. The few extant members of the class Tryblidia inhabit secondary hard bottoms at depths of 175 to 6,500 metres and capture detritus by means of head appendages (velum) around the mouth. The scaphopods dwell in sand or sandy mud down to 7,000 metres and nourish themselves on protozoa, crustaceans, or small mollusks captured by the filamentous head tentacles (captacula). Except for the carnivorous septibranch anomalodermata, all bivalves are ciliary suspension feeders, using food-sorting organs near the mouth (labial palps) and respiratory gills modified to assist in feeding (ctenidia). Found in marine and fresh water, bivalves burrow into sediments to depths of 10,700 metres or attach themselves to hard surfaces by means of tough threads secreted by the byssus gland in the foot. Cephalopods are generally carnivores, feeding on crustaceans and fishes, but some have adapted a microvorous diet of detritus and microscopic organisms and plants. Some cephalopods are offshore (pelagic) jet swimmers, moving from the surface to depths of 5,400 metres, while others dwell near the bottom (benthic) at depths of 8,100 metres.

Gastropod diversity

The greatest ecological diversity is shown by the gastropods. The marine members are found from the springtide line to deep-sea trenches (10,500 metres deep) and inhabit nearly all possible substrata, even floating weeds. Both shelled and naked gastropods have pelagic members; others penetrate marine hot vents or interstices between sand grains. Some gastropods are parasitic, while others are predatory. Freshwater snails also are found in groundwaters and may inhabit hot springs. Widely distributed throughout all terrestrial habitats, various members of the gastropod order Stylommatophora are adapted to certain regions.

Some littoral bivalves, such as *Tridacna*, as well as some sea slugs, such as *Aeolidia*, share an obligatory symbiosis with zooxanthellae (a group of algae). Another metabolic association exists between certain bacteria and several bivalves and gastropods of deep-sea hot vents or other sulfide systems. There are several parasitic mollusks.

Locomotion. Mollusks have a wide range of locomotory patterns. Solenogasters and various smaller gastropods glide upon cilia that beat rapidly against a pathway of mucus secretions. This pattern of movement is supported or replaced in larger mollusks by the propulsive waves that run along the surface of the foot and are initiated by the actions of the dorsoventral musculature (Figure 3). Burrowing occurs as an interaction between musculature and the hydrostatic skeleton (see below *Internal features*);

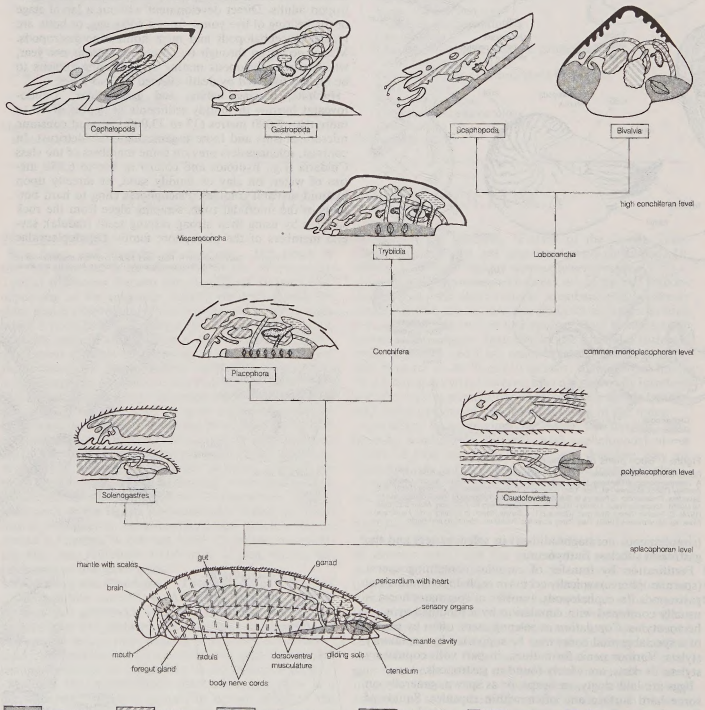


Figure 3: Organizational levels and body diagrams of the eight classes of mollusks evolved from a hypothetical generalized ancestor (archi-mollusk).

it is performed in caudofoveates and several sea slugs by the whole anterior body but is restricted to the foot in scaphopods, bivalves, and some specialized gastropods.

Various bivalves (*e.g.,* cockles) and snails may perform rapid twists or jumps through violent flexion of the foot. Buoyancy floating and jet propulsion are found in cephalopods; floating is also known in gastropods, and swimming of a different kind is practiced in gastropods of the subclass Opisthobranchia as well as in scallops and related bivalves. Octopods use their arms to crawl or even to swim or float with the help of the body skin interconnecting the arms (interbrachiate web). Some bivalve groups bore into hard surfaces by secreting strong chemicals that dissolve the substrate or by drilling, using the shell and radula. A sedentary (sessile) way of life has been adopted by many bivalves and some wormlike internal parasites of gastropods.

Features of defense. The external cover that extends over the mantle may consist of a hardened epithelial layer called a cuticle, separate calcareous plates, or a shell. The mantle cover is one of the most important protective devices, the key characteristics of which were already present at the beginning of molluscan evolution. Another defense includes the ability of most solenogasters and chitons to roll the body up. Chitons, neopilinids, and limpets can adhere firmly to the substrate by a powerful suction pad foot. Protection is also afforded if the animal is able to withdraw into its shell; a snail has the added advantage of having a hardened plate (operculum) on the foot that covers the shell opening (auricle) once the animal has withdrawn. Burrowing by caudofoveates, scaphopods, many bivalves, and some gastropods is a protective behaviour when used to escape predators.

Chemicals, poisons, and camouflage

In many gastropods, slippery mucus is secreted from mantle extensions, or parapodia, as a defense against larger predators, such as the echinoderm starfish. In scaphopods, mucus is secreted against an aggressor from the anterior mantle. Certain molluscan subgroups secrete noxious chemicals either as a poisonous secretion of the salivary glands or as distasteful acids in mantle cells. Glandular secretions by solenogasters or the gastropod superfamily Eolidacea prevent the stinging nettle capsules (nematocysts) of cnidarians, when consumed, from expulsing the stingers; moreover, the gastropods are able to store and then use the capsules when attacked by a predator. Some mollusks secrete fluids to divert or frighten a predator, to provide camouflage, or to inhibit the predator's sense of smell. For example, the ink in cephalopods, the luminous cloud secreted by some deep-sea squids, and the purple fluid from the sea hare (*Aplysia:* a gastropod of the subclass Opisthobranchia) distract and confuse the predator and conceal the prey. Camouflage or frightening coloration are effective in protecting cuttlefishes, octopuses, and sea slugs, as well as other gastropods.

FORM AND FUNCTION

The highly varied evolutionary development of basic molluscan features has left only a few characters that may be taken as typical. As a result, molluscan form varies much among levels and subgroups (Figure 3).

External features. The most obvious external molluscan features are the dorsal epidermis called the mantle (or pallium), the foot, the head (except in bivalves), and the mantle cavity. The mantle in caudofoveates and solenogasters is covered by cuticle that contains scales or minute, spinelike, hard bodies (spicules), or both (aplacophoran level). The placophores develop a series of eight plates or valves still surrounded by a girdle of cuticle with spicules; in all other mollusks (the Conchifera), the mantle secretes an initially homogeneous shell (monoplacophoran level). The mantle and shell are laterally compressed in scaphopods and bivalves; in gastropods and cephalopods the head is free of the mantle and shell. In bivalves a dorsal hinge ligament joins two valves, which are further held together by two adductor muscles with attachment points on the inner aspect of each valve.

The body

The body of the mollusk, containing all the visceral elements, such as the alimentary tract, gonads, and heart, is connected to the mantle by dorsoventral musculature. The head, when present, has tentacles called captacula in scaphopods, labial palps in bivalves, head tentacles in gastropods, and arms in cephalopods. The primitive ciliary gliding surface with forward pedal and sole glands is reduced in caudofoveats and some gastropods, as well as in some bivalves, and it is narrowed to a ridged tract in solenogasters as well as some members of the placophore genus *Cryptoplax.* The foot forms an anteriorly elongated and slendered burrowing organ in scaphopods, is ax-shaped to vermiform in bivalves, and is modified to a siphon or funnel in cephalopods. Among gastropods of the subclass opisthobranchia the foot may be extended laterally to form swimming lobes (parapodia).

The mantle, or pallial, cavity is found between the mantle rim and the body. The pallial complex is a collection of structures at the roof of the mantle cavity and typically contains at least one pair of lamellate gills (ctenidia), a thick layer of glandular epithelium called mucus tracts or hypobranchial glands, and the outlets for the digestive, excretory, and reproductive systems. A loss of the ctenidia (along with the mucus tracts) is seen in scaphopods, advanced gastropods, septibranch bivalves, and solenogasters. Placophores, tryblids, nautilid cephalopods, and some gastropods have a multiple number of ctenidia.

Internal features. *Muscles and tissues.* The internal molluscan organization is almost entirely soft-bodied. The body cavity is filled with fibrous tissue or fluid-filled spaces (hemocoel), or both. The tissues, hemocoel, and body wall act as a hydrostatic skeleton for shape and support; when filled with fluid, the hemocoel expands against the body wall and fibrous tissues, providing a rigid framework. This same framework provides a structure against which the animal can exert internal pressure when protruding the foot from the shell during burrowing. Conversely, extrusion of the head and foot from the shell in the supraclass Visceroconcha (gastropods and cephalopods), shell elevation in gastropods, and the rapid expansion and contraction of the mantle required for jet propulsion in cephalopods of the subclass Coleoidea are the result of a more complicated system carried out by the antagonistic actions of muscles working in opposition to other muscles.

Hydrostatic skeleton

The basic sets of muscle systems, fully retained only in solenogasters, include the subintegumental musculature below the mantle; a pair of longitudinal muscle bundles below the mantle margins, which roll the body up and which are almost disintegrated in conchiferans; and the dorsoventral musculature, which is reduced in caudofoveates and shell-less gastropods and which in shelled gastropods forms the columellar muscles.

The nervous system and organs of sensation. In the nervous system typical of mollusks, a pair of cerebral ganglia (masses of nerve cell bodies) innervate the head, mouth, and associated sense organs. From the dorsal cerebral ganglia, two pairs of longitudinal nerve cords arise: a pair of lateral (pleural) nerve cords, often forming pleural ganglia (which innervate the mantle), and a ventral pair of pedal nerve cords, often forming pedal ganglia (which innervate the foot). In primitive forms both cords are interconnected by lateral branches of nerve fibres. A buccal nerve loop with paired ganglia generally supplies the radular apparatus in the head. Posterior paired visceral ganglia, when present, innervate the viscera. Other mollusks have various grades of ganglia formations, all of which may be concentrated anteriorly. Because of torsion, special nerve configurations are found in gastropods; in cephalopods a cartilaginous capsule encloses the concentrated mass of ganglia.

Sense organs

Supplied by the most posterior aspect of the lateral nerve cords, a paired chemoreceptive sense organ (the osphradium) monitors the water currents of the mantle cavity. This organ has regressed in scaphopods, some cephalopods, and higher gastropods. Pluricellular mantle papillae, which penetrate the cuticle, the valves, and the shell in some conchifers, are differentiated in placophores as photoreceptors. Aside from the cerebral eyes in Visceroconcha, there are photoreceptors on the mantle margins of autobranch bivalves. Orientation in different gastropods is evidenced by reaction to polarized light, which in part serves for homing. Homing in other gastropods and in the

placophores that flee from light appears to be performed by chemoreception along their mucus trails.

The digestive system. The primitive alimentary tract is straight, and the foregut contains glands and chitinized teeth, called the radula, upon a tough membrane or ribbon underlain by a mass of compact tissue as a support and operated by musculature. In bivalves and some other mollusks the whole radular apparatus is reduced. The radula is used to bite, tear, and scrape various food materials. The different structural aspects of the radula in caudofoveates, solenogasters, and gastropods serve in classification. The differentiation of a more flexible radular structure, called the flexoglossate type, among the primitive subclass Archaeogastropoda subsequently enabled successful radiation into diverse habitats. Jaw formation is characteristic for conchifers.

The midgut and digestion

The midgut in caudofoveates divides into a hindgut and a large ventral sac for enzyme production. In contrast, the midgut in placophores and conchifers is subdivided into a slender esophagus with a pair of glandular pouches, a distinct stomach with a pair of digestive glands, and a slender, often looped intestine. In primitive conchifers the stomach is of the so-called style sac type. The esophagus opens into an anterior elaboration of the stomach into which the enzymes from the style sac, an area separated by ridges, also are released; the tapered end of the stomach leads to the intestine. Cilia that line the style sac churn the stomach contents and form a long food-laden mucous mass called a protostyle, which abuts a chitinous area of epithelium in the stomach. Usually found within the style sac is a rod, called the crystalline style. The protostyle or the crystalline style are fully retained in the bivalves and gastropods that subsist on small microorganisms and detritus. The protostyle or crystalline style may vary in form among the bivalves. Digestion in primitive forms appears to have been both intracellular and extracellular, such as is still the case in solenogasters, many bivalves, and most gastropods. In advanced levels either intracellular or extracellular digestion appears to be exclusively elaborated—*e.g.*, advanced crystalline style and intracellular.

Open circulatory system

The circulatory system. Mollusks possess an open circulatory system in which body fluid (hemolymph) is transported largely within sinuses devoid of distinct epithelial walls. The posteriodorsal heart enclosed in a pericardium typically consists of a ventricle and two posterior auricles. Hemolymph is drained from ctenidia, gills, or other specialized respiratory epithelia into the respective auricles. The ventricle pumps the hemolymph through a middorsal sinus (in solenogasters and scaphopods) or vessel (aorta) into the body tissues. Hemolymph drains from the tissues into the gills, whence it returns to the auricles.

The respiratory pigment is commonly dissolved in the fluid, either as hemoglobin (as is especially the case in bivalves) or more generally as hemocyanin; in more-advanced forms, hemoglobin is bound to blood cells. In placophores and conchifers (but not in the caudofoveates and the solenogasters) the heart is also the site of the purifying ultrafiltration, and the waste products are then discharged into the pericardium and via a pair of pericardial outlets modified to excretory organs (emunctoria, such as false kidneys or nephridia).

The reproductive system. In adult cephalopods and some other representatives the paired dorsal gonad retains the developmental connection with the pericardium. In caudofoveates and solenogasters, eggs or sperm are discharged into the pericardial cavity, and from there the pericardial outlets transport them to the environment, where fertilization takes place. In more-advanced mollusks there are usually separate ducts to transport the gametes (gonoducts): a pair of gonoducts, called oviducts for the female gametes and spermiducts, or vasa deferentia, for the male gametes, leads the egg and sperm, respectively, to the mantle cavity. Glands to secrete protective coatings around the egg may be present. In gastropods the left gonad is reduced, and after torsion only the right gonad is operational, leaving the internal body asymmetrical; similar asymmetries also may be found in other molluscan subgroups.

Hormones

The endocrine system. Hormone production is not well documented in mollusks other than gastropods and cephalopods. Antagonistic neurohormonal control of reproductive activity and metabolic processes is performed in the gastropods through cerebral dorsal bodies and lateral lobes or juxtaposed organs and in the cephalopods through optic glands. In cephalopods, the hormones also effect death by starvation after the mollusk has deposited its eggs or has mated. Neurosecretions by cells outside the nerve cell bodies (ganglia) have been described in gastropods and cephalopods, the released hormones diffusing through the tissues rather than being concentrated in special organs.

Heart rate in mollusks plays a crucial role in many metabolic processes, including excretion; hormones that affect the heart are released from the wall of veins in cephalopods or, in gastropods, from the subesophageal ganglia, the junction between the auricles and the ventricle. Insulin-like hormones shed from gastropods and bivalves by certain midgut cells control the amount of glucogen (a storage form of sugar) kept as a reserve nutrient.

EVOLUTION AND PALEONTOLOGY

There are no known fossil records of caudofoveates and solenogasters. Both placophores and conchifers date from the earliest Cambrian time (some 570 to 550 million years ago). These records exclude the scaphopods and cephalopods but include the extinct Merismoconchia, Helcionellida, and Rostroconchia. Most of these fossils represent fairly small organisms of about one to five millimetres (0.04 to 0.2 inch), which metabolically parallel the primitive lecithotrophic, rather than planktotrophic, larval development. The oldest known cephalopods are of the Late Cambrian epoch (which ended some 505 million years ago) and subsequently had a remarkable radiation, including the dominant Ammonites (predominantly spirally coiled cephalopods with complicated sutures between chambers and shell—some 10,000 fossil forms—until the Cretaceous (about 100 million years ago). Extinct bivalves (about 15,000 forms) exceed in number the recent fauna. Scaphopods have not been recorded before the Middle Ordovician (some 450 million years ago).

The fossil record gives little clue as to how the mollusks originated and how the eight classes differentiated in Precambrian times. The evolutionary pathway must thus be largely inferred from comparative anatomy and development. The common archimolluscan base, in spite of the large number of fossils of the ancestors of gastropods and bivalves, was probably of shell-less (aplacophoran) organization; that in turn appears to have been differentiated from some flatwormlike organization that adapted the mantle cover rather than from a coelomate segmented construction. Most obvious is the subsequent elaboration of the mantle cover defining the aplacophoran, the placophoran, and (by fusion) the conchiferan (monoplacophoran) level of organization. The realization that the organization of the mantle and mantle cavity in caudofoveates and solenogasters reflects two separate evolutionary lines also discloses conservative molluscan characters. The solenogasters appear to be linked by developmental characters with the placophores; they have retained, however, the most primitive alimentary tract (in that the radular membrane is poorly elaborated, and no midgut gland is separated). The latter was reorganized at the placophore level and overtaken in the conchifers. The subradular organ, the arrangement of the dorsoventral musculature, the three-layered shell structure with enclosed mantle papillae, and the excretory system also demonstrate the placophore heritage in the tryblids, which are the more primitive of the conchifera. Subsequently this radiated into two branches called subclades: the supraclass Loboconcha (or Diasoma), including the suspension-feeding bivalves, and the infaunal scaphopods, sharing a common ancestor in the fossil class Rostroconchia. These groups have a mantle with the shell enlarged in width to envelop the soft body as well as an anterior elongated foot to live on the bottoms of mobile particles (sand, mud). In contrast, a free head with cerebral eyes is set off from the mantle and shell in the supraclass Visceroconcha, including the gastropods and the cephalopods; both share a posterior mantle cavity,

lateral (or pleural) nerve cords medial to the dorsoventral musculature, and an antagonistic muscle system (see above *Internal features: Muscles and tissues*). The relation of the fossil order Bellerophontacea is controversial.

CLASSIFICATION

This classification is a consensus of recent views mainly of Luitfried v. Salvini-Plawen and Gerhard Haszprunar, generally based on those of Kenneth J. Boss.

Annotated classification.

PHYLUM MOLLUSCA

Unsegmented, soft-bodied metazoans with mantle (or pallium) covered by cuticular or calcareous secretions, or both; ventral body with head region; and ciliar to muscular locomotion organ; lamellate gills (ctenidia); paired chemoreceptive sense organ (osphridia); nervous system tetraneurous with cerebral ganglia, buccal loop, and 2 pairs of longitudinal body cords, though often concentrated; pronounced dorsoventral musculature; pharyngeal teeth (radula); hemocoelic body cavity with coelomatic pericardium and gonosacs; originally the sexes are separate; development includes spiral cleavage and a primitively lecithotrophic trochus larva; about 50,000 marine, limnic, and terrestrial species.

Class Caudofoveata (Aplacophora partim, or **Chaetodermatida;** mudmoles)

Worm-shaped; covered by cuticle and aragonitic scales; ventral gliding area reduced; mantle cavity terminal with 1 pair of ctenidia; midgut with ventrally separated sac; adapted to burrowing habits in mud; marine in 10–7,000 m; 2 mm to 14 cm; about 100 species in 3 families.

Class Solenogastres (Aplacophora partim, **Ventroplicida,** or **Neomeniidea;** narrow-footed gliders)

Narrowed body and gliding sole (foot); mantle with cuticle and aragonitic scales or spicules, or both; mantle cavity modified; no true ctenidia; radular membrane rudimentary; midgut straight without separate glands; hermaphroditic; epibenthic predators of or epizoic on Cnidaria; marine in 5–6,850 m; 0.8 mm to 30 cm; about 200 species in 4 orders.

Class Placophora (Polyplacophora or **Loricata;** chitons)

Generally flattened body and broad foot; mantle covered with cuticle and spicules; 8 middorsal serial shell plates (valves) enclosing photoreceptive papillae (aesthetes); mantle cavity peripedal with multiple pairs of ctenidia; marine; mainly algae-scraping on hard bottoms in 0–7,000 m; 3 mm to 43 cm; about 600 species in 3 orders.

Class Tryblidia (Monoplacophora or **Galeroconcha** partim; neopilinids)

Cap-shaped shell; head with 2 pairs of appendages; mantle cavity peripedal with 5–6 pairs of modified ctenidia; 5–6 pairs of excretory organs; 2 pairs of heart auricles and gonads; marine detritus feeders in 175–6,500 m; 1.5 to 37 mm; 12–15 species in 1 family.

Class Bivalvia (Pelecypoda, Acephala, or **Lamellibranchiata;** clams, mussels, oysters, scallops, and cockles)

Laterally compressed body; 2 middorsally hinged valves; posterior mantle often extended to form siphons; head with labial palps, foot ax-shaped to vermiform; peripedal mantle cavity with 1 pair of ctenidia mostly modified to large plates of lamellae; buccal mass (jaws and radula) reduced; predominantly ciliary suspension feeders burrowing in soft sediments or attached by byssus gland of foot on hard substrata in 0–10,700 m; 1 mm to 1.35 m; 3 subclasses: Ctenidiobranchia (Nuculida), Palaeobranchia (Solemyida), Autobranchia (lamellibranch and septibranch bivalves); about 6,000 marine and 2,000 limnic species.

Class Scaphopoda (Solenoconcha; tusk shells)

Midventrally fused mantle and tubiform to barrel-shaped shell; head with tubular snout and 2 bunches of slender tentacles (captacula); foot pointed and cylindrical; no ctenidia and distinct blood vessels; no heart auricles; radula strong; microcarnivores; marine burrowers in soft sediments, in 0–7,000 m; 2 to 150 mm; about 350 species in 2 orders.

Class Gastropoda (limpets, snails, and slugs)

Mantle cavity undergoes torsion and often secondarily "detorsion"; shell mostly coiled with operculum; head free with paired eyes; left reproductive organs reduced; immense ecological and structural variability; 0.3 mm to more than 1 m; about 40,000 marine, limnic, and terrestrial species.

Subclass Streptoneura

Mostly marine limpets or operculate snails; 3 ganglia at visceral loop; orders include Archaeogastropoda (long cerebropleural connectives) and Apogastropoda (bifurcate tentacle nerves, 2 pedal commissures).

Subclass Euthyneura

Marine, limnic, or terrestrial snails and slugs without operculum; visceral loop with additional parietal ganglia; hermaphroditic; supraorders include Opisthobranchia (marine with Hancock's organs or derivates) and Aeropneusta (mostly limnic and terrestrial with procerebrum/cerebral glands) with orders Gymnomorpha and Pulmonata.

Class Cephalopoda (Siphonopoda; nautiluses, cuttlefishes, squids, and octopuses)

Dorsoventrally elongated body; shell straight, coiled, or almost highly regressive, originally chambered and piercing by a siphuncular tube; head free with paired eyes and 1 or 2 circles of 8–10, or about 90, tentacles (perioral arms); foot modified as a funnel for jet locomotion; mantle cavity restricted to posterior body with 2 ctenidia; alimentary tract with strong jaws and predominantly with a rectal ink sac; nervous system extremely concentrated; about 600 recent species (some 10,000 fossil forms) of 1 cm to 8 m (+14 m arms) in size; basically pelagic marine carnivores from the surface to 5,400 m depth or benthic to 8,100 m; 4 subclasses are Palcephalopoda (Orthoceroida; fossils); Nautiloida (fossil groups and 3–5 recent species); Ammonoida (fossils); and Coleoida (fossils and 4 recent orders).

Critical appraisal. The long-standing classification of Caudofoveata and Solenogastres within one class (Aplacophora) is not tenable. The configuration of the mantle cavity in each group clearly contradicts the derivation of one from the other, and neither possesses a single commonly derived character that would demonstrate closer relationship other than in an archimolluscan ancestry. A similar condition refers to the bivalve subclasses Ctenidiobranchia and Archaeobranchia, often united below one single taxon (Protobranchia).

The term Amphineura, formerly comprising the Polyplacophora (placophores) and Aplacophora (caudofoveates and solenogasters) within one subphylum (side by side with the subphylum Conchifera), is misleading and out-of-date; it may be replaced by the more appropriate term Aculifera.

The term Monoplacophora is not used here because evolutionarily it equalizes the conchiferan level (in contrast to the polyplacophore and aplacophore levels), and classificatorily it is a junior synonym of Tryblidiacea. Moreover, as is the taxon Galeroconcha, it is in part also taken to include several fossil groups (*e.g.,* Bellerophontacea) of still uncertain relationships.

The familiar three divisions of the Gastropoda into Prosobranchia, Opisthobranchia, and Pulmonata is no more satisfying and, according to the nervous system, is generally replaced by Streptonra and Euthyneura.

The popular term Cephalopoda ("head-footed" mollusks) is a misnomer scientifically since the innervation evidences the siphon, or funnel, with its pedal–funnel gland (rather than the perioral arms) as the equivalent of the foot. Siphonopoda is often preferred. (L.v.S.-P.)

MAJOR MOLLUSK GROUPS

Gastropods (snails and slugs)

Gastropod, which means "belly-footed," refers to the broad tapered foot on which these animals glide. The class comprises the snails, which have a shell into which the animal can withdraw, and the slugs—snails whose shells have been reduced to an internal fragment or completely lost in the course of evolution. Gastropods are among the few groups of animals to have successfully radiated in the ocean, fresh waters, and on land. Because of the challenges presented by these diverse habitats, gastropods are very difficult to characterize. A few are used as food, a very few transmit animal diseases (only a fraction of these have been found to carry the agents of human and animal disease), and the shells of some are used as ornaments or in making jewelry. The main role of gastropods is as scavengers, feeding on dead plant or animal matter, or as predators.

GENERAL FEATURES

Size range and diversity of structure. Some adult marine snails (*Homalogyra*) and forest-litter snails (*Stenopylis, Punctum*) are less than one millimetre (0.04 inch) in diameter. At the other extreme, the largest land snail, the African *Achatina achatina,* is almost 20 centimetres (eight inches) long. The largest freshwater snails, *Pomacea* from South America, reach nearly 10 centimetres in diameter, and the largest marine snail, the Australian *Syrinx aruanus,* occasionally grows to more than 0.6 metre (two feet). The longest snail probably is *Parenteroxenos doglieli,* which lives as a parasite in the body cavity of a sea cucumber; it grows to be almost 130 centimetres (50 inches) in length, although it is only 0.5 centimetre (0.2 inch) in diameter. Most snails are much smaller, and probably 90 percent of all adult snails are less than one inch in maximum dimension.

Variations in shape

Snails show a tremendous variety of shapes, based primarily upon the logarithmic spiral (Figure 4). They can be coiled flatly in one plane, as in *Planorbis;* become globose with the whorls increasing rapidly in size, as in *Pomacea;* have the whorls become elongate and rapidly larger, as in *Conus* and *Scaphella;* have a few flatly coiled whorls that massively increase in width, as in *Haliotis;* become elongated spike-shaped, as in *Turritella;* or adopt a limpet shape, as in *Fissurella.* Often a number of such shapes can be found within a single family, but such marine families as the Terebridae, Conidae, and Cypraeidae are conservative in shape.

Traditionally, the three main gastropod groups are the prosobranchs, the opisthobranchs, and the pulmonates. The prosobranchs generally secrete a massive shell into which the animal can withdraw. The operculum, an often calcified disk situated on the rear part of the foot, fills the shell aperture when the snail is inside the shell, protecting the animal against predation and dessication. The body structure shows relatively minor variations. The opisthobranchs are marine species that often have a reduced or absent shell and very colourful bodies. The pulmonates are snails and slugs that lack an operculum but show complex and highly varied body structures. They have a "lung" or pulmonary cavity that serves also as a water reservoir. It long has been recognized that these groups probably represent similar morphology derived independently several times in the more than 400 million years since the origin of the gastropods.

Distribution and abundance. Of the probable 65,000 species, 30,000 are marine, 5,000 live in fresh water, and 30,000 live on land. In general, oceanic gastropods are most diverse in number of species and in structure in tropical areas; several hundred species (most of which are comparatively rare) can be found in a complex coral reef habitat. This is in contrast with Arctic or subarctic coasts, where the few species that are present are common. A

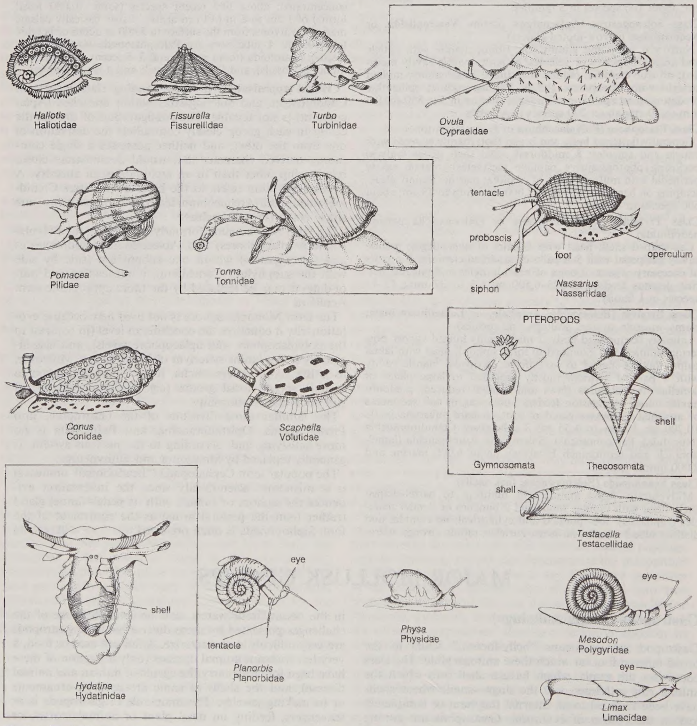


Figure 4: Diversity among gastropods.

number of deep-sea species are known, and a significant snail fauna is associated with hydrothermal vents. Most marine species have relatively large ranges.

Freshwater snails are common in ponds, streams, marshes, and lakes. Usually only a few species are found at one place, but each species will have a rather wide range. Most species are common and feed on algae or dead plant matter. In a few relatively old river systems and lakes—in particular, Baikal in Siberia, Titicaca in South America, Ohrid in Macedonia, the Mekong basin in Southeast Asia, and the African Rift lakes—extensive and complex radiations of snails have occurred in comparatively recent geologic time, producing a large number of species.

Adaptations to terrestrial life

Land snails are marginally, but very successfully, terrestrial. When actively moving, they continuously lose water. During periods when water is unavailable, they retreat into their shells and remain inactive until conditions improve. They hibernate during winter periods, when water is locked into snow or ice, and estivate during periods of summer drought. Land snails have been found above the snow line; species of *Vitrina* crawl on snowbanks in Alpine meadows. Other species inhabit barren deserts where they must remain inactive for years between rains.

Only in such favourable areas as New Zealand, Jamaica, northeastern India, and the wet forests of Queensland (Australia) 30 to 40 different species can be found together; in some parts of western Europe 20 species can be found together, while in most of North America fewer than 10 species live together. In many desert regions, only one or two species are found, and they have significant feeding specializations.

The actual local abundance of snails and slugs can be spectacular. Millions of some brackish-water and freshwater species can live on small mud flats. An acre of British farmland may hold 250,000 slugs, and a Panamanian montane forest was estimated to have 7,500,000 land snails per acre. Despite this abundance, snails and slugs often pass unobserved. Land and freshwater species often stay hidden during the day and are active at night. Most marine species as well are nocturnal, and the shells of many of these species are so heavily covered with algae and other encrusting organisms that they may be mistaken for bits of rock.

Importance to humans. From earliest times, humans have used many species of snails as food. Periwinkles (*Littorina*) in Europe and South Africa, queen conchs (*Strombus gigas*) in the West Indies, abalones (*Haliotis*) in California and Japan, and turban shells (*Turbo*) in the Pacific are the most frequently eaten marine snails. Occasionally limpets and whelks are used for food, but they are more commonly used as fish bait. Freshwater snails rarely are eaten. Land snails of the family Helicidae have been eaten in the Middle East and Europe since prehistoric times. Today many tons of the European edible snails *Helix aspersa* and *H. pomatia* are raised on snail farms or collected wild. Several species of *Otala* and *Eobania* from Morocco and Algeria are exported for food.

In some places, introductions of *Achatina* and *Helix* have resulted in damage to crops and gardens by these rapidly multiplying snails. California orange groves are plagued by *H. aspersa*. Many slugs accidentally introduced from Europe to both the West Coastal and the Eastern to Midwestern United States are a continual nuisance in home gardens. Freshwater snails of the family Bythinidae sometimes become so numerous that they clog the filter systems of pumping stations.

Shells of certain snails are highly prized by collectors. The operculum of some *Turbo* species is used in making earrings; cameos are cut from the shell of the Red Sea snail *Cassis rufa*. Abalone shells are used in many cultures for decorative purposes; the shell of the golden cowrie (*Cypraea aurantium*) served at one time as a badge of a chief in Fiji. Strings of shells have been used as money.

Intermediate hosts of disease organisms

More serious effects are caused by the few freshwater snails (*Pomatiopsis, Bulinus, Biomphalaria*) that serve as intermediate hosts for worms parasitic of humans. Schistosomiasis is a disease caused by minute blood flukes (schistosomes). Both snails and flukes are most common in areas where fields are irrigated. Schistosomes also parasitize birds and mammals. A skin rash called swimmer's itch results from bird schistosomes trying, only partly successfully, to penetrate human skin. They die in the upper skin layers, and their decomposition causes local infection. Other health problems are caused by several snails and slugs (*e.g., Bradybaena, Angustipes, Veronicella*) that serve as intermediate hosts for the rat lungworm. If an infected land snail or slug is accidentally chopped up in a salad and eaten, the worm can migrate to the brain and encyst, causing moderate to severe damage.

Most gastropods, however, are useful to humans in that they help decompose dead plants and animals into substances that can be used by plants to manufacture new organic compounds. In both field and forest, as in ponds, rivers, and oceans, gastropods are an important part of the decomposer community, and some are significant predators.

NATURAL HISTORY

The colonization of freshwater and terrestrial habitats by gastropods is due to the plasticity of their body and considerable alteration in both structure and function of specific organ systems. Most major groups of organisms primarily inhabit one of the three great biospheres (ocean, fresh water, or land); the gastropods are successful in all three.

Reproduction and life cycles. Gastropods originated in the oceans, and relics of this fact are preserved in the early life history of freshwater and land species. Only in the most primitive prosobranchs are the gametes released into the water for fertilization to take place outside the female. The fertilized egg hatches into a free-swimming form (trochophore larva). Upon the expansion of the ciliary girdle of the trochophore larva into large, heavily ciliated swimming lobes (vela), the larva, called a veliger, undergoes torsion, a 180° rotation of the fleshy organs from a posterior to an anterior position behind the head. Torsion is an embryological distinction of the gastropods (see Figure 5).

Torsion

From J.E. Morton. *Molluscs*. 4th ed. (1967); Hutchinson Publishing Group Ltd.

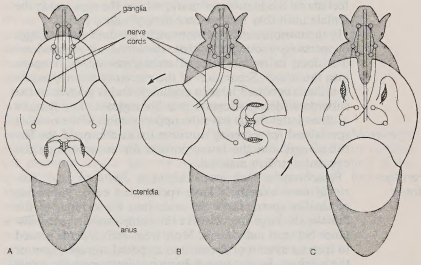


Figure 5: *Torsion.*
(A) Before torsion. (B) 90° rotation. (C) Torsion completed (180° rotation).

In some species the veliger stage may persist for a long period of larval life. The veliger has a small shell into which the velar lobes and head can be withdrawn and a larval heart that seems to exist solely to provide circulation in the velar lobes. Food consists of diatoms (an algae group) and small plankton collected by ciliary currents of the velum and channeled by the currents into the mouth. Special excretory cells located on either side of the mouth and the larval heart disappear when the veliger settles to the bottom and changes into a crawling snail. Upon settling, the snail starts a typical pattern of rapid growth until sexual maturity, at which point growth either ceases or is greatly slowed because energy is being diverted to the production of the next generation. In opisthobranchs and many pulmonates, the life span is about one year, although there are notable exceptions. Prosobranchs in general seem to have a much longer life span, with some species of the freshwater *Vivipara* having lived 20 years

Life span

in captivity. Some Sonoran Desert snails from California have been revived after eight years in estivation. Such desert species may have a life span of 20 to 50 years.

Several trends are evident in gastropod evolution from this basic pattern. First, there is a tendency toward the development of structures to permit internal fertilization. Pallial reproductive tubes of male and female become closed tubes, and a male copulatory organ develops on the right side of the head for transmission of sperm to the female. Second, the trochophore and veliger stages tend to be passed within an egg capsule provided with a food supply, rather than as free-swimming immature organisms that must find their own food. At first, provision of nutriment for the young probably involved laying eggs in a mucous mass. As evolution progressed, capsules containing yolk and with a protective cover might have been laid singly or in masses. Still later forms may have provided parental care of the eggs or egg mass. Finally the eggs are retained inside a brood pouch or the uterus until the young are ready to hatch (ovoviviparity). Third, there are tendencies toward sex reversal and the development of hermaphroditism—the presence of both male and female sex organs in one animal; nearly all opisthobranchs and pulmonates are hermaphrodites.

Such changes occurred more than once during gastropod evolution, and there is no clear pattern of changes that would suggest relationships. The differences correlate with habitat and frequently are seen within species of one genus. *Littorina,* on the English coasts, is a classic example: *L. neritoides* lives in crevices of exposed rocks above normal high water but releases floating (pelagic) egg capsules during fortnightly high tides or storms; *L. littorea,* on the lower half of the shore, also has pelagic egg capsules, which hatch six days later into veligers; *L. littoralis,* which lives on seaweeds that are rarely exposed by the tides, deposits gelatinous egg masses on the seaweeds, and the larvae pass through the veliger stage in the egg mass, emerging in two to three weeks as crawling young; and *L. saxatilis,* which extends from midtide level to several feet above the high-water mark, retains the eggs inside the female until they hatch as crawling young.

In the most primitive prosobranchs the duct carrying eggs or sperm (gonoduct) opens into the kidney or renopericardial duct; in more-advanced archaeogastropods it opens into the ureter. Separation of the excretory and reproductive ducts occurred later in evolution and is evident in the suborders Mesogastropoda and Stenoglossa. The females of these latter forms have the upper portion of the oviduct specialized for secreting nutritive material around the fertilized eggs and the lower portion for encapsulating the egg and nutritive material.

Fertilization

Prosobranchs such as *Cerithiopsis, Janthina,* and *Turritella* have extremely large sperm that carry thousands of smaller sperm from the male into the oviduct of the female; the large sperm swim the comparatively great distance between individuals. More frequently a penis is used to insert a stream of sperm into a special storage organ or the oviduct. In the opisthobranch *Limapontia* the penis stylet injects sperm through the body wall into a storage organ (bursa) of the mate.

Internal fertilization is necessary for land gastropods. The more primitive species directly transfer a stream or gelatinous mass of sperm by insertion of the penis. One individual can act as a male and the other as a female, or copulation can be reciprocal. During evolution, loosely adherent masses of sperm gave rise to enclosed packets of sperm and then to horny or calcareous sperm bundles (spermatophores) with elaborately ornamented exteriors. It is not uncommon for there to be as many as 12 such spermatophores inside the bursa of a female. Closely related species show clear differences in the number and spacing of exterior spikes. Undoubtedly, this difference provides a method of species recognition among these snails. Other pulmonates depend on explicit courtship patterns (such as the slugs from the family Limacidae) or structural differences in the penis (as in the land snails of the family Endodontidae) to distinguish close relatives.

Sex reversal

Most members of the prosobranch family Calyptraeidae begin life as fully functional males but, after a transitional phase, spend their remaining life span as females. *Crepidula* species normally attach to one spot when young and rarely move again. Other members of the species frequently attach to the shell surface of a settled individual, forming piles of as many as 19 specimens. The younger ones on top are male, the old ones on the bottom female, and those in the middle are intermediate in sex. Isolated young individuals function as males for only a week or two, but young males in a pile remain male for a longer period, through some unidentified influence of the larger females underneath. Some limpets also undergo sex reversal.

Egg production is correlated with the degree of care given the eggs or young. The extremes are the production of enormous numbers of eggs, which receive no care and hence suffer mass mortality (a fraction of 1 percent surviving), and the production of only one or two eggs, which receive intensive care. There are many gradations between the extremes. Many members of the suborders Mesogastropoda and Stenoglossa produce egg capsules that may contain from one to more than 1,000 eggs. In *Busycon,* for example, each capsule may contain up to 1,000 eggs, but extensive cannibalization occurs among the early hatched young and upon unhatched eggs in the capsule. *Strombus* can lay a tubular string of eggs 23 metres (75 feet) long, with up to 460,000 eggs. Many *Conus* cement up to 1.5 million eggs in capsules on the undersides of rocks. Opisthobranchs weave delicate ribbons of eggs in colourful sheets—sometimes up to 50 millimetres (two inches) of ribbon per hour—that contain many millions of eggs. In these cases, the eggs hatch into swimming veligers. Freshwater snails frequently deposit eggs in capsules on plant leaves or rocks, but the number of eggs is much less than in the marine gastropods.

Parental care of eggs

Direct care of the eggs is given in different ways. A small trochid, *Clanculus bertheloti,* deposits its eggs in grooves on the shell surface and covers them with a sheet of mucus to hold them in place; many *Neptunea* simply cement the egg capsules to their shell surface. Many *Crepidula* deposit a mass of 5,000 to 20,000 eggs under the shell edge just in front of the female's foot, brooding them until they hatch as veligers. Freshwater viviparids and thiarids have either uterine or neck brood pouches, in which the fertilized eggs develop to a crawling stage. The vermetid *Stephopoma* and the acmaeid *Acmaea rubella* brood their young in the mantle cavity between the fleshy body and the shell. A number of endodontid land snails on Pacific islands deposit their eggs in the umbilicus, an opening in the shell base. In one species, *Libera fratercula,* the young gnaw their way out through the apex of the maternal shell. One pteropod, *Hydromeles,* has an internal brood chamber that apparently ruptures, freeing the young into the body cavity of the parent; it is suspected that the escape of the young results in the parent's death.

Even without direct care of the eggs, land snails generally lay fewer than 200 eggs at a time. This reflects the different problems encountered on land and the lower mortality of larvae that are protected within the egg coverings. Many slugs and some snails bury egg masses in soil or under moist pieces of bark. Others, such as *Discus,* scatter their eggs singly over bark and decaying wood. One tropical genus (*Amphidromus*) rolls a leaf into a tube, seals one end with mucus, and lays its eggs in the cylinder thus formed. The South American *Strophocheilus* lays one large egg about four centimetres (1.5 inches) long. Among the many ways in which land snails minimize losses from drying is the adoption of ovoviviparity, or the hatching of eggs within the parent's body.

The evolutionary trend from the simple release of eggs and sperm toward the provision of a large quantity of nutritive materials and protective encapsulation of each fertilized egg has resulted in an increase in the size of the organs that provide these abilities as well as a reduction in the sizes of the ovary and testis. The shift to direct transfer of sperm masses has led to evolution of both complex structures for species recognition and complicated behaviour to assure species identity.

Ecology and habitats. Although all levels of the ocean are inhabited by snails, they are in greatest abundance in

and just below the tidal zones, where the most abundant quantities of food may be found. The extent of their effect on a coastline is indicated by the estimate that an average population of 860 million *Littorina* on one square mile of rocky shore ingests 2,200 tons of material each year, only about 55 tons of which is organic matter. Limpets of all types are even more influential in such habitats, browsing and grazing on the algae and sessile animals. One interesting characteristic of limpets is that of homing. Numerous species have the tendency to settle on one spot and to feed on regular pathways radiating from this home base, to which they return for rest or under stressful conditions.

Snail damage to rocky coasts

Some larger prosobranchs are selective herbivores, cutting off one- to two-centimetre (0.4- to 0.8-inch) strips of seaweed for swallowing. More characteristic of the sand and mud flats are scavengers that indiscriminately take in surface debris; scavengers are found in various groups, including limpets, strombids, and nassariids. Carnivores include both surface hunters and burrowing forms such as the naticids. As an adaptation to sedentary life, several families have adopted mucociliary feeding by collecting food particles from water currents. Sensory reception to detect prey is highly developed in many carnivores.

Janthina builds a float of air bubbles in mucus; the float is attached to the middle part of the foot. Heteropods swim either by undulations of the foot or by the action of fleshy fins. Pelagic opisthobranchs show almost every conceivable type of swimming mechanism and are at times extremely abundant on the ocean surface. Many opisthobranchs and most small freshwater pulmonates can glide on the underside of the surface film of the water but are not able to swim.

Diversity of mollusks in the ocean has resulted from specialization in food resources. Temperature and salinity are the prime physical factors limiting range extensions, usually by preventing successful breeding rather than by preventing settlement and growth of young.

Adaptations to fresh water and land

Migration of the snails into fresh water and onto land required a number of new adaptations. Snails had extra problems to solve, relating to their basic feeding and reproductive patterns. In the ocean, dispersal can take place by way of a veliger stage transported passively by currents and waves. In streams and rivers such a means of dispersal would result in downstream spread only. Because of this, the veliger stage was suppressed; instead, many freshwater prosobranchs brood the young inside the female, and pulmonates attach egg capsules to rocks, to vegetation, or to other snail shells. This essentially restricts snail dispersal to individual movement. In prosobranchs with separate sexes, the freshwater distributions closely follow drainage systems, because, in order to colonize a new body of water, either a pregnant female must be transported or both a male and a female must arrive at about the same time. The majority of pulmonates in fresh water are hermaphrodites and are capable of self-fertilization as well as cross-fertilization with other individuals. As a result, any pulmonate entering a new body of water can establish a considerable population of that species in a short time. For this reason, isolated ponds often have several species of pulmonates but only rarely prosobranch gastropods. In crawling over waterweeds, the pulmonates frequently come in contact with the feet or feathers of wading birds, to which they adhere accidentally by mucus secretion and are carried to a new pond.

Land snails avoid dessication in several ways. Prosobranchs retreat into their shells, and the operculum effectively seals the opening against the exterior. In the tropics, land operculates have developed elaborate breathing tubes to allow gas exchange during dry periods and yet minimize water loss. Pulmonates lack an operculum, but a great number of the forms secrete either simple mucous coverings (epiphragms) across the shell aperture or, in some of the more arid areas, a calcium-impregnated seal that can be almost as thick as the shell itself. Most land snails, however, have adjusted to life on land primarily through behaviour patterns. They stay in areas of high moisture or retreat into damp niches during short dry spells. A few burrow into soil. *Sonorella* species survive by remaining dormant during the years between rains; the genital structures of many individuals are reduced or lost to minimize use of energy in reproductive activities.

Tree snails

Only in the wet and warm tropics have tree snails been able to develop. These species have brightly coloured shells that usually are much thinner than those of their terrestrial counterparts. In the humid mountain regions of the world, where a constant supply of moisture is available throughout the year, there has been a marked tendency toward reduction of the shell and the evolution of slugs. This tendency probably results from two different selective pressures that reinforce each other. The shell, which is useful primarily in providing protection against dessication, is no longer needed when moisture is plentiful. Secondly, construction of the shell requires that a large quantity of calcium be readily available; calcium is generally in short supply on the slopes of volcanic mountains. With the need for the shell lessened and the primary constituent in short supply, any mutation favouring shell reduction is advantageous. Although most species of slugs seem to have evolved in mountain areas, their spread into lowlands has been greatly aided by crop irrigation and garden watering.

By far the majority of land snails occupy the surface litter and upper soil zone. This microhabitat is generally moist, and food is plentiful in the form of decaying animals and plants as well as fungi. Most land snails have shells that are drab in colour and inconspicuous. Frequently, the shell surface is highly sculpted. The minute species (less than three millimetres [0.1 inch] in diameter) face a problem of predation by small arthropods. The normal instinct of a snail to withdraw into its shell is of no help, since the predator simply follows the snail into its shell. Elaborate barriers that narrow the shell opening and tiny spines along the opening must provide some protection, since this construction occurs in more than 12 pulmonate families.

Most land snails feed directly on decaying plant matter, which is a simple shift in feeding behaviour from the primitive browsing of their marine ancestors. The carnivorous habit probably evolved through a transition period of carrion eaters. Many slugs feed on dead animal matter as well as plants. Pursuit and capture of other snails or earthworms demand increased sensory equipment and more rapid motion. Most carnivores, such as *Euglandina,* have greatly elongated bodies for reaching further into the shells of their victims.

Locomotion. The foot is the organ of locomotion in land gastropods. In swimming and sessile forms, however, the foot is greatly reduced and in many groups greatly modified. The normal progression of a snail is by muscular action, with a series of contraction waves proceeding from the posterior to the anterior end of the gliding portion of the foot. This type of progression is called monotaxic locomotion. A few groups have the foot divided into right and left halves, with separate waves moving on each side, a condition termed ditaxic locomotion. Certain species move by the beating action of cilia of the foot on the mucous sheet secreted by the anterior part of the foot. When the foot is narrow, as in *Strombus* and *Aporrhais,* the animal moves in fits and starts, tumbling along by a digging action of the foot and the pointed operculum. Most prosobranchs are relatively slow-moving, with a speed of less than eight centimetres (about three inches) per minute, although *Haliotis* has been reported to move at almost 10 times that rate.

Movement by contraction of the foot

Many opisthobranchs employ monotaxic locomotion; some can glide on the underside of water-surface films through ciliary action. Swimming has been achieved in a number of ways. Body undulations propel such large snails as *Dendronotus* and *Melibe.* Pteropods, *Gastropteron, Akera,* and others move foot flaps (parapodia) to provide motion. The sea hare, *Aplysia,* uses an inchwormlike progression, and some nudibranchs swim by beating accessory breathing organs (cerata).

Freshwater pulmonates use ciliary action on a bed of mucus secreted by the snail. Many snails, especially *Physa,* can form a cord of mucus from the water surface to the bottom.

Land pulmonates depend upon a combination of muscular action and cilia for locomotion. In many of these

species the foot is divided longitudinally into three parts, with locomotor activity being confined to the central section, which glides on a mucous track. An additional use of slime by slugs is in the act of mating. A slime rope is secreted from which the mating pair of slugs are able to suspend themselves. If irritated, slugs can secrete copious quantities of slime. This reaction is the basis for one of the most effective methods of controlling slugs: spreading enough ashes in slug-infested areas causes exhaustion and death of the animals through the overproduction of slime.

Some of the small, tropical, brightly coloured sluglike species will, when disturbed, travel at a very high rate of speed with the anterior half of the foot lifted off the ground. They can continue moving at this pace for a distance of almost a metre at a rate faster than one metre per minute in snails less than two to three centimetres (or about one inch) in body length. Large species, such as *Achatina* or *Strophocheilus,* are much slower, although carnivores are usually relatively fast-moving.

The odontophore: a rasping organ

Food and feeding. As in all molluscan groups except the bivalves, gastropods have an odontophore at the anterior end of the digestive tract. Generally, this organ forms a broad ribbon (radula) covered with a few to many thousand "teeth" (denticles). The radula is used in feeding: muscles extrude the radula from the mouth, spread it out, and then pull it back into the mouth, carrying particles or pieces of food and debris into the esophagus. Although attached at both ends, the radula grows continuously during the gastropod's life, with new rows of denticles being formed posteriorly to replace the worn denticles cast off at the anterior end. Both form and number of denticles vary greatly among species—the differences correlating with food and habitat changes. Radular denticles are shown in Figure 6.

Evidently, the most primitive type of gastropod feeding involved browsing and grazing of algae from rocks. Some species of the order Archaeogastropoda still retain the basic rhipidoglossan radula, in which many slender marginal teeth are arranged in transverse rows. During use, the outer, or marginal, denticles swing outward, and the radula is curled under the anterior end of the odontophore. The latter is pressed against the feeding surface, and, one row at a time, the denticles are erected and scrape across the surface, removing fine particles as the odontophore is withdrawn into the mouth. As the marginals swing inward, food particles are carried toward the midline of the radula and collected into a mucous mass. By folding the teeth inward, damage to the mouth lining is avoided and food particles are concentrated. Mucous-bound food particles are then passed through the esophagus and into the gut for sorting and digestion.

From this basic pattern, numerous specializations have developed, including docoglossate, taenioglossate, rachiglossate, and toxoglossate radulae. Many limpets, which scrape algae directly from rock surfaces, have a docoglossate radula, with the marginals greatly reduced in number. When the radula is extruded, in *Patella,* for example, several rows of denticles on the lower odontophoral margin are pressed against the surface. There is no elevation of single rows and no lateral movement of the few marginals. Consequently, wear against the rock surface is great, and, although the denticles are heavily impregnated with mineral salts, tooth damage and loss is extensive. In rock-grazing species, replacement and growth are relatively rapid, and the radula is very long in relation to shell size.

Wear and replacement of teeth

Mesogastropods have a taenioglossate radula, in which a central tooth is flanked on either side by three laterals, for a total of seven denticles. This highly flexible pattern has allowed great diversity in feeding by alteration of cusp and tooth size. Often members of a genus may show striking differences. The limpetlike *Hipponyx antiquatus* attaches permanently in rock crevices or on clamshells and feeds on the organic debris that can accumulate. Other limpetlike, or burrowing, mesogastropods collect food particles off the gill and pass them into the mouth by cilia. *Hipponyx* and *Aporrhais* grasp the trapped particles with the radular teeth, whereas in *Crepidula* a food-laden mucous cord is formed, bits of which are torn off by the radula.

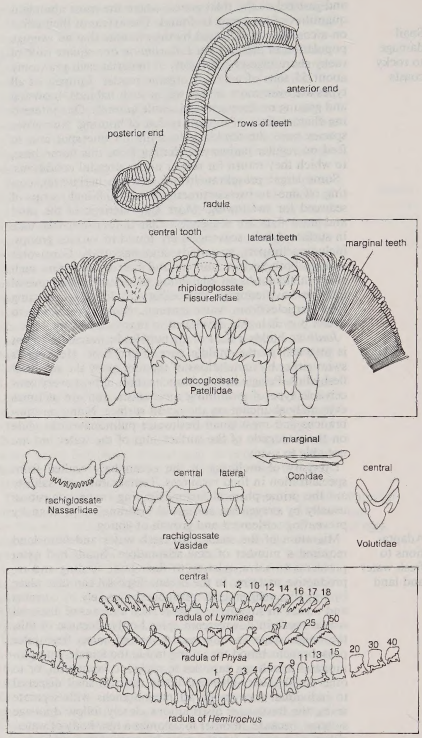


Figure 6: Gastropod radulae and types of teeth.

Gastropods that feed on sessile animals have evolved an extensible proboscis capable of reaching into narrow openings. Such minute sponge feeders as *Triphora* extend the slender proboscis into the openings of a sponge to reach delicate fleshy cells. Similarly, many cowries feed on sea squirts (ascidians). Numerous mesogastropods and prosobranch-opisthobranch transition groups are external parasites (ectoparasites) on larger animals. A few are internal parasites (endoparasites) of echinoderms.

Floating snails

Floating snails such as *Janthina* drift along until they contact prey. Certain mesogastropods are active swimmers; one, *Pterotrachea,* has the foot modified into a small sucker for holding prey. Mesogastropods of the families Naticidae and Doliidae feed upon bivalves and echinoderms. The naticids use their large foot to hold the prey while they drill through the bivalve shell. A combination of mechanical rasping by the radula and chemical loosening of the calcium by secretions produces a hole in the bivalve shell through which the proboscis is inserted to enable the naticid to feed upon the soft tissues.

In stenoglossans the basic radular type is rachiglossate, with only three denticles—a central and two laterals. Families such as the Buccinidae and Nassariidae include carnivores and scavengers. Members of the family Muricidae are predators that may use either a secretion to bore holes into shells or the physical force of their proboscis to

pry into shelled prey. Many genera (*e.g., Busycon, Fasciolaria,* some *Murex*) use part of their shell to wedge open a clam for feeding.

Finally, the toxoglossate radula has only two teeth, which are formed and used alternately. Most toxoglossate gastropods inject a poison via the functional tooth. Prey selection usually is highly specific. Although many cones hunt polychaete worms, others prey on gastropods or fishes, using the radular tooth as a harpoon, with poison being injected into the prey through the hollow shaft of the tooth. Several of the large fish-eating cones, which produce a potent nerve poison, have been known to kill humans.

Opisthobranch gastropods show less clearly defined types of radular structure. Anaspideans such as *Dolabella* may have as many as 460 teeth per row with a total of 25,000 denticles; sacoglossans have only one longitudinal row of teeth. In terms of feeding, opisthobranchs are extremely varied. Besides the algae-sucking sacoglossans, *Aplysia* cuts up strips of seaweed for swallowing, and a number of the more primitive species feed on algae encrusted on rocks. Perhaps the majority of opisthobranchs, including the sea slugs, are predators on sessile animals, ascidians and coelenterates being especially favoured. Pyramidellids are ectoparasites on a variety of organisms. Some of the pteropods are ciliary feeders on microorganisms.

Pulmonate modifications for feeding

Pulmonate gastropods are predominantly herbivores, with only a few scavenging and predatory species. Basically, on the radula there is a central tooth flanked by a few to many denticles, which may be differentiated into laterals and marginals. The central tooth may be reduced in size or lost, whereas the other teeth show modifications correlated with diet. Primitively, the pulmonate radular tooth has three raised points, or cusps (*i.e.,* is tricuspid), but modifications involving splitting of cusps or reductions to one cusp are numerous. With each successive appearance of a carnivorous type during evolution, however, the teeth have been reduced in number, each tooth usually having one long, sickle-shaped cusp.

Much of the diversity achieved by the gastropods relates to the evolutionary shifts in radular structure, which have led to exploitation of a variety of food sources. Predators capable of swimming, surface crawling, and burrowing to capture prey have evolved among the prosobranchs and opisthobranchs; predators that produce chemical substances for entering the shells of their prey have evolved among the mesogastropods (family Naticidae and superfamily Tonnacea), stenoglossans (family Muricidae), and a nudibranch opisthobranch (*Okadaia*); and, in the pulmonates, predation and thus a carnivorous diet have evolved at least 12 times.

FORM AND FUNCTION

Gastropods present such a variety of structures and adaptations that few all-encompassing characteristics can be presented. A detailed presentation on the radula and reproductive changes, which are keys to understanding gastropod diversification, has been given above. The following survey focuses on the external shell and the body.

The shell. The typical snail has a calcareous shell coiled in a spiral pattern around a central axis called the columella. Generally, the coils, or whorls, added later in life are larger than those added when the snail is young. At the end of the last whorl is the aperture, or opening. The shell is secreted along the outer lip of the aperture by the fleshy part of the animal called the mantle, first by outward additions to the shell lip and then by secretion of inner thickening layers. The outer layer, or periostracum, is a mixture of proteins known as conchin. Inner layers of calcium carbonate interlace with a network of conchin and are impregnated with a variety of mineral salts. The calcium usually is in the form of calcite crystals in marine species and aragonite crystals in terrestrial species, but mixtures of crystal types do occur.

Shell ornamentation

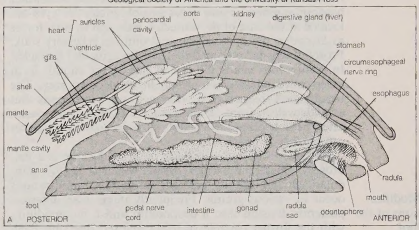
Modifications and ornamentations of the basic shell are widely variable. Frequently, the shell is altered into a non-spiral cap or a cup-shaped limpet form as an adaptation to life in swift currents (the freshwater family Ancylidae) or amid pounding waves on rocks (the marine families Acmaeidae, Patellidae, Fissurellidae, and Calyptraeidae). In many groups, such as the abalones (the family Haliotidae), only traces of spiral coiling are evident, because the rate of successive whorl widths is so large that the last, or body, whorl occupies more than 90 percent of the shell volume. Elaborate surface sculpture, including knobs and spines, develop as protection against predation. In a few species of the genera *Leucozonia* and *Acanthina,* a spine on the lip edge is used to wedge open clam valves so that the snail can feed. As implied earlier, land gastropods in dry regions tend to have very thick shells; on the other hand, those in very humid mountain situations have thin shells or none at all. Many carnivorous snails have the calcareous part of the shell greatly reduced.

The body. The gastropod body consists of four main parts: visceral hump, mantle, head, and foot. The body is attached to the shell either by one columellar muscle or by a series of muscles. Typical snails can withdraw the head and foot into the shell, but numerous species have shells so reduced in size as to be unable to contain the body; slugs, of course, have either an internal shell vestige or no shell at all.

The visceral hump. The visceral hump of gastropods is always contained within the shell; it generally holds the bulk of the digestive, reproductive, excretory, and respiratory systems (Figure 7). A significant part of the visceral hump consists of the mantle, or pallial, cavity. In both prosobranchs and shelled opisthobranchs this is a cavity completely open anteriorly; in pulmonates it is closed except for a narrow pore. The upper surface of the mantle cavity serves a respiratory function. In marine species the ciliated lining of the mantle cavity produces a water current that passes posteriorly across the gill, or

The mantle cavity

From (B) *Treatise on Invertebrate Paleontology,* courtesy of the Geological Society of America and the University of Kansas Press



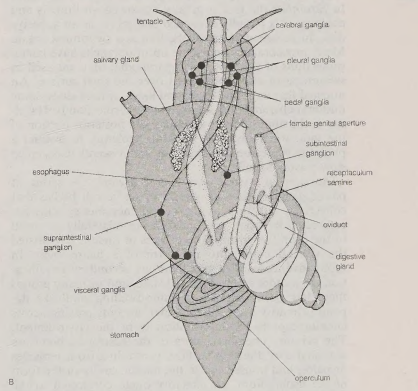


Figure 7: *Adult gastropod structure.*
(A) Primitive. (B) Advanced.

ctenidium, and the osphradium, which is thought to be a sensory receptor that can detect chemical changes in the environment. Both organs lie on the left anterior side of the cavity. The water current sweeps across the posterior part of the mantle cavity, where the nephridiopore, or kidney opening, lies; the water current then passes anteriorly along the right margin past the anus, through which undigested particles of food are eliminated, and usually moves past the gonopore, through which sexual products are released.

The mantle cavity serves as a space for the head and foot when these organs are retracted. Many land pulmonates apparently also use the mantle cavity to retain water.

Operculum

Prosobranchs use the operculum, the horny or calcareous disk located on the back of the foot at the posterior end, to seal the shell opening after the head and body have been retracted.

The mantle. The mantle is the fleshy lining of the outer wall of the shell; it roofs the mantle cavity. At its anterior end lie glandular tissues that deposit the various shell layers. In terrestrial forms with reduced shells, various lobes and laps extend anteriorly over the neck and head or are reflected back over the shell surface. These are highly vascularized and probably serve both in respiration and in water balance of the body. Many marine forms have the mantle collar extended forward and rolled into a siphon, which functions in both food location and chemoreception.

The head. Generally, the head is bilaterally symmetrical, bearing one or two pairs of tentacles, often with accessory palps, and the mouth in the middle of the ventral margin. In stylommatophoran land snails the upper tentacles, or ommatophores, are invaginable (capable of being rolled in), and the eyes are borne at the tips. In freshwater basommatophorans and most prosobranchs the eyes are located at the base of the tentacles, although in such forms as *Strombus* the eyes are elevated onto an accessory stalk. Prosobranchs have contractile (not invaginable) tentacles. In carnivorous snails the lateral lips of the mouth form lobes called labial palps, which help to locate prey. The mouth itself frequently is prolonged into a proboscis that extends well in front of the tentacles. Carnivorous species often have a proboscis capable of great extension, either invaginable or contractile.

The foot. Although the basic form of the foot is a flat, broadly tapered, muscular organ, which is highly glandularized and usually ciliated, numerous modifications occur in various groups. Frequently there is an anterior-posterior division into a propodium and a metapodium, with the former capable of being reflexed over the shell. In *Strombus* the foot is greatly narrowed; in limpets and abalones it is broadly expanded and serves as an adhesive disk. In pelagic gastropods the foot is a swimming organ. Many prosobranchs and some opisthobranchs have lateral projections of the foot called parapodia; they are used in swimming or else are reflexed over the shell surface. An unusual feature found in several kinds of land slugs, some nudibranchs, and the stenoglossan marine family Harpidae is the ability to self-amputate the posterior portion of the foot, which remains wriggling violently to distract a predator while the anterior foot and visceral mass creep slowly away to safety.

Modifications of the foot

The nervous system and sense organs. A series of paired ganglia (knotlike masses of nerve cell bodies that collectively function as the central nervous system) are connected by nerve cords, which are bilaterally arranged in the primitive forms. The process of torsion has twisted the visceral cords into the form of a figure eight. In more-advanced gastropods there are secondary modifications to a more nearly bilateral state, and in many groups there has been detorsion. Water-dwelling mollusks depend primarily upon ciliary water currents passing across chemoreceptors for information from the environment. The primary chemoreceptors in the gastropod body are scattered over the skin surface, protruding from tentacles or palps, and housed inside the mantle cavity in the form of the osphradium, an olfactory organ connected to the respiratory system. Sense organs are more highly developed in carnivores than in herbivores. Eyespots, located at the base (most gastropods) or tip (land pulmonates) of the eye tentacles, are primarily light-sensitive rather than image-forming. A pair of statocysts, thought to be balancing organs, is present in nonsessile taxa.

Digestive system. The radular motion conveys food particles into the mouth, and ciliary currents move the food through the tract, except in carnivores, where muscular action plays an important role. Various salivary and digestive glands secrete enzymes into either or both the buccal cavity and the stomach, where digestion takes place. The apical digestive gland, or "liver," can store digested food for use during periods of inactivity.

The excretory system. There are two kidneys, or nephridia, in only the primitive gastropods, such as the archaeogastropods, while, in the advanced forms, one kidney is small or lost. The kidney plays different roles, depending upon the environment in which the snail lives. Most marine gastropods have the same total concentrations of solutes as in the surrounding seawater, and thus a small osmotic differential (*i.e.,* an equilibrium) exists between the water leaving and that entering the cell. Little energy is needed therefore to prevent the cells from losing or gaining too much water. Freshwater gastropods, however, have a higher total solute concentration than that of the surrounding water. The kidney must expend energy to control water balance (osmoregulation). The flow of water through the mantle cavity is restricted in freshwater species by the closure of the mantle cavity by the mantle collar. Land prosobranchs have an open mantle cavity and, in order to conserve water, secrete nearly crystalline urine. Land pulmonates have a ureteric groove or closed ureter that resorbs water from the urine. In both marine and freshwater species, ciliary water currents sweep the excreted matter out of the mantle cavity.

Respiration. In marine and freshwater gastropods, respiration takes place as water currents pass across the gill surfaces within the mantle cavity in most species with spiral shells, across gill elements along the sides of the bodies in most limpets, or through projections from the body surface in sea slugs or taxa with reduced shells. The upper surface of the mantle cavity is heavily vascularized in land snails, which use muscular contractions to pump air in and out of the small respiratory pore at the anterior edge of the mantle cavity. In some land slugs or tropical snails with reduced shells, respiratory functions have shifted either to external projections from the mantle collar or to the skin as the area of mantle roof available for respiration has decreased in size.

The reproductive system. The primitive archaeogastropods retain two nephridia; the right nephridium provides the passage for eggs or sperm from the ovary or testis to the mantle cavity. The sexes are separate in nearly all prosobranchs, although in a few taxa, such as *Crepidula,* an animal begins life as a male and then changes to a female later. Both the opisthobranchs and pulmonates are hermaphroditic, often protandrous (male gonads maturing first), but many taxa when fully adult become simultaneous hermaphrodites (male and female gonads are functional at the same time). Internal fertilization is common in the more advanced marine taxa but mandatory in the freshwater and terrestrial groups. A very few gastropods are parthenogenetic (gametes developing without fertilization).

Features of defense. Warning coloration is found in some of the brilliantly coloured shells and bodies of carnivorous marine snails that possess highly toxic poisons. Similar bright colours characterize some land snails and slugs that secrete noxious chemicals and thus will be sampled only once by a predator. Camouflage coloration provides partial protection against predation by some European land snails.

EVOLUTION AND PALEONTOLOGY

The basic trends in snail evolution involve changing from a herbivorous to a carnivorous diet, shifting from the ocean to freshwater and terrestrial life, and adopting a sluglike form through reduction or loss of the shell and visceral hump. Each change has occurred independently several times in the course of gastropod evolution.

Prosobranch gastropods are the most primitive. One group, the Diotocardia, which retains two sets of mantle organs, is nearest the generalized gastropod in structure. Gradual loss of the right set of mantle organs occurs in the primitive archaeogastropod superfamilies Trochacea and Neritacea, thus providing a transition to the more highly developed order Monotocardia, with only one set of mantle organs. Among the numerous changes in the Monotocardia are fewer radular teeth and a shift from grazing on algae and fungi to predation and the consumption of larger sessile organisms. The two main divisions of the Monotocardia show different evolutionary patterns. Although most mesogastropods have remained coastal marine, several families moved into fresh water. Others crossed to land directly from the tidal zone, rather than passing through a freshwater transitional period. At the peak of prosobranch evolution is the predatory suborder Stenoglossa, all marine inhabitants, with highly modified radular teeth and often well-developed poison glands to aid in capturing prey. Reduction and loss of the right mantle organs are correlated with more efficient respiration and sensory apparatuses, in which a water current crosses over the sensory organs and gills on the left side, then out on the right side, together with excretory and fecal deposits.

Opisthobranchs probably arose from an unknown group of primitive prosobranchs and have evolved extensively into different lines showing a reduction of the visceral hump and shell. In certain forms the foot is shortened, and external cerata develop to provide a respiratory surface to replace the lost mantle-cavity surface. Such opisthobranch groups as the order Pyramidellacea contain a mixture of prosobranch and opisthobranch characteristics.

Pulmonates show varying degrees of adjustment to freshwater and land life, with increasing union of the male and female gonoducts characterizing the more advanced groups. Similarly, the highly advanced suborder Holopoda and superfamily Limacacea show complex accessory organs on the genitalia and a more sophisticated means of water conservation through development of a closed secondary ureter and resorption of water from the excretory products. More than a dozen different groups of pulmonates have become predators, usually upon other snails or earthworms.

The earliest gastropods

Fossil gastropods are known from Cambrian deposits. Since the shell is often very similar in unrelated families, fossil gastropods more than 350 million years old are not usually placed in the classification outlined below but instead are treated separately. Most stenoglossan prosobranchs appeared near the end of the Mesozoic (66.4 million years ago), and many groups of land snails are known from Eocene formations (57.8 to 36.6 million years old). Snails had their adaptive radiation early in geologic history. Living genera of marine, freshwater, and land snail families are known from Oligocene to Miocene deposits (36.6 to 5.3 million years old). Unlike mammals, who have undergone great evolutionary change in the last 50 million years, gastropods have shown little progressive evolution during that time.

CLASSIFICATION

Since the 1980s, gastropod classification has been the subject of extensive debate. Major revisions based on detailed information about traditional anatomy and shell features have been challenged by cladistic attempts to identify changes that have taken place once in the evolutionary history of a group and thus derive phylogenetic schemes, attempts to delineate the geneology of groups based primarily on neurological structures. Both traditional and cladistic classification schemes are being tested by data from molecular studies. Given the antiquity of the gastropods as a group, however, it is perhaps realistic to expect that most changes have occurred more than once. Graham gave an excellent review of anatomic and functional trends, concluding that many of the groups historically recognized as advanced are grades reached by several taxa independently, not monophyletic clades (groups with the same ancestor).

A conservative classification is presented below, basically using concepts from Vera Fretter and Alistair Graham (1962) for the prosobranchs, Louise Schmekel (1985) for the opisthobranchs, and Alan Solem (1978) for the pulmonates, with minor modifications from a number of sources. The remarkable radiation of primitive limpets associated with the hydrothermal vents was still under analysis in the late 1980s and is not included.

The pattern of change in the respiratory and nervous systems and in the mantle complex is fundamental. Among the major trends are the change from a streptoneurus (twisted) to a euthyneurus (straight) nerve loop, the progressive loss of the right part of the primitively paired mantle organs, the increasing sophistication of hermaphroditism, the tendency toward the reduction of the visceral hump and shell, the multiple changes from a herbivorous to a carnivorous diet, the shifts from marine to freshwater or land environments and occasionally the return from the land to the ocean, and the shifts in locomotor mechanics.

CLASS GASTROPODA (snails and slugs)

Snails typically with a calcareous shell, slugs with greatly reduced shell; length ranges from about 1 mm to 130 cm; about 65,000 species widely distributed in marine, freshwater, and land regions.

Subclass Prosobranchia

Streptoneurous (twisted) gastropods with an anteriorly located mantle cavity (space lined with epidermis); operculum (protective cover) generally present; sexes separate; shell can usually hold entire animal; primarily marine, several freshwater and terrestrial groups; about 33,000 species.

Order Diotocardia (*Archaeogastropoda*)

Heart usually with 2 auricles; 1 or 2 internal gills; no penis, siphon (organ used in food location), or proboscis (feeding organ); nervous system not concentrated; sex cells discharged by way of the right nephridium (kidney); about 3,000 species.

Superfamily Zeugobranchia (*Pleurotomariacea*). Slit shells (Pleurotomariidae) in deep ocean waters; abalones (Haliotidae) in shallow waters along rocky shores of western North America, Japan, Australia, and South Africa; keyhole limpets (Fissurellidae) in intertidal rocky areas.

Superfamily Patellacea (*Docoglossa*). Conical-shelled limpets, without slits or holes, found in rocky shallow waters (Acmaeidae and Patellidae).

Superfamily Trochacea. Small to large spiral shells in shallow to deep ocean waters, often brightly coloured, with or without heavy shell ornamentation; Trochidae (top shells), Turbinidae (turban shells), and Phasianellidae (pheasant shells).

Superfamily Neritacea. Small, generally intertidal marine shells (Neritidae), with some freshwater dwellers, particularly in Indonesia and the Philippines (Neritidae), and 2 groups of land dwellers: 1 sparsely distributed in the Old World (Hydrocenidae) and 1 widely distributed in both Old and New World tropics (Helicinidae).

Order Monotocardia

Heart with 1 auricle; 1 gill, often modified; siphon and chemoreception osphradium (sensory receptor) progressively more complex; penis present; head frequently modified into a proboscis; nervous system progressively more concentrated; about 30,000 species.

Suborder Mesogastropoda (*Taenioglossa*). Radula taenioglossate (with 7 denticles, or teeth) or reduced; most taxa herbivorous; a few families parasites or predators.

Superfamily Cyclophoracea. Land snails; particularly abundant in the West Indies and southern Asia to Melanesia.

Superfamily Viviparacea. Large, 2.5- to 5-cm globular pond and river snails of the Northern Hemisphere (Viviparidae) and tropical regions (Ampullariidae); frequently used in freshwater aquariums with tropical fish.

Superfamily Littorinacea. Periwinkles, on rocky shores (Littorinidae) of all oceans; land snails of the West Indies, part of Africa, and Europe (Pomatiasidae).

Superfamily Rissoacea. Small to minute, generally cylindrical, marine, freshwater and land snails found in most tropical and warm temperate regions of the world; about 17 families.

Superfamily Cerithiacea. Minute to large, generally elaborately sculptured shells, common in mud flats and mangroves, many species sand dwellers, with 1 group of families (Thiaridae, Pleuroceridae, Melanopsidae) especially abundant and varied in the Tennessee and Alabama river systems; 13 marine families, including worm shells (Vermetidae), horn shells (Potamididae), and button shells (Modulidae).

Superfamily Strombacea. Foot and operculum greatly modified and move with a lurching motion; feed on algae and plants; some species used for human food; conchs (Strombidae) of tropical oceans and the pelican's foot shells (Aporrhaidae) of near Arctic waters.

Superfamily Calyptraeacea. Cap shells (Capulidae) and slipper shells (Calyptraeidae) are limpets with irregularly shaped shells with a small internal cup or shelf; many species show sex reversal, becoming males early in life, then changing into females during old age; common on rocks and clamshells and in dead large snail shells in most oceans.

Superfamily Cypraeacea. Cowrie shells (Cypraeidae) and egg shells (Ovulidae) have highly polished and brilliantly coloured shells; mantle, which may cover the shell, is a totally different colour pattern; if touched, members of group suddenly withdraw, the change in colour serving to confuse predators; common in shallow tropical oceans, some species in cooler waters.

Superfamily Naticacea. Moon shells (Naticidae) medium-sized, globular predators on burrowing bivalves; bore a hole in the clamshell using acid secretions, then insert the radula to feed; common in most oceans.

Superfamily Ptenoglossa (Scalacea). Wentletraps (Epitoniidae) live in shallow to deep ocean waters; purple snails (Janthinidae) float on the ocean surface after building a raft of bubbles; large numbers of bubble shells occasionally blow ashore.

Superfamily Aglossa. Parasitic or predatory snails either with a reduced radula or with none, jaws often modified into a stylet-shaped structure; many occur on echinoderms; consists of several poorly known families.

Superfamily Doliacea (Tonnacea). Generally tropical predators on echinoderms; often burrow in sand; includes helmet shells (Cassidae), tun shells (Doliidae), frog shells (Bursidae), triton shells (Cymatiidae), and fig shells (Ficidae); frog and triton shells often live in rocky areas; most species large in size.

Suborder Stenoglossa (Neogastropoda). Carnivorous or scavengers with rachiglossate (with 3 denticles) or taxoglossate (with 2 denticles) radula; shell often with long siphonal canal; proboscis well developed and often extensible; shells generally large; all marine.

Superfamily Muricacea. Murex shells (Muricidae), rock shells (Purpuridae), and coral shells (Coralliophilidae) are common predators, often boring into shells of their prey; rock shells common in cooler waters, others mostly tropical.

Superfamily Buccinacea. Scavengers that have lost the mechanisms for boring; dove shells (Columbellidae), mud snails (Nassariidae), tulip shells (Fasciolariidae), whelks (Buccinidae), and crown conchs (Galeodidae) mainly cool-water species; but dove and tulip shells have many tropical representatives.

Superfamily Volutacea. Harp shells (Harpidae), olive shells (Olividae), mitre shells (Mitridae), volute shells (Volutidae), nutmeg shells (Cancellariidae), and marginellas (Marginellidae) generally have operculum reduced or lacking; most are tropical ocean dwellers, active predators or scavengers; many olive, volute, and marginella shells are highly polished and colourful.

Superfamily Toxoglossa. Auger shells (Terebridae), cone shells (Conidae) and turrid shells (Turridae) are carnivorous marine snails with poison glands attached to highly modified radular teeth; several cone shells have caused human deaths through poisoning and can catch and kill fish.

Subclass Opisthobranchia

Shell reduced or lacking, usually too small for withdrawal of animal; mantle cavity often lost, rotated to right side and facing anteriorly; hermaphroditic; operculum generally lost; nerve ganglia (clusters) very concentrated; marine except for 4 species; about 4,000 species.

Order Cephalaspidea

Shell present, often capable of containing whole body; head shield developed; Acteonidae with operculum; 14 families.

Order Pyramidellacea

Spiral shell; operculum present; gill and radula absent; long proboscis with stylet; ectoparasitic; in warm oceanic areas, generally minute.

Order Acochlidacea

Three families with visceral mass longer than foot; 4 species in fresh water; a few with sexes in separate animals; size minute.

Order Philinoglossacea

No head appendages; gill lacking; no external shell; 2 families.

Order Anaspidea

Shell reduced to flat plate; feed on large seaweed rather than microscopic algae; sea hares (Aplysiidae); 1 other small family.

Order Notaspidea

Shell and gill usually present; no parapodia (extensions of foot); sperm groove open; shell prominent, reduced, or hidden by mantle; 2 families.

Order Sacoglossa

One file of radular teeth; sperm duct a closed tube; shell reduced to bivalved (Julidae); many feed by sucking juices out of algae; several families with uncertain limits.

Order Thecosomata

Shell present; pelagic ciliary feeders; no gill; 6 families.

Order Gymnosomata

Shell absent; no mantle cavity; complicated feeding mechanisms; pelagic carnivores; 7 families.

Order Nudibranchia

Sea slugs without shell, mantle cavity, osphradium, or internal gill; many feed on sessile animals; few swimmers (family Tethyidae); highly colourful, often conspicuous.

Subclass Pulmonata

Mantle cavity altered into a pulmonary sac; no gills or operculum; 1 auricle of heart anterior to ventricle; hermaphroditic; shell spiral to limpetlike, often reduced to a fragment hidden by mantle; mainly terrestrial or freshwater, few marine; about 28,000 species.

Superorder Systellommatophora

Mantle cavity absent; anal and usually nephridial opening at posterior; male gonopore behind right tentacle; female gonopore middle of right side; sole of foot narrow; no shell; 2 pairs of retractile, or invaginable, tentacles; marine (Onchidiidae), terrestrial and herbivorous (Veronicellidae), or terrestrial and carnivorous (Rathouisiidae); about 200 species.

Superorder Basommatophora

Mantle cavity present; eyes at base of 1 pair of tentacles; male and female gonopore separate, usually on right side of body; shell conical to patelliform; mostly freshwater but a few land and marine taxa; about 1,000 species. (No agreement exists concerning suprafamilial classification of the Basommatophora. The following superfamilies, though not grouped into formal orders and suborders, are listed in order of increasing specialization.)

Superfamily Patelliformia. Brackish water or marine limpets with (Siphonariidae) gill-like structures or with a lung (Gadinidae).

Superfamily Amphibolacea. Operculum present; shell conical; with pulmonary cavity; brackish water; burrow in sand; 1 family.

Superfamily Ellobiacea. Conical shells; pulmonary chamber, in tidal zone or salt flats, under rocks in spray zone, or completely terrestrial; 2 families.

Superfamily Lymnaeacea. Small to large, spiral-shelled snails of ponds, lakes, and rivers; 1 limpet group (Lancidae) and larger typical group (Lymnaeidae).

Superfamily Ancylacea. Limpets (Ancylidae), ramshorns (Planorbidae), and pond snails (Physidae); all restricted to freshwater habitats.

Superorder Stylommatophora

Mantle cavity a pulmonary sac; gonopores with common opening on right side or at most narrowly separated; shell conical to vestigial, heavily to weakly calcified; eyes at tips of upper (usually) tentacles; terrestrial; about 26,800 species.

Order Orthurethra

Pore of ureter opening into mantle cavity (part of the viscera) near anterior margin of lung after ureter passes forward from anterior kidney margin; about 6,000 species.

Superfamily Achatinellacea. Minute to medium-sized Pacific land snails with multicuspid radular denticles; many Hawaiian species highly coloured and variable.

Superfamilies Cionellacea and Pupillacea. Minute leaf-litter to arboreal snails, occasionally (Enidae) large; shells often with denticles in the aperture; 10 families.

Superfamily Partulacea. Small, generally arboreal snails found on high volcanic islands of Polynesia and Micronesia, a few in Melanesia.

Order Mesurethra

Ureter represented by lateral opening of very short kidney, pore of ureter opening near or behind middle of mantle cavity; about 1,500 species.

Superfamily Clausiliacea. Elongated shells of West Indian shore salt-spray zone (Cerionidae) or Andean mountains of South America and Eurasia (Clausiliidae).

Superfamily Strophocheilacea. Large helicoidal to elongated shells of South America (Strophocheilidae) or southwestern Africa (Dorcasiidae).

Order Sigmurethra

Ureter originates near anterior margin of kidney, follows backward to posterior end, then reflexes forward along hindgut to open alongside anus; position greatly altered in sluglike forms; about 18,000 species.

Suborder Holopodopes. A group of 4 superfamilies.

Superfamily Achatinacea. Besides the giant African snail, 4

families, including many species spread by commerce throughout the world.

Superfamilies Streptaxacea and Rhytidacea. Carnivorous snails and slugs (4 families) in most tropical areas, plus the herbivorous Acavidae of Australia, Sri Lanka, and Madagascar.

Superfamily Bulimulacea. Large, often arboreal snails of Melanesia and Neotropica (Bulimulidae); long, cylindrical snails of West Indies and Central America (Urocoptidae).

Suborder Aulacopoda. A group of 3 superfamilies.

Superfamily Succineacea. A problematic group including amber snails (Succineidae), which inhabit swamps and damp areas, and peculiar slugs from the South Pacific (Athoracophoridae).

Superfamily Arionacea. A group possessing marginal teeth of radula with squarish basal plates and 1 to several cusps; small litter or tree snails mainly in Southern Hemisphere (Endodontidae); slugs (Arionidae and Philomycidae) in the Northern Hemisphere.

Superfamily Limacacea. Marginal teeth of radula with narrow, lengthened basal plates, usually unicuspid; zonitid snails with smooth shells and many sluglike species, common in wet, tropical areas and in temperate regions; about 12 families, including limacid and milacid slugs.

Suborder Holopoda. A group of 3 superfamilies.

Superfamily Polygyracea. Common woodland snails of eastern North America (Polygyridae), plus a Neotropical group (Thysanophoridae) and a relict group of Asia (Corillidae).

Superfamily Oleacinacea. Carnivorous (Oleaciniidae) and herbivorous (Sagdidae) snails of the Neotropical region.

Superfamily Helicacea. Land snails without (Oreohelicidae and Camaenidae) or with (Bradybaenidae, Helminthoglyptidae, and Helicidae) accessory glands on the genitalia; dominant land snails in most regions, including the edible snails of Europe (Helicidae). (G.A.So.)

Bivalves (clams, oysters, mussels, and relatives)

The class Bivalvia, sometimes called Pelecypoda, is characterized by a shell that is divided from front to back into left and right valves. Enclosure in a shell has resulted in loss of the head. Similarly, the adoption of deposit-feeding using labial palps and, later, suspension feeding utilizing the respiratory gills modified into organs of filtration called ctenidia have resulted in loss of the radula from the mouth.

GENERAL FEATURES

Size range and diversity of structure. Bivalves range in size from about one millimetre (0.04 inch) in length to the giant clam of South Pacific coral reefs, *Tridacna gigas,* which may be more than 137 centimetres (54 inches) in length and weigh 264 kilograms (582 pounds). Such an animal may have a life span of about 40 years.

The shell forms are used in classification. In most surface-burrowing species (the hypothetical ancestral habit) the shells are small, spherical or oval, with equal left and right valves (Figure 8). In deeper-burrowing species the shells are laterally compressed, permitting more rapid movement through the sediments. The shells of the most efficient burrowers, the razor clams *Ensis* and *Solen,* are laterally compressed, smooth, and elongated. Surface-burrowing species may have an external shell sculpture of radial ribs and concentric lines, with projections that strengthen the shell against predators and damage.

From (Cerastoderma) W. de Haas and F. Knorr, *The Young Specialist Looks at Marine Life* (1968), Burke Publishing Co., London

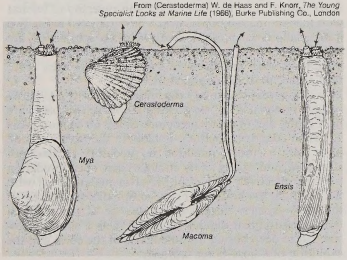


Figure 8: *Shallow- and deep-burrowing dimyarian bivalves. Cerastoderma* lives close to the sediment surface and has limited burrowing powers. When disturbed, *Mya* retracts its long siphons as does *Macoma,* but *Macoma* and *Ensis* can also dig deeper into the sediment using the muscular foot. Arrows indicate direction of current flow into the mantle cavity via the inhalant and exhalant siphons.

A triangular form, ventral flattening, and secure attachment to firm substrates by byssal threads (byssus; chitinous threads secreted by the foot) have allowed certain bivalves to colonize hard surfaces. This form, referred to as epibyssate for its byssal attachment to surfaces, has been adopted by many groups, most importantly the true mussels (family Mytilidae) of marine and estuarine shores and the family Dreissenidae of fresh and estuarine waters. Such a shell form and habit evolved first within sediments (endobyssate), where the byssus serves for anchorage and protection when formed into an enclosing nest. The byssus is a larval feature retained by some bivalve groups into adult life. The significance of this is crucial to an understanding of how bivalves have radiated. In addition to the triangular form, other bivalves have used the byssus to attach securely within crevices and thus to assume a laterally flattened, circular shape. The best example of this is the windowpane shell *Placuna.* This form has allowed the close attachment of one valve to a hard surface, and although some groups still retain byssal attachment (family Anomiidae), others have forsaken this for cementation, as in the true oysters (family Ostreidae), where the left valve is cemented to estuarine hard surfaces. Some scallops (family Pectinidae) are also cemented, but others lie on soft sediments in coastal waters and at abyssal depths. By limiting shell thickness to reduce weight, smoothing the shell contours to reduce drag, and assuming an aerofoil-like leading edge, such scallops can swim many metres.

Endobyssate and epibyssate

Shell form in the bivalves is thus intimately related to habitat and the relative degree of exposure to predation. From the simple burrowing, equivalve ancestor, the various bivalve groups have repeatedly evolved an elongated, triangular or circular shell; thus, similar body adaptations have been responses to similar modes of life.

Distribution and abundance. Most bivalves are marine and occur at all depths in or upon virtually all substrates. In shallow seas, bivalves are often dominant on rocky and sandy coasts and are also important in offshore sediments. They occur at abyssal and hadal depths, either burrowing or surface-dwelling, and are important elements of the midoceanic rift fauna. In addition, bivalves bore into soft shales and compacted muds but may be important also in the bioerosion of corals. Bivalves thus occur at all latitudes and depths, although none are planktonic. There are also estuarine bivalves, and two important families, the Unionidae and Corbiculidae, are predominantly freshwater with complicated reproductive cycles. There are no terrestrial bivalves, although some high-intertidal and freshwater species can withstand drought conditions.

To be expected within a class comprising more than 8,000 living species, abundance varies considerably. Commensal and parasitic species are small, often highly host-specific, and comprise some of the rarest animals. Others, such as cockles and clams on soft shores and mussels and oysters on rocky coasts, can occur in densities high enough that they dominate entire habitats and assume important roles in nutrient cycles.

Importance. The total marine catch of mollusks is twice that of crustaceans, and the great majority of this is bivalve. Some three million metric tons (6,615,000,000 pounds) of bivalves are harvested throughout the world each year. Virtually all bivalves, with the possible exception of the thorny oyster *Spondylus,* are edible and fall into the main categories of oysters, mussels, scallops, and clams.

Economic importance

The most important edible oysters are representatives of the genus *Crassostrea,* notably *C. gigas* in the western Pacific, *C. virginica* in North America, and *C. angulata* in Portugal. Most mussels are cultivated on ropes suspended from floats. The European mussel *Mytilus edulis* has been introduced into the northern Pacific, and the

practice now flourishes widely in Japan and China. Most scallops, *Pecten, Placopecten,* and *Amusium,* are caught by offshore trawlers, although cultivation is being attempted. A wide variety of clams are cultivated—*e.g., Mya arenaria* and *Mercenaria mercenaria* in the North Atlantic and *Venerupis japonica* and *Tapes philippinarum* in the Pacific. In some parts of the world, red tides, caused by large numbers of toxic protozoan dinoflagellates, are lethal to fish and certain invertebrates. Bivalves, by virtue of their filter-feeding apparatus, concentrate the toxin and, if eaten by humans, can cause paralysis or death.

Pearls

Bivalves of the genera *Pinctada* and *Pteria* have been collected in many tropical seas for the natural pearls they may contain, although in many countries, most notably Japan, pearl oyster fisheries have been developed. The windowpane oyster, *Placuna placenta,* has flat translucent valves that are used, primarily in the Philippines, in the manufacture of lampshades, trays, mats, and bowls, collectively called *tapis.* In developing countries, many kinds of bivalve shells are used in the manufacture of jewelry and ornaments.

Bivalves are important agents in bioerosion, most notably of calcium carbonate rocks and wood in the sea. Piddocks (family Pholadidae) bore into concrete jetties (particularly where the source of obtained lime is coral), timber, and plastics. Shipworms (family Teredinidae) bore softer woods. Date mussels (*Lithophaga*) bore into rocks and corals. Marine mussels (family Mytilidae) foul ships, buoys, and wharves; they may also block seawater intakes into the cooling systems of power stations.

Few bivalves are host to human parasitic infections. Industrial and agricultural effluents—notably trace metals, chlorophenothane (DDT), and chlorinated hydrocarbons—have contaminated bivalves, with subsequent concern over human health.

NATURAL HISTORY

Reproduction and life cycles. Although most bivalves are either male or female (dioecious), some produce both sperm and eggs (hermaphroditic); sexual dimorphism is rare. In dioecious species there is usually an equal division of the sexes. Some groups of bivalves, typically those occupying specialized habitats, have adopted hermaphroditism as a reproductive strategy, although expression of this condition may take various forms (simultaneous, consecutive, rhythmical consecutive, and alternative hemaphroditism). Simultaneous hermaphroditism occurs when sperm-producing tubules and egg-producing follicles intermingle in the gonads (as in the family Tridacnidae), or the gonads may be developed into a separate ovary and testis, as in all representatives of the subclass Anomalodesmata. In consecutive hermaphroditism, one sex develops first. Typically, this is the male phase (protandry), but in a few cases it is the female (protogyny). This is most clearly seen in the wood-boring family Teredinidae, where a young male becomes a female as it ages. Rhythmical consecutive hermaphroditism is best known in the European oyster, *Ostrea edulis,* in which each individual undergoes periodic changes of sex. Alternative hermaphroditism is characteristic of oysters of the genus *Crassostrea,* in which most young individuals are male. Later the sex ratio becomes about equal, and finally most older individuals become female.

Hermaphroditism

Bivalve sperm have two flagellae. Most eggs are small, and synchronized spawning results in the discharge of both types of gametes into the sea for external fertilization. Hermaphrodites either inhale sperm from another individual or fertilize their own eggs within the ctenidia; the eggs are then brooded, typically also within the ctenidia. There, the fertilized eggs, well endowed with yolk, develop directly (without a larval stage), and the young are released as miniature adults. Although ctenidial incubation is most common, there are other patterns: egg capsules are produced by *Turtonia minuta;* a brood chamber is plastered to the shell of the palaeotaxodont *Nucula delphinodonta;* and in members of the Carditidae the female shell is modified into a brood pouch.

Larval stage

For most marine species, however, the fertilized egg undergoes indirect development first into a swimming trochophore larva and then into a veliger larva in which the embryonic shell and rudiments of other organs are established. The veliger has a ciliated velum for swimming and also for trapping minute particles of food. Following a period in the plankton, the veliger settles to the seafloor, where metamorphosis into the adult takes place: the velum is lost, the foot develops and usually secretes one or two byssal threads for secure attachment, and the ctenidia develop.

In the freshwater Unionidae the released larva, called a glochidium, often has sharp spines projecting inward from each valve. The larva is attracted to fish and attaches to either their gills or fins, where it encysts, is temporarily parasitic, and eventually ruptures the cyst wall and falls to the lake floor. There it metamorphoses into an adult.

Ecology and habitats. The division and lateral compression of the shell into two valves is clearly related to the adoption of a burrowing mode of life, which is achieved by a muscular foot. Primitive forms were detritivorous, whereas modern bivalves are filter feeders that have modified the respiratory gills into complex structures called ctenidia. The burrowing, filter-feeding mode of life restricts bivalves to aquatic environments.

Retention of the larval anchoring byssus into adult life has freed many bivalves from soft substrates, allowing them to colonize hard surfaces. This has also been achieved by cementation, as, for example, in oysters.

Movement

There are no pelagic bivalves, except for *Planktomya hensoni,* which is still benthic as an adult but has an unusually long planktonic larval stage. Some bivalves can swim, albeit weakly, when removed from the sediment, as can some file shells. True swimming is, however, seen only in the family Pectinidae but is used mostly as an escape reaction.

Many representatives of the superfamily Galeommatoidea are commensal, a few are parasitic, and both have thus become miniaturized. Most bivalves are found in coastal seas, but their diversity is greatest on continental landmasses, where large rivers create suitable deltaic habitats and the continental shelf is broad. Except on tropical ones with coral reefs, few bivalves are found on islands.

Of the various subclasses, two are most important ecologically: the Heterodonta, which are modern burrowers that feed primarily on suspended material, and the Pteriomorphia, an older group that is epibyssate and dominates hard substrates. Some of their older representatives are endobyssate, exposing their evolutionary history. Most of these two classes occupy a wide diversity of subhabitats, with simple reproductive strategies, external fertilization, and planktonic larvae to effect wide dispersion. They apportion the shallow-water marine domain virtually everywhere. The Palaeoheterodonta are exclusively fresh water and infaunal although a few in South America are epifaunal, but all have significantly more complicated life cycles.

The Palaeotaxodonta are coastal and deepwater detrivores, always infaunal. They share this diversity of habitat with the Anomalodesmata, which have radiated along two lines: shallow-water species that are highly specialized, are hermaphroditic, occupy narrow niches, and have a short planktonic stage and deep-sea species that are even more specialized, most being predators.

Most bivalves are primary consumers, typically exploiting organic material. The two dominant bivalve subclasses are high in the diet of many predators. Some 60 million years ago great adaptive radiation, notably in the Bivalvia, took place with a similar radiation in predatory crustaceans, starfishes, and snails. It is thought that such predation pressure effectively drove the Bivalvia underground with the resultant evolution of many antipredation devices on the shell—spines, ridges, and teeth—or of the habit of burrowing to great depths. On coral reefs a similar pressure led to deep boring into the fabric of the coral and the evolution of a host–borer intimacy.

Locomotion. Unlike in other molluscan groups, locomotion in bivalves is used only when dislodgement occurs or as a means to escape predation.

The bivalve foot, unlike that of gastropods, does not have a flat creeping sole but is bladelike (laterally compressed) and pointed for digging. The muscles mainly responsible

for movement of the foot are the anterior and posterior pedal retractors. They retract the foot and effect back-and-forth movements. The foot is extended as blood is pumped into it, and it is prevented from overinflating by concentric rings of circular, oblique, and longitudinal muscle fibres, which also help to direct pedal extension and permit fine mobility.

Burrowing

During burrowing, the foot is greatly extended anteriorly from between parted shell valves. Taking a grip on the substratum, typically by dilation of the tip, the pedal retractors pull the shell downward. This is accompanied by sharp adduction of the shell valves, forcing water out of the mantle cavity into the burrow, helping to fluidize the sediment, and making movement through it more efficient. So effective is this mechanism that fast burrowers, when removed from the sediment, can swim.

Food and feeding. The primitive bivalve was almost certainly a detritivore (consumer of loose organic materials), and the modern palaeotaxodonts still pursue this mode of life. The posterior leaflike gills serve principally for respiration; feeding is carried out by the palp proboscides, which collect surface detritus.

The vast majority of other bivalves feed on the plant detritus, bacteria, and algae that characterize the sediment surface or cloud coastal and fresh waters. The gills have gradually become adapted as filtering devices called ctenidia. The primitive posterior respiratory gills have enlarged and moved to lie lateral to the body as paired folds, or demibranchs. Further increases in surface area have been achieved by folding the platelike gill lamellae into plicae. Each lamella comprises vertical rows of filaments upon the outer head of which are complex arrays of cilia that create a flow of water through the gill, form a filtration barrier, and transport retained particles to food grooves in the dorsal axes or ventral margins of the ctenidia. Bound in mucus, the food is transported to the mouth via the labial palps, where further selection occurs (see below *Internal features*).

Evolution of the ctenidia

Two groups of bivalves have exploited other food sources. These are the shipworms (family Teredinidae) and giant clams (family Tridacnidae). Shipworms are wood borers and are both protected and nourished by the wood they inhabit. They possess ctenidia and are capable of filtering food from the sea. When elongating the burrow, they digest the wood as well. In the Tridacnidae, symbiotic zooxanthellae (minute algal cells) are contained within the inhalant siphon. The relationship between clam and algae is probably mutually beneficial, the algae having access to the dissolved waste products of the clam and the clam benefiting from the nutritional value of either culled zooxanthellae or their metabolic products.

A few bivalves are parasitic—*e.g.*, species of *Entovalva*, which live either in the esophagus or upon the body of sea cucumbers (Holothuroidea), and the larvae of freshwater Unionidae, which parasitize fish.

The most exotic adaptations of the basic bivalve feeding plan are found in two groups of deepwater bivalves. These are scallops of the genus *Propeamussium* and the various deepwater families of the Anomalodesmata. In *Propeamussium* what appear to be typical ctenidia are present in the mantle cavity, but on closer examination these prove to be wholly atypical in that the filament heads are internal. The ctenidia are incapable of filtering. The gut is minute, and detected prey is sucked into the mantle cavity by an inrush of water when the valves open. The food is then pushed into the mouth with the foot.

Many deepwater Anomalodesmata have modified the typical bivalve ctenidium into a septum—the "septibranch" ctenidium—that creates pressure changes within the mantle cavity and produces sudden inrushes of water, carrying prey into a funnellike inhalant siphon (*Cuspidaria*). Food is then pushed into the mouth by the palps and foot. Others evert the inhalant siphon, like a hood, over the prey (*Poromya* and *Lyonsiella*). Prey items include small bottom-dwelling crustaceans, polychaete worms, and larvae of other benthic animals.

Adaptations

Associations. The greatest affinity of bivalves is with coral reefs. Indo-Pacific, but not Caribbean, reefs are the habitat of giant clams, *Tridacna*. Dead corals are bored by representatives of the Gastrochaenidae, living corals by species of *Lithophaga*. A greater degree of intimacy between living coral and bivalve borer is now known, some species associating with a single coral.

Similarly with wood borers: piddocks (Pholadidae) are more common in hardwoods, while shipworms (Teredinidae) favour softwoods. In the degradation of wood in the sea, a variety of species may colonize it with time and with depth.

One group of bivalves, the superfamily Galeommatoidea, form highly intimate relationships with other marine invertebrates, particularly on soft shores and coral reefs. Typically less than 10 millimetres (0.4 inch) long, most are commensal; *i.e.*, they form an association in which there is no detriment to the host and exploit it for protection, food, and respiratory currents. On soft shores they share the burrows of polychaete worms and crustaceans, sometimes attaching to the body of the host.

FORM AND FUNCTION

General features. The bivalve body comprises a dorsal visceral mass and a ventral foot, which is enclosed within a thin mantle, or pallium. The mantle secretes from its outer surface a shell divided into left and right valves. Between the body and mantle is the mantle cavity, within which hang the left and right gills, or ctenidia. The ctenidia are divided into two demibranchs, inner and outer, each in turn comprising inner and outer lamellae. Anteriorly, the ctenidia unite with paired (left and right) labial palps, which are food-sorting organs. The mantle margin can be fused at various places leaving medial apertures anteriorly for the extension and retraction of the locomotory foot and, in most bivalves, posteriorly to create inhalant and exhalant apertures that may be formed into siphons of variable length according to habitat. Foot and siphons can be withdrawn between the shell valves into the mantle cavity for protection.

External features. The bivalves occupy a wide variety of habitats and, as a consequence, deviate widely from the basic body plan. The shell form is an obvious adaptation to the environment. Shells of many modern burrowers are ornamented and coloured, and those of near-surface-dwelling cockles are thick and radially ribbed. These adaptations stabilize the animal in the substrate and may confer some degree of protection against predators. Such bivalves are slow burrowers. In contrast, the shells of deep-burrowing species are thin and nonornamented. They are often brightly coloured, as in the Tellinidae. The shell is laterally compressed and thus more bladelike, but the adductor muscles are still of similar size (the isomyarian form). Such structural features adapt the animal for rapid movement through the sand; long siphons project to the surface above. Deep burrowing has been achieved by a different mechanism in the razor shells (e.g., the family Solenidae), where the anterior region of the shell is reduced and the posterior enormously elongate. Because of their short siphons, *Ensis* and *Solen* live close to the sediment surface, but, with the lateral compression of their polished shells, they are among the most proficient burrowers. Other bivalves—*e.g.*, *Mya* (family Myidae)—live at great depths but do not burrow rapidly. The shell is largely unornamented and wider to accommodate the greatly elongated siphons, which can be retracted deeply within its borders.

The shell

Rock and wood boring are also specialized consequences of burrowing—the evolution of borers proceeded from the habitation of stiff muds or from nestling within crevices. Mechanical borers tunnel anterior end first; that face of the shell having a sculpture of spines. Borers derived from a nestling epibyssate ancestor are chemical borers that produce a calcium carbonate chelating secretion from the mantle margin. In such cases the shell is typically smooth, although calcareous encrustations on the posterior shell protect the borer from aperture-attacking predators. Reduction of the anterior adductor (the anisomyarian form) creates a triangular-shaped shell, as in the buried fan shell *Pinna* (Pinnidae) and the mussels (Mytilidae) of rocky coasts. Although such bivalves lack ornamentation, the shell is typically thick and dark.

Mechanical versus chemical borers



Figure 9: *Anisomyarian and monomyarian bivalves, with sketches of the internal gill and muscle arrangements.*
Arrows indicate inhalant and exhalant water currents. (A) *Pinna*, endobyssate with reduction of the anterior, and enlargement of the posterior, adductor. (B) *Geukensia*, endobyssate with reduction of the anterior, and enlargement of the posterior, adductor. (C) *Mytilus*, epibyssate with reduction of the anterior, and enlargement of the posterior, adductor. (D) *Pinctada*, epibyssate, laterally flattened, with loss of the anterior adductor. (E) *Lima*, epibyssate and monomyarian, with long tentacles and capable of limited swimming. (F) *Pecten*, with loss of the anterior adductor, byssus, foot, and associated musculature and capable of swimming. (G) *Ostrea*, cemented and with loss of the anterior adductor, byssus, foot, and associated musculature.

From (Geukensia) S.M. Stanley, *Relation of Shell Form to Life Habits of the Bivalvia (Mollusca)*, Geological Society of America Memoir no. 125 (1970); (*Mytilus, Pinctada, Lima*) R.C. Moore (ed.), *Treatise on Invertebrate Paleontology: Mollusca 6* (1969), Geological Society of America and University of Kansas Press; (Ostrea) W. de Haas and F. Krivor, *The Young Specialist Looks at Marine Life* (1966), Burke Publishing Co., London

Loss of the anterior adductor creates a shell with a circular outline, left and right valves being either equal or unequal. In some, lateral flattening and byssal attachment allows occupation of narrow crevices. Cementation by either valve is a further consequence of the loss of the anterior adductor muscle (the monomyarian form). Subsequent freedom from attachment, as in the scallops (Pectinidae), is associated with an almost circular outline, flat upper and cup-shaped lower valves, a deep radial sculpture, and, typically, bright coloration (*Pecten*).

Internal features. The general classification of the bivalves is typically based on shell structure and hinge and ligament organization (Figure 9). The internal anatomy is also a tool in classification, particularly the organs of the mantle cavity, the pattern of water movement through it, and the structure and functioning of the ctenidia and labial palps. Early anatomists established a correlation between shell and gill structure that is still often used as a basis for classification but which is now relegated to defining the evolutionary sequence from a deposit-feeding to a filter-feeding mode of life.

The primitive bivalve form

Nucula, from the subclass Protobranchia, reflects the primitive bivalve ancestor. Burrowing close to the sediment surface, *Nucula* is equivalve, anteriorly and posteriorly symmetrical, and isomyarian. The medial foot is wide. There are no mantle fusions ventrally, and the aerating water current passes through the mantle cavity from front to back, a feature not typical of most modern bivalves. The structure of the small gills (Figure 10), located posteriorly, is interpreted as being similar to the earliest mollusks—hence the name protobranch, or "first gills." The paired gills, separated by a central axis, are suspended from the mantle roof. Individual short gill filaments extend outward from either side of the axis, and cilia on their surfaces create an upward respiratory water current that passes from the mantle cavity below the gill (the

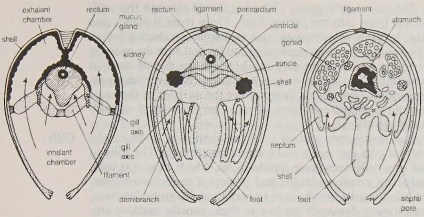


Figure 10: Transverse sections through the bodies of (A) *Nucula*, with a protobranch gill, (B) *Spisula*, with a lamellibranch gill, and (C) *Poromya*, with a septibranch gill. Arrows indicate the water currents through the gill for respiration but also for filter feeding in *Spisula*.

infrabranchial, or inhalant, chamber) to that area above it (the suprabranchial, or exhalant, chamber). The anus and the urogenital pores also open into the exhalant chamber so that all waste products exit the animal in the exhalant stream. The paired labial palps in the mantle cavity are used in feeding. The outer palp on each side bears a long, extensible proboscis with a ciliated groove that collects organic material, which is then sorted by the inner pair and outer pair of palps. Certain particles are transferred to the mouth by the ciliary currents of the inner pair of palps, while the remaining particles are sent by the outer palps into the mantle cavity as a mucus-bound mass known as pseudofeces, which are ejected by periodic contractions of the adductor muscles.

An important event in the evolution of the modern bivalve from the more primitive form illustrated above was the reorientation of the anterior inhalant stream to the posterior below the exhalant stream so that water both enters and exits the mantle cavity posteriorly. For burrowing bivalves, such a body organization allows deep burrowing in a vertical (head down) orientation, and thus escape from the sediment surface. These changes generally are associated with changes in the method of feeding and, as a consequence, the selective fusion of left and right mantle margins to exclude sediment from the mantle cavity.

Evolution of a new gill structure

The burrowing *Spisula* illustrates these changes. It, like *Nucula*, is equivalve and anteriorly and posteriorly symmetrical (isomyarian). The mantle margin is fused ventrally, allowing the foot to extend through an anterior pedal gape. The posterior inhalant and exhalant orifices are formed into tentacle-fringed siphons. The gills are here positioned on either side of the visceral mass. Gill filaments are greatly elongated and folded (forming the shape of a W) to increase their surface area. The central axis of the W joins it to the body, and the outermost arms unite with the visceral body on one side and the mantle on the other. A complex arrangement of cilia on the apex of each filament constituting the gill lamellae draws a water current through the gill, which provides oxygen, but more importantly now sieves food from this current and transfers such material along tracts in the gill axes or their ventral margins (bound in mucus) toward the labial palps. The palps process this food and eliminate the pseudofeces as in *Nucula*.

The modified gill is called a ctenidium, and its structure is best explained by the term lamellibranch. The lamellibranch structure may be further qualified as filibranch, pseudolamellibranch, or eulamellibranch. In filibranchs the filaments are only weakly united by cilia, and often the ctenidium retains some inherent sorting mechanism. Collection and sorting of potential food has not yet been definitively ascribed to gills and labial palps, respectively. In the pseudolamellibranch ctenidium, filaments and lamellae are more securely united, and an inherent sorting mechanism still exists in some. In many, however, the filaments are vertically aggregated into folds, or plicae, that greatly increase the total surface area. In the eulamellibranch ctenidium the filaments and lamellae are closely united, the selection function is lost, and gill structure varies widely. Most modern bivalves are filter feeders, and except in a few members the siphons suck in particles suspended in the water column.

In the deep seas, modification of the lamellibranch ctenidium has allowed the adoption of carnivory. The predatory bivalves of the subclass Anomalodesmata have an inhalant siphon that can be everted rapidly to form a capacious hood beneath which small crustaceans are trapped and brought into the mantle cavity. The eversion of the siphon is assisted by a horizontal septum across the mantle cavity, which is derived from the mantle and the greatly reduced ctenidium. This is the septibranch ctenidium.

Importance of the byssus

The release from a burrowing mode of life has been facilitated by the retention of a larval structure (the byssus) into adult life. The byssus, secreted by a gland in the foot, secures the animal to a hard surface in preparation for burrowing. Its retention and enlargement in the adult has provided a secure means of attachment to the open surfaces of rocks in the intertidal, estuarine, and fresh waters.

In the triangular mussels (Mytilidae) of such habitats the anterior is reduced, and the body and organs of the mantle cavity are contained in the expanded posterior regions of the shell. The reduction of the anterior adductor muscle is matched by a reduction in the size of the anterior pedal retractor muscles (and enlargement of the posterior equivalents). Since such muscles are less concerned with locomotion and more with pulling the shell down against the substrate, they are more correctly redefined as byssal retractors. The ctenidia and palps fulfil the same role as they do in burrowing lamellibranch bivalves, but, because of the triangular cross section of the shell, they come to lie largely underneath the visceral mass instead of beside it.

Further reduction of the anterior adductor, leading to its eventual loss, creates what is called the monomyarian condition. In bivalves with such a configuration, the anterior shell and mantle are confined to a small area; the foot, where present, is always greatly reduced and positioned anteriorly. The visceral mass and organs of the mantle cavity are arranged around the central posterior adductor muscle, and there is extreme reduction or loss of the anterior pedal/byssal retractor muscles. Shell valves may be so compressed that the space between them, as in *Placuna*, the windowpane oyster, is very narrow. Alternatively, as in oysters and scallops, one valve is cup-shaped, with the other fitting against it like a lid. In such a case, the body occupies the former valve, the left in oysters and generally the right in all others, such as the scallops. In these bivalves the bilateral symmetry of the shell and mantle is replaced by a radial symmetry from the midpoint of the hinge line. In these bivalves, too, the adductor muscle is more clearly demarcated into "quick" (striated) and "slow" (smooth) components for rapid and sustained adduction respectively. The capacity for work of the greatly enlarged quick component of the scallop muscle permits rapid adduction that facilitates swimming by directing jets of water out of the mantle cavity to each side of the hinge line characterized by shell auricles.

Shell structure

The shell. The bivalve shell is made of calcium carbonate embedded in an organic matrix secreted by the mantle. The periostracum, the outermost organic layer, is secreted by the inner surface of the outer mantle fold at the mantle margin. It is a substrate upon which calcium carbonate can be deposited by the outer surface of the outer mantle fold. The number of calcareous layers in the shell (in addition to the periostracum), the composition of those layers (aragonite or aragonite and calcite), and the arrangement of these deposits (*e.g.*, in sheets, or foliate) is characteristic for different groups of bivalves. Middorsally an elastic ligament creates the opening thrust that operates against the closing action of the adductor muscles. The ligament typically develops either externally (parivincular) or internally (alivincular) but comprises outer lamellar, and inner fibrous, layers secreted by the mantle crest. The ligament type is generally characteristic of each bivalve group. The hinge plate with ligament also possesses interlocking teeth to enforce valve alignment and locking, when closed, to prevent shear. Many variations in teeth structure occur.

The mantle and musculature. The mantle lobes secrete the shell valves; the mantle crest secretes the ligament and hinge teeth. Growth takes place at the margins, although increases in thickness take place everywhere. The mantle is withdrawn between the shell valves by mantle retractor muscles; their point of attachment to the shell being called the pallial line.

Musculature

The musculature comprises two (dimyarian) primitively equal (isomyarian) adductor muscles; the anterior and the posterior. The anterior of these may be reduced (anisomyarian; heteromyarian) or lost (monomyarian). Only very rarely is the posterior lost and the anterior retained.

Internal to the adductors are paired anterior and posterior pedal retractor muscles. Where the anterior adductor muscle is reduced, so are the anterior pedal retractors. In highly active burrowers, paired anterior pedal protractors and pedal elevator muscles occur—for example, the family Trigonioidea.

In byssally attached bivalves, pedal retractors are reduced and byssal retractors serve to pull the animal down in closer opposition to the rock surface. In oysters, commensurate with the extreme reduction of the foot, pedal retractors are lost. This is also the case in swimming scallops.

The nervous system and organs of sensation. The nervous system is simple, reflecting the sedentary habit. In primitive bivalves (*e.g.,* Palaeotaxodonta) there are four pairs of ganglia—cerebral, pleural, pedal, and visceral. In all other bivalves the cerebral and pleural ganglia are fused into two cerebropleural ganglia, located above and on either side of the esophagus. The pedal ganglia are in the base of the foot, and the visceral ganglia are located under the posterior adductor muscle. Nerve fibres arising from the cerebropleural ganglia extend to the pedal and visceral ganglia. In some bivalves with long siphons, there are accessory siphonal ganglia, and in many swimming bivalves the visceral ganglia are much enlarged, presumably to coordinate complex swimming actions.

Again reflecting the sedentary life, sensory functions are largely taken over by the posterior mantle margins and typically comprise tentacles developed from the middle mantle folds that are mechanoreceptors and chemoreceptors. Scallops (family Pectinidae) have complex eyes with a lens and retina. In other bivalves, eyes are simple ciliated cups, although some variation is possible. In the predatory deepwater septibranchs the inhalant siphon, which captures food, is surrounded by tentacles that have vibration-sensitive papillae for detecting the movements of prey.

Statocysts

Situated close to the pedal ganglia but with direct connections to the cerebropleural ganglia are a pair of statocysts, which comprise a capsule of ciliated sense cells. In the lumen is either a single statolith or numerous crystalline statoconia. Their points of contact with the surrounding cilia yield information about the animal's orientation. Additionally, most bivalves with or without eyes have light-sensitive cells that respond to shadows. Below the posterior adductor muscle an osphradium has been identified in some bivalves that may monitor water flow and quality.

The digestive system and nutrition. The bivalve digestive system comprises a complex stomach and associated structures but an otherwise simple intestine. The various types of stomach have been used to erect an alternative classification. Digestion typically takes place in two phases: extracellular in the stomach and intracellular in the digestive diverticula, opening laterally from the stomach wall. Transport of food particles is effected by cilia, creating an array of tracts and sorting areas within the stomach. The principal organ of extracellular digestion is the crystalline style. It is rotated in its sac by cilia; the head, projecting into the stomach, grinds against a part of the stomach wall lined by a chitinous gastric shield. As it rotates, it dissolves, releasing enzymes and initiating primary extracellular digestion of the mucus-bound food. Products of this process are passed in a fluid suspension into large embayments and thence into the digestive diverticula, where intracellular digestion takes place. Waste material is consolidated in the midgut and rectum and expelled as firm fecal pellets from an anus opening into the exhalant stream. Feeding and digestion are highly coordinated, typically regulated by tidal and diurnal cycles.

The excretory system. Blood is forced through the walls of the heart into the pericardium. From there it passes into the kidneys where wastes are removed, producing urine. The paired kidneys (nephridia) are looped with an opening into the pericardium and another into the suprabranchial chamber. The kidneys may be united. Bivalves also possess pericardial glands lining either the auricles of the heart or the pericardium; they serve as an additional ultrafiltration device.

Gills

The respiratory system. In the primitive bivalves the paired gills are small and located posteriorly. The gills in all other bivalves (save septibranchs, which have lost their gills) are greatly enlarged and possess a huge surface area. While the gills are thought to serve a respiratory function, respiratory demands are low in these mostly inactive animals, and, since the body and mantle are both bathed in water, respiration probably takes place across these surfaces as well. Such a mechanism has been demonstrated for a few bivalves, most notably freshwater species that are exposed to occasional drought. In such species, drying induces slight shell gaping posteriorly, the mantle margins exposing themselves to air. For most intertidal bivalves (which are alternately exposed to wetting and drying), respiration all but ceases during the drying phase.

The vascular system. The heart, enclosed in a pericardium, comprises a medial ventricle with left and right auricles arising from it. Blood oxygenated within the ctenidia flows to the auricles and from there to the ventricle, where it is pumped into anterior and posterior aortas. The blood then enters hemocoelic spaces in the mantle and visceral mass and returns to the heart via the ctenidia or the kidneys. The blood serves both to transport oxygen and metabolic products to tissues deep within the body and as a hydrostatic skeleton (for example, in the extension of the foot during locomotion and siphons during feeding). There are amoeboid corpuscles but, except in a few bivalves, no respiratory pigment.

The reproductive system. The reproductive system is simple and comprises paired gonads. These gonads discharge into the renal duct in primitive bivalves but open by separate gonopores into the suprabranchial chamber in more modern bivalves. Typically, the sexes are separate, but various grades of hermaphroditism are not uncommon. Eggs and sperm are shed into the sea for external fertilization in most bivalves, but inhalation of sperm by a female permits a type of internal fertilization and brooding of young, usually within the ctenidia.

Significant adaptations

Features of defense and aggression. The most significant adaptation is the earliest division of the shell into two valves within which the animal was wholly contained. Slow components of the adductor muscle permit sustained adduction, while the interlocking hinge teeth prevent shear. In addition, the shell may be strongly ridged, forming an interlocking shell margin, and it may be concentrically ringed with spines or sharp ridges projecting outward. Posterior sense organs, including photophores and eyes, are developed around the siphons and mantle margins. Detection leads to withdrawal deep into the sediment by burrowing species. In such animals the shell is smooth and compressed. Scallops respond to predation by swimming; shallow-burrowing cockles can leap using the foot. In the razor clams the siphons can break off (autotomize) when bitten, to be regenerated later. Similarly, noxious secretions are produced by the similarly autotomizing long tentacles of the Limidae (file shells). The unique pallial organ of fan shells (family Pinnidae) produces a secretion of sulfuric acid when bitten.

Only the deepwater subclass Anomalodesmata (families Verticordiidae, Poromyidae, and Cuspidariidae) and the scallops are predators. Prey is captured either in the sudden rush of water into the mantle cavity or by the rapid eversion of the inhalant siphon.

EVOLUTION AND PALEONTOLOGY

Oldest bivalve

The oldest known bivalves are generally believed to be *Fordilla troyensis,* which is best preserved in the late Early Cambrian rocks of New York (about 550 million years ago), and *Pojetaia runnegari* from the Cambrian rocks of Australia. *Fordilla* is perhaps ancestral to the pterio-

morph order Mytiloida, *Pojetaia* to the Palaeotazodonta order Nuculoida.

By the Ordovician period (505 to 438 million years ago) most modern subclasses were represented by definable ancestors. The oldest Ordovician bivalves are, however, the subclass Palaeotaxodonta, which are thought to have given rise to the Cryptodonta by elongation. Modern assessment of their shell structure and body form, notably with the possession of posterior protobranch gills and with palp proboscides for deposit feeding in the Palaeotaxodonta, generally supports this view. An extinct subclass Actinodontia also arose in the Ordovician period and may be represented today by the superfamily Trigonioidea (placed in the subclass Palaeoheterodonta), which are an aberrant group of the subclass Pteriomorphia. The remaining, more typical, members of the Pteriomorphia also arose at this time and persist today, still characteristically occupying a range of substrate types but with byssal attachment and a trend toward loss of the anterior adductor muscle. The common mussels (family Mytilidae) are thought to be derived from an extinct group, the family Modiomorphidae. The subclass Orthonotia also arose in the Ordovician period and are the probable ancestors of the deep-burrowing razor shells (Solenoidea). The origins of the subclass Anomalodesmata are less clear, but they too arose in the Ordovician period and may have links to the order Myoida, which presently includes deep-burrowing forms and borers. Representatives of the superfamily Lucinoidea are very different from all other bivalves, with an exhalant siphon only and an anterior inhalant stream. Some of these deposit feeders also possess, like the subclass Cryptodonta, sulfur-oxidizing bacteria in the ctenidia and are thought to have ancient origins, represented by the fossil *Babinka. Babinka* is itself interesting and is closely related either to *Fordilla,* one of the oldest bivalves or to the ancestors of the molluscan class Tryblidia. Today the superfamily Lucinoidea is generally placed within the subclass Heterodonta, which is a younger group that traces back to the Paleozoic era, when the first radiation of all bivalves took place.

The stamp of modernity was placed upon the Bivalvia in the Mesozoic era (245 to 66.4 million years ago), when virtually all families currently recognized were present. Throughout time, the fortunes of the subclasses have waxed and waned, with repeated modification of form allowing repeated diversification into different habitats. Similarity of habitat is matched by similarity in structure and form, allowing for various interpretations of the fossil record. It is clear, however, that most modern bivalves can trace their ancestry back a long way and that the inherent plasticity of the bivalve form is responsible for the success of a molluscan experiment in lateral compression of the shell.

CLASSIFICATION

No system of classification erected for the Bivalvia has been accepted by all. Paleontologists interpret bivalves on the basis of shell features, notably shell and ligament structure, arrangement of hinge teeth, and body form as interpreted from internal muscle scars.

Investigators of Recent (Holocene; 10,000 years ago to the present) forms use other anatomic features, such as adductor muscle arrangement, the ctenidia and their junction with the labial palps, the extent and complexity of mantle fusion, and stomach structure. Cluster analysis using many morphological features is effective with lower taxa but less so with higher taxonomic categories because of the many examples of parallel evolution from the basic bivalve plan. The triangular mussel form, for example, has evolved in representatives of virtually every subclass, resulting in similar morphologies. Shell microstructure and mineralogy evidence generally support paleontological conclusions that the class Bivalvia comprises six subclasses, recognizing, however, that some of these taxa may have more than one first ancestor (polyphyletic). In a group with a fossil history extending back to the Cambrian period and occupying a wide range of aquatic habitats, this is not unexpected, particularly since the basic bivalved form permits repeated modification.

Annotated classification.

CLASS BIVALVIA

Laterally symmetrical; left and right calcareous shell valves; dorsal elastic hinge ligament; anterior and posterior adductor muscles; lateral paired filtering ctenidia surrounding the visceral mass; primitively burrowing by means of a muscular foot, but some crawl, some attach to rocks by byssal threads from the foot, some are cemented, and some bore into soft rocks, corals, and wood; some commensal, a few parasitic, and some deepwater species predatory; microphagous feeding; mostly marine, at all depths, also estuarine and freshwater; about 8,000 extant species.

Subclass Palaeotaxodonta

Numerous similar teeth along the hinge plate; isomyarian; unique shell microstructure of aragonitic composite prisms and internal nacre; posterior ctenidia comprising 2 divergent rows of flat, short, filaments; protobranch respiratory gill; food collected by labial palps; mostly near-surface-dwelling marine detritivores; considered to be the most primitive of living bivalves, if not the most ancient.

Order Nuculoida

Equal shell valves with taxodont hinge teeth; isomyarian; posterior protobranch ctenidia; large labial palps usually with palp proboscides, which effect feeding; foot with flat sole; marine; unattached; infaunal.

Subclass Cryptodonta

Hinge either weakly taxodont or edentulous; distinctive shell structure of aragonitic simple prisms and nacre internally; large posterior protobranch ctenidia; small labial palps; of primitive and ancient lineage; marine; unattached; infaunal.

Order Solemyoida

Shell valves equal and elongate, lacking hinge teeth, covered by a shiny periostracum; dimyarian or monomyarian; some with protobranch ctenidia containing symbiotic sulfur-oxidizing bacteria; minute palps; minute or absent gut; foot with flat sole; marginally papillate; marine; deep-burrowing; infaunal.

Subclass Pteriomorphia

Highly variable shell form and structure; dimyarian, anisomyarian, or monomyarian; variable hinge dentition; lateral filibranch ctenidia comprise paired demibranchs of weakly united filaments; mostly marine; some cemented; most epibyssate; some infaunal; representative of the earliest filter-feeding bivalves.

Order Arcoida

Shell solid, elongate or circular-oval, often heavily ribbed; fibrous periostracum with simple crossed-lamellar outer layer and inner complex crossed-lamellar layer, thereby differing from all other pteriomorphs; dimyarian; hinge with vertical denticulations; ctenidia filibranch; mantle margin with uniquely divided outer fold; foot often byssate; marine; epibyssate; infaunal.

Order Trigonioida

Shell valves equal, trigonally oval, strongly ribbed; shell with outer aragonitic prismatic layer and inner nacre layers; strong hinge teeth transversely grooved; typically isomyarian, with pedal elevator and protractor muscles as well as retractors; ctenidia filibranch, without mantle fusions; powerful foot; marine; infaunal; living species confined to Australia.

Order Mytiloida (common mussels)

Shell equivalve, rounded, elongate or triangular depending on habits; anisomyarian tending toward monomyarian; hinge edentulous; shell microstructure of outer calcitic fibrous prisms and inner nacre; ctenidia filibranch; mantle margin lacking fusions; foot creeping; typically byssate; marine, estuarine, rarely freshwater; endobyssate and epibyssate.

Order Pterioida (pearl oysters and fan shells)

Shell equivalve, variably shaped; anisomyarian but often monomyarian; shell structure of outer simple calcitic prisms and inner nacre; ctenidia pseudolamellibranch, often plicate (deeply folded); mantle margin lacking fusions; foot reduced; marine; endobyssate or epibyssate.

Order Limoida

Shell equivalve, ovally elongate, ribbed, often thin and transparent, with outer foliated calcite and inner crossed-lamellar aragonitic layers; hinge short and edentulous; monomyarian; ctenidia pseudolamellibranch, encircling the adductor; palps small and lips of mouth variably fused; mantle margins unfused and often red, with long autotomizing tentacles; some swim weakly; marine; epibyssate with byssus sometimes formed into a nest.

Order Ostreoida (oysters and scallops)

Shell valves unequal, variable, typically lacking hinge teeth; shell structure of foliated calcite, upper valve with outer pris-

matic calcite; most scallops with inner crossed-lamellar layers; dimyarian but most monomyarian; ctenidia pseudolamellibranch; mantle fusions lacking; foot often lost in adult; scallops capable of swimming; some deepwater scallops predatory; marine; epibyssate; cemented by lower or left valve or free.

Subclass Palaeoheterodonta

Characterized by equal shell valves with a variable hinge dentition; aragonitic shell with outer prismatic and inner layers of nacre; most approximately isomyarian; ctenidia eulamellibranch; mantle fusions lacking, especially ventrally; complicated life cycles; wholly freshwater; nonbyssate; infaunal.

Order Unionoida

Large, equivalve, varying from round to elongate and with equally variable sculpture; shell of outer prismatic layer and inner layers of nacre; hinge schizodont; dimyarian; ctenidia eulamellibranch with either 1 or both demibranchs functioning as an incubatory marsupium; ovoviviparous; parasitically larviparous; freshwater; some cemented and oysterlike; mostly infaunal.

Subclass Heterodonta

Shell highly variable; hinge plate teeth may be reduced or absent; shell comprises crossed-lamellar, complex crossed-lamellar, or prismatic layers, but never nacreous; primitively isomyarian but with wide range of adductor muscle configurations; ctenidia eulamellibranch; mantle margins extensively fused, particularly posteriorly, often to form long inhalant and exhalant siphons; mostly marine but also estuarine and freshwater; some epibyssate, some bore soft rocks and wood; generally infaunal.

Order Veneroida

Shell typically equivalve and of outer crossed-lamellar and inner complex crossed-lamellar layers; hinge comprises radiating cardinal and lateral teeth, often weakly developed; adductor muscles of varying proportions according to habit; ctenidia eulamellibranch, mantle margins extensively fused, often developed into long siphons; most are active burrowers with a large foot; some epibyssate; mostly marine, some estuarine and freshwater; includes the poorly known miniature commensals and parasites; widely divergent, accounting for 50 percent of the extant bivalves.

Order Myoida

Shell typically thin, equivalve, comprising either 2 or 3 layers; hinge plate with cardinal dentition, often degenerate; approximately isomyarian but with much variation; boring forms develop accessory shell plates; ctenidia eulamellibranch, mantle margins extensively fused and covered in periostracum; small foot; marine deep burrowers with long siphons but also rock- and wood-boring.

Subclass Anomalodesmata

Characterized by highly variable shell, either equivalve or inequivalve, often gaping either posteriorly or anteriorly; hinge plate thickened and enrolled but generally edentulous; shell of two or three layers, the inner nacreous; typically isomyarian but with wide variation; ctenidia either eulamellibranch and plicate or septibranch; mantle margins extensively fused, often covered in periostracum; foot reduced; siphons of variable length; consistently hermaphroditic; marine; mostly burrowing; some epibyssate or cemented.

Order Pholadomyoida

Shell more or less equivalve but of widely divergent form; shell comprises aragonitic prisms and nacre or homogeneous structures; typically isomyarian; ctenidia eulamellibranch and plicate but many deepwater species are septibranch; extensive mantle fusions, reduced foot and pedal gape; siphons of variable length; shallow-water forms are burrowing, nestling, epibyssate, or cemented suspension feeders; some deepwater forms are predators with exotic modifications to the bivalve plan.

Critical appraisal. Generally, the classification scheme is accepted up to the level of family and even superfamily. The arrangement of higher categories is, however, still debated. Some authors, for example, combine the subclasses Palaeotaxodonta and Cryptodonta into a single group of primitive detrivores with protobranch gills. Differences in shell structure, however, argue against this. Similarly, the order Arcoida is separated by some from the subclass Pteriomorphia; shell structure again supports this, but other anatomic features do not. The order Trigonioida traditionally has been located within the subclass Palaeoheterodonta, but this has also been disputed, anatomic features suggesting instead an affinity with the subclass Pteriomorphia. This means that the subclass Palaeoheterodonta comprises only the order Unionoida, which has come to occupy the freshwater domain exclusively. Some authors would prefer to relocate the order Myoida from the subclass Heterodonta into the subclass Anomalodesmata, arguing that the edentulous shell, extensive mantle fusions, and deep-burrowing habit are characteristics shared with early ancestors of the order Pholadomyoida. The subclass Anomalodesmata, however, is itself possibly too narrowly demarcated, and some authorities would, for example, separate the deepwater carnivorous septibranchs from the shallow-water pholadomyoids into their own order, the Septibranchoida.

This lack of classificatory agreement is not unusual with regard to a group that has adopted a simple sedentary, filter-feeding mode of life. Simplification and parallel evolution will lead to similarity in form, structure, and function. Debate in creating classificatory trees and reconstructing the historical record is thus about the relative significance of the fossil shell record, as there is little information on tissue morphology, and the importance of morphological data obtained from living representatives. (Br.M.)

Cephalopods (octopuses, squids, cuttlefishes, and nautiluses)

Cephalopoda is a small class of highly advanced and organized, exclusively marine mollusks, of which the octopus, squid, cuttlefish, and chambered nautilus are familiar representatives. The extinct forms outnumber the living, the class having attained great diversity in late Paleozoic and Mesozoic times. The extinct cephalopods are the ammonites, belemnites, and nautiloids, except five living species of *Nautilus*.

GENERAL FEATURES AND IMPORTANCE TO HUMANS

The cephalopods agree with the rest of the Mollusca in basic structure, and the ancestors appear to have the closest affinity with the ancestors of the class Gastropoda. The best-known feature of the cephalopods is the possession of arms and tentacles, eight or 10 in most forms but about 90 in *Nautilus*. Except for the nautilus, all living members of the class show great modification and reduction of the characteristic molluscan shell.

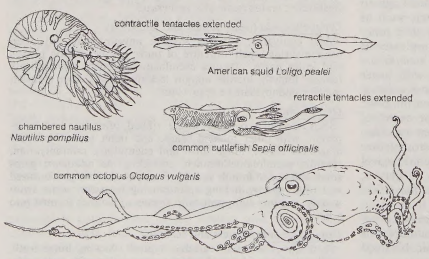


Figure 11: Body plans of typical cephalopods.

Size range

Cephalopods range greatly in size. The giant squids (*Architeuthis* species) are the largest living invertebrates; *A. dux* attains a length of more than 20 metres (60 feet), including the extended tentacles. The smallest cephalopod is the squid *Idiosepius*, rarely an inch in length. The average octopus usually has arms no longer than 30 centimetres (12 inches) and rarely longer than a metre (39 inches). But arm spans of up to nine metres (30 feet) have been reported in *Octopus dofleini*. The shell of the fossil ammonite *Pachydiscus seppenradensis* from the Cretaceous measures 205 centimetres (6 feet 8 inches) in diameter; it is considered to have been the largest shelled mollusk.

Cephalopods occur in large numbers and form one of the greatest potential food resources of the oceans. They are eaten in most parts of the world and have been accepted as part of the general diet in North America and northern Europe. They also are indirectly important to humans since they furnish a large part of the diet of sperm whales and smaller whales, seals, fishes, and seabirds.

NATURAL HISTORY

Reproduction and life cycles. The sexes are usually separate in the Cephalopoda. Sexual dimorphism is usually expressed in slight differences of size and in the proportions of various parts. In the argonaut and the blanket octopus (*Tremoctopus*) the males differ in appearance and size from the females.

Reproductive systems

The female reproductive system is simple, consisting of the posterior ovary and paired oviducts. Nidamental glands exist in species that lay eggs encased in heavy gelatinous capsules.

In males the reproductive system contains a series of chambers or sacs along the course of the vas deferens, which produce long tubes (spermatophores) to contain the spermatozoa. The final sac (Needham's organ) is used for storage of spermatophores. The spermatophores are complicated, containing sperm reservoir, cement body, cap, and a delicate triggering mechanism for releasing the tube and cementing it to the female's body, where the sperm are released when the eggs are mature and ready to be laid. Since spermatophores vary in appearance from species to species, they are important taxonomic characters.

During courtship the male deposits spermatophores in the female, either within the mantle cavity or on a pad below the mouth, by means of a specially modified arm, the hectocotylus. The hectocotylized arm of *Octopus* bears a deep groove on one side, ending in a spoonlike terminal organ. In *Argonauta* and *Tremoctopus* the arm is highly modified and in mating is autotomized (self-amputated) and left within the mantle cavity of the female. In the squids a much larger section of the arm may be modified; often the suckers are degenerate and the distal half of the arm bears rows of slender papillae, although special pouches and flaps may often be found. The modified arm of *Nautilus* is termed the spadix.

Cephalopod mating habits

Little is known about the mating habits of most cephalopods. In the common octopus the male and female remain some distance apart while the male caresses the female with the tip of the hectocotylized arm. The male then inserts the tip of the arm into the mantle cavity of the female, where it remains for more than an hour, during which time the spermatophores travel down the spermatophoral groove of the arm. In the cuttlefish (*Sepia*), according to the Dutch zoologist L. Tinbergen, the pair swims side by side, the male indulging in some courtship behaviour with its arms. Eventually, mating takes place by the pair intertwining their arms and remaining together while the spermatophores are placed on the inner side of the female's mouth membrane. In loliginid squids a somewhat similar type of mating occurs, except that it takes place en masse in schools of thousands of individuals.

Eggs may be laid shortly after mating or after a prolonged period of maturation during which time the sperm remain viable. In loliginids they are fertilized as they are ejected and before being fixed in the egg capsule. In the octopods they may be fertilized as they pass through oviductal glands near the end of the oviduct. In cuttlefishes the eggs are fertilized before the heavy capsule is formed. Egg laying in octopods is accomplished by the female individually fixing the eggs singly or in festoons by a short stalk or thread. In loliginids the eggs in fingerlike capsules often form immense moplike patches, the result of the communal spawning of perhaps hundreds of individuals. Spawning of oceanic squids is very poorly known. The number of eggs laid during a spawning period varies greatly; it may range from only a few dozen in octopuses with large eggs to more than 100,000 in the common octopus, laid over a period of about two weeks. In cuttlefishes the number of eggs is smaller, about 200 to 300 being laid in a season. In loliginids several thousand eggs may be laid by a single female, and the egg mop of the European common squid, resulting from the efforts of many individuals, may contain more than 40,000 eggs.

Egg laying

The eggs of most cephalopods are enclosed within a capsule that may be gelatinous and transparent (the squids of the genus *Loligo*) or opaque and leathery (*Octopus* and cuttlefishes). The eggs of oceanic species may be laid in large sausagelike gelatinous masses or singly. The eggs of most coastal species are laid inshore and are attached singly or in clusters, primarily to rocks and shells on the bottom. Parental care is exhibited by some octopuses, in which the female broods over the eggs in the den, and in the argonaut (*Argonauta*), in which the eggs are carried in a special shell secreted by the female. In most squids and cuttlefishes the eggs are left uncared-for. Squids that attach their eggs to the bottom engulf them in a gelatinous mass that protects them from disease and deters predators. Cuttlefishes squirt their eggs with ink when they are laid to camouflage the otherwise white eggs.

All cephalopod eggs have a remarkable amount of yolk, unlike that in the rest of the Mollusca, so that segmentation is incomplete and restricted to one end of the egg, where the embryo develops. The embryo of a cuttlefish (*Sepia*), squid (*Loligo*), or octopus (*Octopus*) has a yolk sac. In certain presumably archaic Teuthoidea there is less yolk, and the yolk sac is nearly absent. Development of the embryo is direct, without the distinctive larval stages and metamorphoses that occur in other mollusks.

Development

Incubation time varies, but in *Octopus* young hatch in about 50 days and in *Loligo* in about 40 days. At hatching, the young may closely resemble the adult and assume the adult habitat or they may differ from the adult and spend a considerable time in the plankton as part of the drifting life. The juveniles of many cephalopods were described as distinct genera before their juvenile status was discovered. In octopods with small eggs (*e.g., Octopus vulgaris*) the juveniles are planktonic, spending several weeks in the plankton; the "*Macrotritopus*" stage of *Scaeurgus* may greatly prolong its juvenile life until a favourable bottom substrate is found. In octopods with large eggs (*e.g., Octopus briareus*) the young resemble the adult and immediately assume a bottom-dwelling mode of life.

In the order Sepioidea (cuttlefishes and bottle-tailed squids) the young closely resemble the adults and are only briefly planktonic. In the Teuthoidea (squids), especially the Oegopsida, the larvae may differ widely from the adult and the juvenile period may be quite long.

Life span

Little is known about the life span of cephalopods. Studies have shown that in *Octopus joubini* raised from the egg in aquariums, sexual maturity and spawning were reached in five months; in a loliginid squid (*Sepioteuthis sepioidea*), likewise raised from the egg, sexual maturity and full growth were also attained in five months. It thus appears that the smaller inshore species may have a life span of no more than one year or, exceptionally, two or three. Nothing is known of the life span of the large oceanic squids, but it is presumed that giants such as *Architeuthis* attain their bulk only after a period of perhaps four to five years. In the smaller octopuses and squids, observational data indicate that many of the males die after mating and females after the first major spawning.

Behaviour. Cephalopods are unique among the invertebrates in the degree of cephalization and cerebralization attained. The uniting of the major ganglionic centres of the central nervous system constitutes a brain of considerable complexity. Studies undertaken at the Zoological Station in Naples by the British zoologists J.Z. Young, Martin J. Wells, and others have demonstrated that *Octopus* is

capable of learning and has considerable intelligence. The behaviour of squids and octopuses differs considerably because of their different modes of life. Laboratory behavioral studies have dealt mainly with learning processes and have centred around food acceptance, reward and punishment, maze work, and shape discrimination. By means of surgical techniques it has been possible to determine the various functional centres of the brain of *Octopus* and the transmission and receiving pathways.

Research of a detailed nature has been concerned with colour change. Most cephalopods possess colour pigment cells (chromatophores) and reflecting cells (iridocytes) in the skin. The chromatophores are expanded by nerves controlled by the brain, and the colours are exposed (brown, black, red, yellow, or orange red). Colours and colour patterns are exhibited according to specific behavioral conditions—*e.g.,* attack on prey, camouflage, rest, and alarm or defense. Alarm patterns are the most readily recognized, consisting of strong contrasting light and dark areas, bars and peripheral dark outlines, or vivid displays of spots, like huge eyes.

Other behavioral patterns are found in changes in skin texture, including the erection of branched or spikelike papillae and curling of the arms. These actions often are attempts by cephalopods to conceal or camouflage themselves through imitating bottom objects such as sand, coral, or seaweed.

Discharge of ink

The ink of cephalopods is used for both defense and escape. In *Octopus* under attack by a moray eel, the cloud of ink seems to paralyze for some time the eel's senses of sight and smell. In squids the ink is ejected as a spindle-shaped mass about the size of the squid itself, the ink coagulating in the water. With this "dummy" left behind, the squid contracts its chromatophores, becomes nearly transparent, and jets away.

Many cephalopods (but not *Nautilus* and *Octopus*) possess special light organs (photophores), which emit chemical light or bioluminescence. Light is produced by the enzymatic reaction of luciferin and luciferase or, in bottle-tailed squids (sepiolids), indirectly, through cultures of luminescent bacteria. Photophores distributed over the body are employed at night or in the mid depths in various ways: mating play, recognition of the sexes, aid in schooling, attracting prey, defense, and camouflage. The light organs of the squid *Histioteuthis* are highly complicated, consisting of reflector, light source, directive muscles, lens, diaphragm, window, and colour screens.

Octopuses, squids, and cuttlefishes display considerable skill and cunning in hunting, stalking patiently, or luring prey within reach of their arms or tentacles. Both cuttlefishes and octopuses may use the tips of their arms as wormlike lures to attract small fishes, and octopuses have been reported to thrust stones between the valves of clams to prevent their closing. This has not been verified by later observers, but such intelligence is not beyond belief.

Locomotion. Cephalopods move by crawling, swimming, or jet propulsion, mainly the latter. The mantle, which has a passive role in the majority of mollusks, has become involved in locomotion in cephalopods, having almost entirely lost its rigid shell and become highly muscular. Its expansion and contraction produce a locomotory water current by drawing water into the mantle cavity and expelling it through the funnel. The rapid ejection of this jet of water enables the animal to execute quick backward and forward movements.

Jet propulsion

Water is drawn into the mantle cavity by the relaxation of the circular muscles and resultant expansion of the mantle. It enters around the neck region or aperture of the mantle (through the funnel in some deep-sea octopuses). In the oceanic squids the system is more efficient, with a nonreturn valve that prevents water from entering the wrong way through the funnel. When the mantle is contracted the aperture is closed by locking mechanisms and contraction of the anterior ring muscle, and the water is forced out through the funnel. This flexible tube is constructed similarly to a jet nozzle and may be turned in any direction, giving the animal great flexibility of motion for steering.

Squids also possess terminal or lateral fins used in slow movement or hovering. Locomotion is by the rapid undulation of the outer edges of the fins. Movement through the water is aided by lateral expansions (swimming keels) on the outer surface of the third pair of arms. Some squids (*Onychoteuthis, Thysanoteuthis*) are able to "fly" for several hundred feet, driven into the air by powerful thrusts from their jets and gliding on their expanded fins and arm keels. This normally occurs when the squids are pursued by predatory fishes and dolphins. When the squid jets rapidly through the water, the fins are often curled tightly around the mantle. Cuttlefishes, because of the large cuttlebone, are less active animals and spend most of their life lying on or hovering slightly above the bottom. Both jet and fins are used, the latter more frequently.

The benthic octopods are bottom crawlers, gliding about the bottom and in and out of crannies with amazing agility through the use of their eight arms and hundreds of suckers. Because of the extraordinary flexibility of the body, they are able to pass through openings hardly larger than the diameter of one eye. When disturbed, octopods swim rapidly by jet propulsion. Mass swimming migrations have been reported.

The finned octopods and the bottle-tailed squids have paddle-shaped fins that probably are most useful for hovering and slow swimming. The female argonaut (*Argonauta*) propels herself by jet propulsion while encased in her paper-thin shell. The chambered nautilus (*Nautilus*) is a less active swimmer, partly due to the inefficient funnel, which is composed of two flaps instead of a single fused tube, and to a reduced mantle cavity.

The active swimmers and most bottom dwellers apparently possess no hydrostatic organ. The cuttlefish, however, which swims or hovers above the bottom or rests on the bottom, adjusts its buoyancy through the amount of gases contained in the porous cuttlebone. *Nautilus,* which swims slowly above the bottom or in midwater, accomplishes this similarly, adjusting the gases in the chambered shell. Inactive oceanic squids, such as some cranchiids, concentrate ions lighter than seawater in the body chamber, while others, such as *Bathyteuthis,* concentrate buoyant oil in the chambers associated with the digestive gland.

Distribution

Ecology. The Cephalopoda are exclusively marine animals. There are numerous littoral species, but few have been reported from brackish water except for the squid *Lolliguncula brevis,* which occurs along the Florida coast in bays where the salinity is as low as 8.5 parts per thousand (about one-fourth that of the open ocean). Cephalopods are excluded from the Baltic Sea by lower salinities but have been found in areas of the Suez Canal where salinities are higher than in the oceans. There is some evidence that in parts of the open sea that differ only slightly in salinity there may be a varying cephalopod fauna. Grace E. Pickford, an American zoologist, has found that the vertical distribution of young in *Vampyroteuthis* is governed by water density, and, according to the American zoologist Clyde F.E. Roper, a similar situation exists in the deep-sea squid *Bathyteuthis.*

The Coleoidea are carnivorous and live principally on other cephalopods, crustaceans, mollusks, and small fishes. In the food cycle of the squid *Illex,* in which the adults feed upon young mackerel and the adult mackerel feed upon young squid. Squids also are cannibalistic. *Octopus* feeds upon bivalve mollusks and on decapod crustaceans, sometimes causing severe losses to the lobster fishery by entering the traps and eating the captive lobsters. The smaller oceanic squids probably feed primarily upon small fish, copepods, heteropods, and caridean shrimp. The Cirrata, which have reduced musculature and radula, indicating reduced activity and masticatory power, probably feed on bottom dwellers or small plankton.

The Cephalopoda are fed upon by many marine mammals, large fish, and seabirds. Sperm whales and other toothed whales feed primarily on squids.

Associations

The 19th-century French naturalist Alcide d'Orbigny asserted that the Cephalopoda are in general sociable, and this statement is certainly true of *Nautilus,* which are found together in large numbers. Some authorities, studying the Mediterranean cephalopods, have concluded that only certain pelagic cephalopods are gregarious (*Todaro-*

des, Ocythoe). Schools of the large oceanic squid *Thysanoteuthis rhombis* have been reported at Madeira. Although there is no proof that numbers constitute gregariousness, octopus colonies have been reported.

The breeding season has a marked effect on the local distribution of certain cephalopods. The common cuttlefish comes into shallow water in the spring and summer to breed, and similar migrations have been observed in some squids (*Loligo, Alloteuthis, Illex*).

The geographic distribution of cephalopods is incompletely known. Some open-ocean pelagic and bathypelagic forms are cosmopolitan in warm and temperate waters (*Onychoteuthis banksi, Cranchia scabra*). Others may be limited by genera to particular oceans or to continental waters. Even some species of bathypelagic habitat are limited to one ocean. The Octopoda, as a result of their bottom-dwelling habits, show stronger restrictions in their distribution, but *Octopus vulgaris* and *O. macropus*, both species with planktonic larvae, have gained worldwide distribution. In general, the pelagic and planktonic cephalopods conform in their distribution to other pelagic animals.

The vertical distribution is also incompletely known. *Nautilus* moves vertically through the water, living near the bottom, and has been obtained at a depth of about 550 metres (1,800 feet). It is fished in the Philippines when it comes into shallow water. Of the cuttlefishes, the Sepiidae are littoral, whereas the Sepiolidae dwell on or near the bottom, down to considerable depths. Among the squids the Myopsida are coastal forms, whereas the Oegopsida are oceanic, living from the surface to depths in excess of 5,000 metres (16,400 feet). The Octopoda occur from the surface of the open ocean (*Tremoctopus*) to the ocean floor (*Pareledone, Bentheledone, Cirroteuthis*) in excess of 5,000 metres (16,400 feet); most are bottom-dwelling forms restricted to the continental shelf and its slope.

FORM AND FUNCTION

Cephalopods vary from elongate, streamlined oceanic organisms to saccular, slow-moving bottom and drifting forms. Their body plan is indicative in many ways of the habitat in which they dwell and their mode of life.

The viscera of a generalized cephalopod are covered by a dome-shaped or elongated sheath of muscle, the mantle, which is connected with the head anteriorly. Ventrally, the mantle is free and encloses the mantle cavity, the space into which the gills project and the excretory and reproductive systems open.

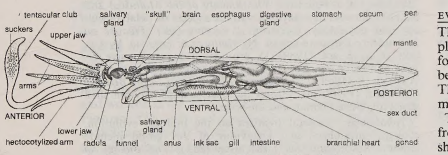


Figure 12: Internal structure of squid (*Loligo*). Left side of body, with four arms and one tentacle removed.

Number of arms and tentacles

Anterior to the mantle is the head-foot, which bears a ventral muscular tube, the funnel. Surrounding the mouth are eight long, prehensile arms, provided with suckers in octopuses and argonauts (order Octopoda), or eight arms and two tentacles, equipped with horny ringed suckers bearing teeth or hooks in squids and cuttlefishes (orders Teuthoidea and Sepioidea). The primitive *Nautilus* has about 90 small suckerless appendages.

The fossil nautiloids and ammonites (represented today only by *Nautilus*) were primitive, less-specialized forms, probably leading a rather inactive sluggish life. The modern octopuses, squids, and cuttlefishes have acquired an active, vigorous life that has led to marked departures in structure and function from the type represented by *Nautilus*. Modern forms are divided into three basic life-styles: the sluggish life in the great depths of the sea, a floating life in the midwaters, and a more active, aggressive existence near the surface. The nautiloids and ammonites were probably shallow-water animals living near the bottom and, like the slow-moving *Nautilus*, relied for protection on a coiled or curved calcareous external shell.

All cephalopods have an internal cartilaginous covering of the consolidated ganglia of the nervous system. In all except ammonites and nautiloids, it constitutes a cranium. Various other skeletal supports are found at the base of the fins and in the "neck," gills, and arms.

The alimentary system consists of a buccal mass with a pair of jaws (mandibles) and a rasping tongue (radula), esophagus, salivary glands, stomach, cecum, digestive gland ("liver"), intestine, and anus. In the Octopoda the esophagus may be expanded to form a crop, while in the deep-sea Cirrata the radula may be degenerate or lacking. Except in *Nautilus* and certain deep-sea Octopoda there is an ink sac located near the anus. This secretes a dark fluid, the sepia or ink, which is forcibly ejected through the funnel.

All members of the Coleoidea (octopuses, squids, and cuttlefishes) possess a closed circulatory system of blood vessels; in *Nautilus* it is partly lacunar (*i.e.,* made up of sinuses). The blood contains a blue respiratory pigment, hemocyanin (a copper compound), dissolved in the plasma. There are three hearts, the main systemic heart and the two branchial hearts, one at the base of each gill. The rhythmical contractions and expansions of the mantle cause a circulation of water over the gills where gas exchange takes place between the seawater and blood. The featherlike gills, consisting of a central axis with a row of lamellae on either side, are suspended in the mantle cavity from the mantle wall.

The excretion of nitrogenous wastes is carried out exclusively by the kidneys. There are four kidneys in *Nautilus* and two in the coleoids.

The central nervous system is highly developed, the major ganglionic centres being concentrated in the head. In some of the cuttlefishes (Sepioidea) the cerebral centres are subdivided for specialization, with the pedal ganglia divided into brachial and epipodal elements that innervate the arms and funnel respectively. In active squids the mantle is innervated by giant paired dorsal axons. Much of the present knowledge of mechanisms of nerve impulse conduction has come from the study of these giant axons. The sense organs of the cephalopods are eyes, rhinophores (olfactory organs), statocysts (organs of equilibrium), and tactile organs. In *Nautilus* the eyes are open pits without lenses. In the Coleoidea the eyes are complex and approach those of some lower vertebrates in efficiency.

EVOLUTION AND PALEONTOLOGY

The first cephalopods were probably provided with a simple, caplike shell. With elongation of the shell and the formation of septa or partitions, the nautiloid shell could be formed (Late Cambrian, 523 to 505 million years ago). The primitive elongate shell of *Orthoceras* became unmanageable and coiling resulted, as in the Gastropoda.

The Ammonoidea are usually considered to have evolved from Devonian (408 to 360 million years ago) straight-shelled forms (*Bactrites*) with certain nautiloid traits. Coiled ammonites appeared in the Late Devonian epoch (*Goniatites*). The subclass became extinct in the Cretaceous.

The shell

Modern cephalopods possess an internal and partly degenerate shell, straight except in *Spirula*. The state of the shell in modern forms is due to the progressive overgrowth of it by the mantle, probably accompanying the evolution of an active swimming life. The first evidence of the modification of the shell is in *Aulococeras* in the Triassic period (245 to 208 million years ago). The belemnites, with their modified, internal shell, gave rise to *Spirula* (coiled shell), to cuttlefishes (calcified phragmoconal septa, forming a thick shell), and to the squids (only the proostracum as a horny "pen"). These forms appeared in the Jurassic period (208 to 144 million years ago) and were probably derived from belemnite-like ancestors.

In the Octopoda the shell persists as cartilaginous stylets or fin supports. *Palaeoctopus newboldi,* the oldest known octopod, from the Cretaceous of Syria, was already too advanced to provide a clue to the derivation of the Octopoda. The Vampyromorpha are considered to be a possible connecting link between the Teuthoidea and the Octopoda.

CLASSIFICATION

Distinguishing taxonomic features. In fossil cephalopods, reliance is placed upon shell details (general shape, type of coiling, external sculpture, and sutures). In living forms, except for the Sepioidea, the shell is strongly degenerate or missing and the characters used consist of details of the soft parts: presence or absence of an eyelid, tentacles retractile or contractile or both, shape and size of fins, number of arms, number of sucker rows, presence or absence of teeth and hooks on arm and tentacular suckers, radular dentition, structure of funnel organ, spermatophores, details of the hectocotyles, number of gill lamellae, and the presence, patterns, and types of photophores.

Annotated classification. The following classification has gained considerable acceptance among modern specialists. Groups indicated by a dagger (†) are known only as fossils.

CLASS CEPHALOPODA

Mollusks in which typical molluscan foot surrounds head and forms arms and tentacles; mantle surrounds mantle cavity and is part of locomotory system; central nervous system highly developed, forming true brain encased in cartilaginous cranium; mouth contains pair of parrotlike jaws (or beak); body usually somewhat streamlined; eyes highly developed, most closely resembling in acuity those of some vertebrates; about 650 living species.

Subclass Nautiloidea (nautiloids)

Cambrian to present; now living only in the Indo-Pacific region, particularly East Indies; external coiled or straight chambered shell present, chambers connected by median siphuncle; smooth septa; sutures simple, little or no external sculpture; tentacles suckerless, adhesive; living and supposedly fossil forms with 4 gills; funnel formed of 2 nonfused flaps; about 5 living species, in genus *Nautilus*.

†Subclass Ammonoidea (ammonites)

Devonian to Cretaceous; fossils only; external, coiled or straight chambered shell with marginal siphuncle, last chamber protected by single horny plate or 2 calcareous plates; septa wrinkled; complex sutures; external sculpture.

Subclass Coleoidea (octopuses, squids, belemnites, cuttlefishes)

Triassic to present; shell internal, reduced, vestigial, or lacking; 2 sets of gills; 8 or 10 arms, having suckers or hooks.

†Order Belemnoidea (belemnites)

Triassic to Tertiary; fossils only; shell consisting of solid rostrum, small chambered phragmocone and anterior, broad proostracum; 6 to 10 arms bearing hooks in 1 or 2 rows; total length 5 to 210 cm.

Order Sepioidea (cuttlefishes and bottle-tailed squids)

Tertiary to present; worldwide with family exceptions; shell coiled and chambered (Spirulidae), straight with vestigial chambering (Sepiidae), vestigial, or lacking; eyes covered with transparent membrane; 8 sucker-bearing arms and 2 tentacles retractile into pockets; total length 2.5–90 cm.

Order Teuthoidea (squids)

Tertiary to present; shell thin, horny gladius; 8 arms, 2 tentacles, which are contractile only; worldwide; total length 1.5 to at least 1,800 cm (0.75 in. to 60+ ft).

Suborder Myopsida. Eye covered by transparent membrane; neritic, inshore animals.

Suborder Oegopsida. Eye open to water, completely surrounded by free eyelid; open-ocean animals living from the surface down to at least 3,000 m.

Order Vampyromorpha

Purplish-black gelatinous animals with 1 or 2 pairs of paddle-shaped fins at various stages of growth; 8 arms and 2 small retractile filaments not homologous with tentacles; deep web between the arms; worldwide; 1 species.

Order Octopoda (octopuses)

Cretaceous to present; shell lacking or vestigial, nonhomologous shell or egg case in female argonautids; fins absent or present; body generally saccular, with 8 mobile, highly contractile sucker-bearing arms; worldwide; total length 5–540 cm (2 in. to 18 ft); maximum arm spread to about 900 cm (30 ft).

Suborder Palaeoctopoda (finned octopod). Cretaceous, some living.

Suborder Cirrata (*Cirromorpha*). Holocene; soft-bodied, deep-webbed forms with cirri on arms and small to large paddle-shaped fins; primarily deep-sea.

Suborder Incirrata (common octopus). Holocene; compact, saccular to round bodied, finless forms with muscular, contractile arms; somewhat secretive; pelagic to deep-sea and shallow waters.

Critical appraisal. The elucidation of higher classification of the cephalopods is fraught with difficulties. Early specialists divided the living cephalopods into Octopoda and Decapoda without relation to their internal structure; these were both placed in the Dibranchia, in contrast to all fossil forms, which were considered as Tetrabranchia because *Nautilus* has four gills rather than two. This unnatural classification, accepted by the French zoologist Alcide d'Orbigny in 1838, was gradually modified through the efforts of the Swiss zoologist Adolph Naef and the German zoologist Georg Grimpe and later workers to the form given above. Phylogenetic linkages are still highly theoretical, but, with X-ray techniques that reveal soft parts in fossils and with new paleontological finds, the unfolding of the evolutionary history is in sight.

(G.L.V./C.F.E.R.)

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(L.v.S.-P./G.A.So./Br.M./G.L.V./C.F.E.R.)

Monet

Claude Monet was the initiator, leader, and unswerving advocate of the Impressionist style. In his mature works, he developed his method of producing repeated studies of the same motif in series, changing canvases with the light or as his interest shifted. These series were frequently exhibited in groups—for example, his images of wheat stacks (1891) and the Rouen Cathedral (1894). At his home in Giverny, France, Monet created the water-lily pond that served as inspiration for his last series of paintings. His popularity soared posthumously in the second half of the 20th century, when his works traveled the world in museum exhibitions that attracted record-breaking crowds and marketed popular commercial items featuring imagery from his art.

Childhood and early works. Oscar-Claude Monet, the eldest son of Adolphe Monet, a grocer, was born on Nov. 14, 1840, in Paris. When he was five years old, the family moved to the Normandy coast, near Le Havre. This event has more than biographical significance, for it was Monet's childhood, spent along the beaches, and the intimate knowledge he gained of the sea and the rapidly shifting Norman weather, that would one day give rise to his fresh vision of nature. Monet's first success as an artist came when he was 15, with the sale of caricatures that were carefully observed and well drawn. In these early years he also executed pencil sketches of sailing ships, which were almost technical in their clear descriptiveness. Monet studied drawing with a local artist, but his life as a painter did not begin until he was befriended by Eugène Boudin, who introduced the somewhat arrogant student to the practice—then uncommon—of painting in the open air. The experience set the direction for Monet, who for more than 60 years would concentrate on visible phenomena and on the innovation of effective methods to transform perception into pigment.

Painting outdoors

Although oil landscapes had been painted at least since the 16th century, they usually were produced in the studio—recollections of observations, rather than direct impressions, of nature. The English painters John Constable and J.M.W. Turner made small oil sketches out-of-doors before 1810, but it is unlikely that Monet knew these studies. He first visited Paris in 1859–60, where he was impressed by the work of the Barbizon-school painters Charles Daubigny and Constant Troyon. To his family's annoyance, he refused to enroll in the École des Beaux-Arts. Instead, he frequented the haunts of advanced artists and worked at the Académie Suisse, where he met Camille Pissarro. This informal training was interrupted by a call to military service; he served from 1861 to 1862 in Algeria, where he was excited by the African light and colour. Monet's choice of Algeria for service was perhaps a result of his admiration for the Romantic painter Eugène Delacroix, whose colouristic work had been influenced by a visit to Morocco in 1832.

In 1862 Monet returned to Le Havre, perhaps because of illness, and again painted the sea with Boudin, while also meeting the Dutch marine painter Johan Barthold Jongkind. Later that year he continued to study in Paris, this time with the academician Charles Gleyre, in whose atelier he met the artists Frédéric Bazille, Alfred Sisley, and Pierre-Auguste Renoir. After disagreements with their master, the group departed for the village of Chailly-en-Bière, near Barbizon in the forest of Fontainebleau. It was also during this period—or at least before 1872—that Monet discovered Japanese prints, the decorativeness and flatness of which were to have a strong influence on the development of modern painting in France.

The exceptional achievements of Monet's prolific youthful period can be measured in works completed between 1865 and 1870, before he had begun to fragment his brushstrokes into the characteristic broken touches that were to become the hallmark of Impressionist style. One of the most ambitious of these early works (which was never finished, supposedly because of negative comments by Gustave Courbet) was "Déjeuner sur l'Herbe" (1865–66; "Luncheon on the Grass"), named after Édouard Manet's notorious painting shown in the Salon des Refusés in 1863. In contrast to Manet's masterpiece, which was a shocking adaptation of a Renaissance visual idea to a contemporary setting, Monet's painting, about 15 feet (4½ metres) high by 20 feet (6 metres) wide, was an utterly contemporary yet unprovocative representation of a group of fashionably dressed picnickers in the forest of Fontainebleau. Monet did share with Manet, however, a concern for representing actual scenes of modern life rather than contrived historical, romantic, or fanciful subjects. Thus, Monet's "Déjeuner" was an extension, by virtue of a more immediate empiricism, of the realism of Courbet.

"Déjeuner sur l'Herbe"

Impressionism, broadly viewed, was a celebration of the pleasures of middle-class life; indeed, Monet's subject matter from this period often involved domestic scenes featuring his wife, son, and garden. Yet, painting *la vie moderne* ("modern life") was not to be the primary aim of Monet's art. Of more significance in his case was his ceaseless search for painterly means to implement his radical view of nature. More so than his ambitious figure paintings, such works as "The River" (1868) or "The Beach at Sainte-Adresse" (1867) give a clear accounting of Monet's advance toward the Impressionist style. In the beach and sea pictures of 1865–67 Monet was plainly not trying to reproduce faithfully the scene before him as examined in detail but rather attempting to record on the spot the impression that relaxed, momentary vision might receive—what is seen rather than what is known, with all its vitality and movement. Boats, buildings, incidental figures, and the pebble beach are swiftly brushed in as flat colour patterns, with little attention paid to their weight or solidity.

First Impressionist paintings. Monet's life during the 1860s was precarious and itinerant, and he sold almost nothing; but several works were accepted for exhibition in the yearly Salons, most notably, and with great success, a fine but not yet Impressionist portrait of his future wife, Camille. Having already painted in Paris, Le Havre, Chailly, Honfleur, Trouville, and Fécamp and at other stations between Paris and the sea, Monet ended the 1860s at the Seine River resort known as La Grenouillère, at Bougival, where he and Renoir worked together for the first time. In canvases almost identical in style, they made rapid notations of pleasure-seekers and bathers, rowboats bobbing in the foreground, and the scintillating reflections in the lapping water. Regarded by Monet as "bad sketches," they were precursors of the Impressionist style. Both artists' Bougival studies interpret the light and movement of outdoor life in strong, abbreviating strokes, improvised at the moment of perception, that serve as equivalents for visual experiences never before committed to canvas in such a direct manner. In 1870 at Trouville, in broad, assured gestures, Monet painted a study of Camille on the beach. It is as animated an example of visual realism as had ever been painted: grains of sand remain embedded in the pigment.

Bougival

As the 1870s began, Monet continued his pursuit of natural phenomena. In order to avoid the Franco-German War, he left his son and Camille, whom he had just married, and traveled to London. There, with Pissarro, he was introduced by Daubigny to Paul Durand-Ruel, who was to become his dealer. In 1871 and 1872 he painted canals, boats, and windmills in The Netherlands and worked again at Le Havre. On his return, Monet rented a house at Argenteuil, on the Seine near Paris. The years he lived there mark the height of the Impressionist movement. He helped organize an independent exhibition, apart from the official

Salon, of the Impressionists' work in 1874. "Impression: Sunrise" (1872), one of Monet's works at the exhibition, inspired the journalist Louis Leroy to give the group their name.

Later Impressionism. Monet's celebrated method of producing works in series, each representing the same motif under different light and weather conditions, was not fully implemented until the 1890s, but what is usually regarded as the first series was executed in or around the Gare Saint-Lazare in Paris during the winter of 1876–77. A total break with the customary Impressionist subjects, these works portray the train engines belching smoke and steam in the great shed, recalling J.M.W. Turner's "Rain, Steam, and Speed—The Great Western Railway" of 1844 and prefiguring the mechanical subjects painted by Italian Futurists after 1909. Monet's life was less happy after he moved to Vétheuil, farther from Paris. In 1876 a liaison began between Monet and Alice Hoschedé, the wife of a department-store owner and collector. Monet had incurred a burden of debts in Argenteuil, and Camille was pregnant and ill. At Vétheuil the Monets were joined by Hoschedé, who had left her husband, and six of her children. Using funds from her dowry, she assumed Monet's debts and cared for Camille, who died in September 1879.

Early series

By 1881 the original Impressionist group had begun to disintegrate, although it was still to hold two more exhibitions—the eighth and last (in which Monet did not show) in 1886, after the advent of Neo-Impressionism. Only Monet continued with the same fervour to carry on the scrutiny of nature. Among the sites he chose during the 1880s were Pourville, Étretat, Fécamp, and Varangéville in Normandy; the rugged and isolated Breton island of Belle-Île; the wild Creuse River valley; Menton and Antibes in the Midi; and Bordighera in Italy. In 1886 he made a second visit to The Netherlands, to paint the tulip fields, before important sojourns at Étretat and Belle-Île.

In 1883 Monet, Hoschedé, her children, and Monet's sons, Jean and Michel, settled at Giverny, a hamlet near Vernon, 52 miles (84 km) from Paris, on the tiny Epte River. There Monet purchased a farmhouse surrounded by an orchard, which was to be his home until his death and is now a French national monument. After the travels of the 1880s, Monet spent the '90s at or near Giverny, concentrating on one series after another.

Last years. After 1900, two ambitious projects, both far from Giverny, concluded Monet's search for new motifs. The first (for which he made at least three trips to London between 1899 and 1904) was the extensive multiple series representing the River Thames, the Waterloo and Charing Cross bridges, and the Houses of Parliament. The works—with their exotic coloration and mysterious romantic mood—recall the Thames paintings of Turner and James McNeill Whistler. In these paintings it is atmosphere, more than the particularities of these structures, that is Monet's subject; buildings and bridges are less tangible than the pulsating brushstrokes that give volume to the light-filled fog and mist. The second and last of the architectural motifs Monet pursued was the canals and palaces of Venice. Monet began this series in 1908 and continued in 1909, although he worked on these subjects at Giverny until 1912. Venice was a perfect Impressionist subject, but the light, water, movement, architecture, and reflections in the water are more generalized in these works than the specific weather effects of the wheat stack and cathedral series.

Garden at Giverny

In 1893 Monet had bought a strip of marshland across the road from his house and flower garden, through which flowed a tributary of the Epte. By diverting this stream, he began to construct a water-lily garden. Soon weeping willows, iris, and bamboo grew around a free-form pool, clusters of lily pads and blossoms floated on the quiet water, and a Japanese bridge closed the composition at one end. By 1900 this unique product of Monet's imagination (for his impressionism had become more subjective) was in itself a major work of environmental art—an exotic lotus-land within which he was to meditate and paint for almost 30 years. The first canvases he created depicting lilies, water, and the Japanese bridge were only about one square yard, but their unprecedented open composition, with the large blossoms and pads suspended as if in space, and the azure water in which clouds were reflected, implied an encompassing environment beyond the frame. This concept of embracing spatiality, new to the history of painting and only implicit in the first water-lily paintings, unfolded during the years from 1915 until the artist's death into a cycle of huge murals to be installed in Paris in two 80-foot oval rooms in the Orangerie of the Tuileries. These were described in 1952 by the painter André Masson as "the Sistine Chapel of Impressionism." This crowning achievement of Monet's long, probing study of nature—his striving to render his impressions, as he said, "in the face of the most fugitive effects"—was not dedicated until after his death. The many large studies for the Orangerie murals, as well as other unprecedented and unique works painted in the water garden between 1916 and 1925, were almost unknown until the 1950s but are now distributed throughout the major private collections and museums of the world. Despite failing eyesight due to cataracts, Monet continued to paint almost until his death on Dec. 5, 1926, in his beloved Giverny.

Assessment. Although critical acclaim was slow in coming, Monet attracted the dedicated support of collectors throughout his career, most notably from Americans who discovered his work in the 1880s. His influence on other artists was wide-ranging, from his near contemporaries such as Vincent van Gogh to a diverse new generation of artists such as Émile Bernard, Pierre Bonnard, Henri Matisse, and Maurice de Vlaminck. During the years 1886 to 1914, a predominantly American colony of artists gathered around him in Giverny and regarded him as an exemplar of modern French painting. They adopted his fresh palette, subject matter, and spontaneous style, eventually introducing these elements to American art.

After his death, Monet's influence on contemporary art ebbed among the avant-garde, who favoured the more radical examples of artists such as van Gogh, Paul Cézanne, Matisse, and Marcel Duchamp. A revival of interest in his work occurred in the early 1950s. Monet's epic scale and formal innovations influenced Abstract Expressionist painters such as Mark Rothko and Jackson Pollock, and a general scholarly reassessment of his importance began to develop. Wildly popular retrospective exhibitions of his work toured the world during the last decades of the 20th century and established his unparalleled public appeal, sustaining his reputation as one of the most significant and popular figures in the modern Western painting tradition.

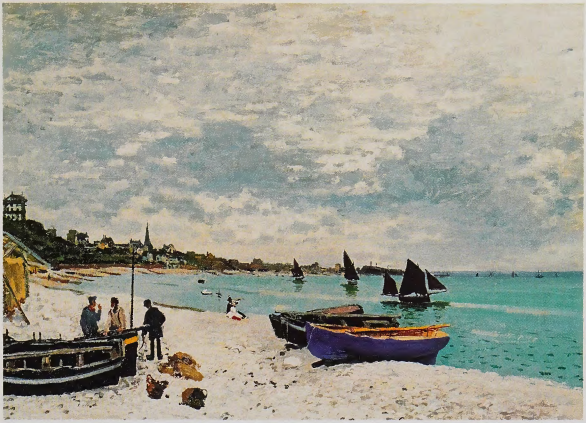
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"The Beach at Sainte-Adresse," oil painting by Claude Monet, 1867. In the Art Institute of Chicago. 75.8 x 102.5 cm.

"Poppies; near Argenteuil," oil painting by Claude Monet, 1873. In the Musée d'Orsay, Paris. 50 x 65 cm.



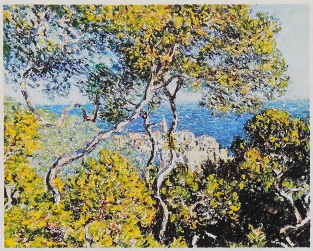


"Impression, Sunrise," oil painting by Claude Monet, 1872. In the Musée Marmottan, Paris. 50 x 67 cm.

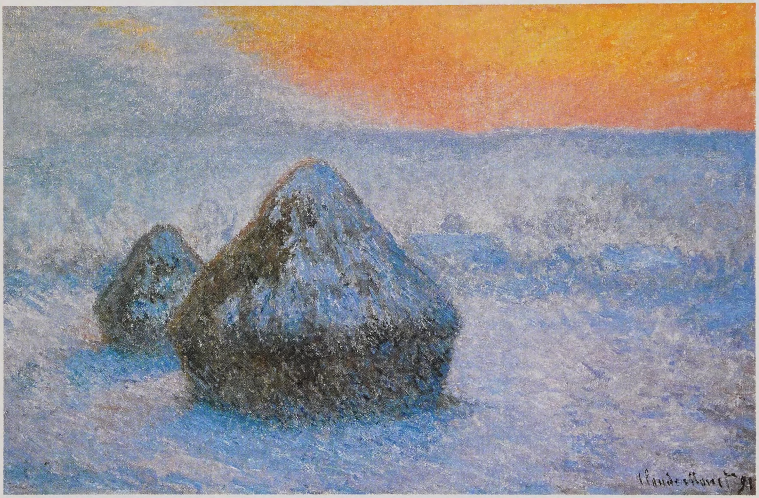


"Arrival of the Normandy Train, Gare Saint-Lazare," oil painting by Claude Monet, 1877. In the Art Institute of Chicago. 59.6 x 80.2 cm.

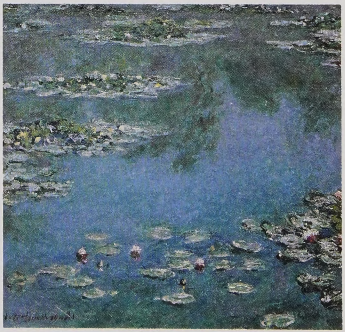
Plate 1: By courtesy of (top) the Art Institute of Chicago, Mr. and Mrs. Lewis Larned Coburn Memorial Collection, (bottom) the Art Institute of Chicago, Mr. and Mrs. Martin A. Ryerson Collection; photographs, (centre left) SCALA/Art Resource, New York City, (centre right) Giraudon/Art Resource, New York City



"Bordighera," oil painting
by Claude Monet, 1884.
In the Art Institute of Chicago.
64.8 x 81.3 cm.



"Stacks of Wheat (Sunset,
Snow Effect)," oil painting
by Claude Monet, 1890–91.
In the Art Institute of Chicago.
65.3 x 100.4 cm.



"Water Lilies," oil painting by
Claude Monet, 1906. In the
Art Institute of Chicago.
87.6 x 92.7 cm.

Plate 2: By courtesy of (top and centre) the Art Institute of Chicago, Potter Palmer Collection, (bottom) the Art Institute of Chicago, Mr. and Mrs. Martin A. Ryerson Collection

Money

A commodity accepted by general consent as a medium of economic exchange. The medium in which prices and values are expressed, money circulates from person to person and country to country, thus facilitating trade, and it is the principal measure of wealth.

People accept money at face value because they know that others will do the same. This universal acceptance means that money is a social convention and one of uncommon strength that people will abide by even under extreme provocation. Yet money is not indestructible. When great variations occur in the quantity of currency—as they have during and after wars—money may be seen as no more than pieces of paper. People will then seek substitutes—like the cigarettes and cognac that for a time became the medium of exchange in Germany after World War II. New money may substitute for old under less extreme conditions than war. In countries with a history of high inflation, such as Argentina, Israel, or Russia, prices may at times be quoted in a foreign currency, such as the U.S. dollar, because its value is more stable than that of the local currency. Furthermore, the country's residents accept the foreign currency as a medium of exchange because it is well-known and offers more purchasing power than local money.

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FUNCTIONS OF MONEY

The basic function of money is to enable buying to be separated from selling. If a person has something to sell and wants something else in return, it is not necessary to find someone able and willing to make the desired exchange of items. The person can sell the surplus item for general purchasing power—that is, "money"—to anyone who wants to buy it and then use the proceeds to buy the desired item from anyone who wants to sell it.

Medium of exchange

Separation of the act of sale from the act of purchase requires the existence of something that will be generally accepted in payment—this is the "medium of exchange" function of money. But there must also be something that can serve as a temporary abode of purchasing power, in which the seller holds the proceeds in the interim between the first sale and the subsequent purchase, or from which the buyer can extract the general purchasing power with which to pay for what is bought. This is the "asset" function of money.

VARIETIES OF MONEY

Anything can serve as money that habit or social convention and successful experience deem acceptable, and a variety of items have so served—from the wampum (beads made from shells) of American Indians, to cowries (brightly coloured shells) in India, to whales' teeth among the Fijians, to tobacco among early colonists in North America, to large stone disks on the Pacific island of Yap, to cigarettes and liquor in post-World War II Germany. The wide use of cattle as money in primitive times survives in the word pecuniary, which comes from the Latin *pecus*, meaning cattle.

Metallic money. The use of metals as money has occurred throughout history. As Aristotle observed, the various necessities of life are not easily carried about; hence people agreed to base their transactions on something that was intrinsically useful and transportable—for example, iron, silver, and the like. The value of the metal was at first measured by weight, but in time governments put a stamp upon it, thus saving the trouble of weighing or otherwise proving the value upon each transaction. Some of the earliest uses of metal for money can be traced back to Babylon more than 3000 years BC, but standardization and certification in the form of coinage, as referred to by Aristotle, did not occur except perhaps in isolated instances until the 7th century BC. Historians generally assign to Lydia, a state in Anatolia, priority in using coined money. The first coins were made of electrum, a natural mixture of gold and silver, and were crude, bean-shaped ingots bearing a primitive punchmark certifying to either weight or fineness, or both.

The use of coins enabled payment to be by "tale," or count, rather than weight, greatly facilitating commerce. But this in turn encouraged clipping (shaving off tiny slivers from the sides or edges of coins) and sweating (shaking a bunch of coins together and collecting the dust that was thereby knocked off) in the hope of passing on the lighter coin at its face value. Gresham's law (that "bad money drives out good" when there is a fixed rate of exchange between them) came into operation, and heavy, good coins were held for their metallic value, while light coins were passed on. The coins became lighter and lighter, and prices higher and higher. Then payment by weight would be resumed for large transactions, and there would be pressure for recoinage. These problems were largely ended by the "milling" of coins (making serrations around the circumference), which began in the late 17th century.

Gresham's law

A more serious matter was the attempt by sovereigns to benefit from the monopoly of coinage. In this respect, Greek and Roman experience offers an interesting contrast. Though Solon, on taking office in Athens in 594 BC, did institute a partial debasement of the currency, for the next four centuries, until the absorption of Greece into the Roman Empire, the Athenian *drachma* had an almost constant silver content (67 grains of fine silver until Alexander, 65 grains thereafter) and became the standard coin of trade in Greece and in much of Asia and Europe as well. Even after the Roman conquest, the *drachma* continued to be minted and widely used.

The Roman experience was very different. Not long after the silver *denarius*, patterned after the Greek *drachma*, was introduced about 212 BC, the prior copper coinage (*aes*, or *libra*) began to be debased until, by the time the empire began, its weight had been reduced from one pound to half an ounce. The silver *denarius* and the gold *aureus* (introduced about 87 BC) suffered only minor debasement until the time of Nero (AD 54), when almost continuous tampering with the coinage began. The metal content of the gold and silver coins was reduced, and the proportion of alloy was increased. Debasement in Rome was a reflection of the state's inability or unwillingness to finance its expenditures through explicit taxes. But the debasement in turn worsened Rome's economic situation and undoubtedly contributed to the collapse of the empire.

Paper money. In the late 18th and early 19th centuries, paper money and banknotes spread widely. The bulk of the money in use came to consist not of actual gold or sil-

ver but of fiduciary money—promises to pay specified amounts of gold and silver. These promises were initially issued by individuals or companies as banknotes or as the transferable book entries that came to be called deposits. But gradually the state assumed a role.

Fiat money

From fiduciary paper money promising to pay gold or silver, it is a short step to fiat paper money—that is, notes that are issued on the "fiat" of the sovereign are specified to be so many dollars or francs or yen and are legal tender, but they are not promises to pay something else. The first large-scale issue in a Western country occurred in France in the early 18th century (though there are reports of paper money in China many centuries earlier). Later, the French revolutionary government issued paper money in the form of assignats from 1789 to 1796.

Electronic money. Currency can be lost, stolen, or forged, so it is used most often for relatively small transactions or where anonymity is valued. "Electronic money" is the name given to several different means of electronic funds transfers (EFTs). Common EFT methods include automated teller machines (for transactions such as withdrawing money from a bank account), smart cards (also known as stored-value cards, used when making and receiving payments), and automated clearinghouses (commonly used for paying bills or settling other transactions), all of which increase the speed of regular payments and settlements.

STANDARDS OF VALUE

In the Middle Ages, when money consisted primarily of coins, silver and gold coins circulated simultaneously. As governments increasingly took over the coinage, and especially as fiduciary money was introduced, they tended to specify their nominal monetary units in terms of fixed weights of both silver and gold—to adopt a national bimetallic standard. Gresham's law, however, usually assured that the bimetallic standard degenerated into a monometallic standard. If one had gold (typically of greater value than silver), it was better to buy silver and bring it to be coined. Silver, the cheaper metal, "drove out" gold and became the standard. This happened in most of the countries of Europe, so that by the early 19th century all were effectively on a silver standard. In Britain, on the other hand, the ratio established in the 18th century on the advice of Sir Isaac Newton, then serving as master of the mint, overvalued gold and therefore led to an effective gold standard. In the United States a ratio of 15 ounces of silver to one ounce of gold was set in 1792. This ratio overvalued silver, so silver became the standard. In 1834, however, the ratio was altered to 16 to one, which overvalued gold, so gold became the standard.

The gold standard. The great gold discoveries in California and Australia in the 1840s and '50s produced a temporary decline in the value of gold in terms of silver. This price change, plus the dominance of Britain in international finance, led to a widespread shift from a silver standard to a gold standard. The early 20th century was the great era of the international gold standard. Gold coins circulated in most of the world; paper money, whether issued by private banks or by government, was convertible on demand into gold coins or gold bullion at an official price (with perhaps the addition of a small fee); and bank deposits were convertible into either gold coin or paper currency that was itself convertible into gold.

There was, in effect, a single world money called by different names in different countries. A U.S. dollar, for example, was defined as 23.22 grains of pure gold (25.8 grains of gold 0.9000 fineness). A British pound sterling was defined as 113.00 grains of pure gold (123.274 grains of gold 11/12th fine). Accordingly, one British pound equalled 4.8665 U.S. dollars (113.00/23.22) at the official parity. The actual exchange rate could deviate from this only by an amount that corresponded to the cost of shipping gold. If the price of the pound sterling in terms of dollars rose to a considerably higher value than this in the foreign exchange market, someone in New York City who had a debt to pay in London might find that, rather than buy the needed pounds on the market, it was cheaper to get gold for dollars at a bank or at the U.S. subtreasury, ship the gold to London, and get pounds for the gold from the Bank of England. This set an upper limit to the exchange rate. Similarly, the cost of shipping gold from Britain to the United States set a lower limit. These limits were known as the gold points.

The international gold standard

Under such an international gold standard, the quantity of money in each country was determined by the specie-flow adjustment mechanism analyzed by 19th-century economists. If the quantity of money in a country rose unduly, this would tend to raise prices in that country relative to prices in other countries; the rise in prices would then discourage exports and encourage imports. The decreased supply of foreign currency from the sale of exports plus the increased demand for foreign currency to pay for imports would tend to raise the price of foreign currency in terms of domestic currency. As soon as this price hit the upper gold point, gold would be shipped to other countries. The decline in the amount of gold would produce in turn a reduction in the total amount of money—because banks and government institutions, seeing their gold reserves decline, would want to protect themselves against further demands by reducing the claims against gold that were outstanding. This would tend to lower prices at home. The influx of gold abroad would have the opposite effect, increasing the quantity of money there and raising prices. These adjustments would continue until the gold flow ceased or was reversed.

This is precisely the mechanism that operates within a unified currency area, the mechanism that determines how much money there is in Illinois compared to how much there is in other states or how much there is in Wales compared to how much there is in other parts of the United Kingdom. In the early 20th century, most of the world was a unified currency area, so the gold standard functioned throughout the world. Its great advantage was that—if permitted to operate—it would greatly limit the power of any national government to engage in irresponsible monetary expansion. This was also its great disadvantage. In an era of big government and of full-employment policies, a real gold standard would tie the hands of governments in one of the most important areas of policy.

The dollar standard. In the wake of World War I, the international gold standard wavered, then recovered somewhat, before ending finally as a result of the Great Depression. The world's monetary system operated on a dollar standard from the end of World War II until 1971, when, in an attempt to control inflation, the United States unilaterally severed the connection between the dollar and gold. Under the dollar standard, the dollar was widely used in international trade, even in trade between countries other than the United States. Other countries maintained their "official" exchange rates by buying and selling U.S. dollars and held dollars as their primary reserve currency for that purpose. The existence of a dollar standard did not mean that other countries could not change their exchange rates—as Germany and France did in 1969—just as the gold standard did not mean that they could not "devalue" or "appreciate" in terms of gold. What it did mean was that the United States could not determine its own exchange rate or its balance of payments position. It also meant that U.S. monetary policy had a major effect on the world economy.

MODERN MONETARY SYSTEMS

Monetary systems are today very much alike in all the major countries of the world. They consist of three levels: (1) the holders of money (the "public")—individuals, businesses, governmental units; (2) commercial banks (privately or governmentally owned), which borrow from the public and make loans to individuals, firms, or governments; and (3) central banks, which have a monopoly on the issue of certain types of money, serve as the bankers for the central government and the commercial banks, and have the power to determine the quantity of money.

Public money holdings. The public holds its money as: (1) currency (including coin) and (2) bank deposits.

Currency. In many countries the bulk of the currency consists of notes issued by the central bank. In the United Kingdom these are Bank of England Notes; in the United

States, Federal Reserve Notes; and so on. It is hard to say precisely what "issued by the central bank" means. In the United States, for example, the currency bears the words "Federal Reserve Note," but these notes are not obligations of the Federal Reserve Banks in any meaningful sense. The holder who presents them to a Federal Reserve Bank has no right to anything except other pieces of paper adding up to the same face value. The situation is much the same in most other countries. Members of the European Union (EU) are adopting the euro as a standardized currency, meaning that the currencies of EU nations will eventually disappear.

Bank deposits. Bank deposits also are counted as part of the money holdings of the public. In the 19th century most economists regarded only currency and coin as "money," treating deposits only as claims to money. As deposits became more and more widely held, and as a larger fraction of transactions came to be effected by check, economists started to include not the checks, but the deposits they transferred, as money on a par with currency and coin.

The term *deposits* is highly misleading. It connotes something deposited for safekeeping, like currency in a safe-deposit box. Bank deposits are not like that. When one brings currency to a bank for "deposit," the bank does not put the currency in a vault and keep it there. It may put a small fraction of the currency in the vault as "reserves," but it will lend most of it to someone else or buy an investment—that is, a bond or some other security.

The deposits of commercial banks are assets of their holders but liabilities of the banks. The assets of the banks consist of "reserves"—currency plus deposits at other banks—and "earning assets"—loans plus investments in the form of bonds and other securities. The reserves are only a small fraction of the aggregate deposits.

Central banking. An important part of the monetary system is the central bank. The Bank of England was the first modern central bank, serving as the model for many others. It was established as a private bank in 1694 but quickly came to be largely an agency of the government. The Bank of France was established as a governmental institution by Napoleon in 1800. In the United States, the 12 Federal Reserve Banks, which, together with the Board of Governors in Washington, D.C., constitute the Federal Reserve System, are technically owned by their member commercial banks, but for all intents and purposes, the system is a governmental agency.

Open-market operations

The way in which a central bank increases or decreases the total amount of high-powered money is, typically, by making loans (discounting) or by buying and selling government securities (open-market operations). If, for example, the Federal Reserve System purchases $1,000,000 of government securities, it will pay for these securities by a check on itself, adding $1,000,000 to its assets and $1,000,000 to its liabilities. The seller can take the check to a Federal Reserve Bank, which will exchange for it $1,000,000 in Federal Reserve Notes. Or the seller may deposit the check at a commercial bank, and the bank will in turn present it to a Federal Reserve Bank, which will "pay" the check by making a book entry increasing that bank's deposits with it by $1,000,000. The bank may, in turn, transfer this sum to a borrower, who again will convert it into Federal Reserve Notes or deposit it.

The important point is that these bookkeeping operations simply record a process whereby the central bank has created, out of thin air as it were, additional high-powered money—the direct counterpart of printing Federal Reserve Notes. Similarly, if the central bank sells government securities, it destroys high-powered money. (See also GOVERNMENT FINANCE: *Monetary policy.*)

In addition to the high-powered money of the central bank, the total quantity of money at any given time depends on the preferences of the public as to the relative amounts of money it wishes to hold as currency and as deposits and on the preferences of the banks as to the ratio they wish to maintain between their reserves and their deposits. (The reserve ratio is, of course, dominated by legal reserve requirements, where they exist, but may vary somewhat as banks think it prudent to keep a larger or smaller cushion in excess of required reserves.)

It follows that a central bank can vary the total quantity of money as it wishes within broad limits. The major problem of modern monetary policy is how the central bank should use this power.

MONETARY THEORIES

The relation between money and what it will buy has always been a central issue of monetary theory. Economists have generally held that the level of prices is determined by the quantity of money. But precisely how the quantity of money affects the level of prices, and what the effects are of changes in the quantity of money, have been conceptualized in different ways at different times. From the mid-1930s to the mid-1960s, there was a widespread rejection of the quantity theory by professional economists. The following discussion of monetary theory will deal first with the quantity theory of money, as it developed before the 1930s, then with the Keynesian theory and its subsequent revisions.

The quantity theory of money. In whatever way it has been formulated, the quantity theory of money has involved a distinction between the nominal quantity of money and the real quantity of money. The nominal quantity is that expressed in whatever units are used to designate money—talents, shekels, pounds, francs, lire, drachmas, dollars, yen, and so on. The real quantity is that expressed in terms of the volume of goods and services that the money will purchase. The quantity theory assumes that what ultimately matters to holders of money is the real rather than the nominal quantity. If this is so, then—whatever factors may determine the nominal quantity of money—it is the holders of money who determine the real quantity and, in the process, the price level.

Nominal and real quantities

The following may be considered a hypothetical example. In a certain community the quantity of money in existence is $1,000,000, and the total income of the community is $10,000,000 a year. On the average, each member of the community holds an amount of money equal in value to one-tenth of a year's income, or to 5.2 weeks' income. Put differently, the income velocity of circulation is equal to 10 per year; that is, each $1 on the average is paid out 10 times a year. For the sake of simplicity there are no business enterprises; the members of the community buy and sell services from and to one another.

The quantity of money is somehow then doubled, but in such a way that no one expects the quantity to change again. Each member of the community will regard himself as better off, because each now has 10.4 weeks' income in the form of cash instead of the previous 5.2 weeks'. If everyone were to hold onto the extra cash, nothing further would happen. But people will try to spend it. One person's spending, however, is another's receipts. All the people together cannot spend more than all the people receive. The attempt of each to do so is bound to be frustrated. In the attempt to spend more than they receive, people will simultaneously try to buy more of various services from each other and to sell less. To induce others to sell, they will offer higher prices; to induce others not to buy, they will ask higher prices. Whether the quantity sold goes up or down depends on whether the attempt to buy more is stronger or weaker than the attempt to sell less. But in either case total spending is sure to go up and so are total income and prices paid. When income has doubled, to $20,000,000, the amount of money in existence will again be equal in value to 5.2 weeks' income. The community will have succeeded in reducing its real cash balances to their former level, not by reducing nominal balances but by raising incomes and prices. The process of adjustment may not be smooth; spending may go too far and leave people with real balances that are too small, requiring a subsequent fall in the price level; but the final position will tend toward a doubling of prices, and the previous real flows of services will be resumed with no one any better off than before the new money was distributed.

This simple example embodies most of the basic principles of monetary theory: (1) the central distinction between the nominal and the real quantity of money; (2) the equally crucial contrast between the alternatives open to the in-

dividual and to the community as a whole. To each individual separately (in the hypothetical example and in the real world) it looks as if income is outside personal control, but each individual can determine how much cash to hold. To the community as a whole, the total amount of cash is fixed, but it is able to determine the size of its income in dollars; (3) the importance of attempts. The attempt of people as a whole to spend more than they receive, even though doomed to frustration, has the effect of raising total nominal expenditures and receipts.

The Keynesian critique. The groundwork for the Keynesian attack on the quantity theory was laid by two historical experiences. One was the British experience after the return to the gold standard in 1925. In order to maintain the parity set for the pound in terms of gold, the Bank of England followed a consistently tight monetary policy. But prices did not move downward sufficiently, and there was persistent unemployment. This raised doubts about the allegedly classical postulate that money was only a veil, that total output was determined by real conditions, and that full employment was the "equilibrium," or normal, position. The second and even more dramatic experience was the Great Depression.

This stimulated the British economist John Maynard Keynes—who had been a highly sophisticated quantity theorist on strictly classical lines—to develop an alternative interpretation of the debacle after 1929 and an alternative prescription for policy. It also produced a sympathetic climate for his new theory, so that the Keynesian revolution swept the economics profession in a remarkably short time.

Keynes's interpretation. The basis for Keynes's critique was the quantity equation, expressed as:

$$MV = Py.$$

In this equation y represents national income in constant prices (the total value at fixed prices of all final goods and services, including additions to the stock of capital), P is a price index, M represents the amount of money, and V is the average number of times that the money is used for making income transactions (such as payments for final goods and services).

Keynes did not, of course, deny the validity of the quantity equation. What he maintained was very different: that the right-hand side—Py, or prices times output—was determined by forces largely independent of the left-hand side (quantity of money, M, and velocity of money, V). P, he argued, was largely an institutional datum, linked to customary nominal rates of wages that were very resistant to change. Real income or output, y, he argued, was determined by aggregate demand, which depended primarily on the amount of "autonomous spending"—that is, spending that was not linked directly to current income and that consisted mostly of investment expenditures by enterprises and spending by government. The rest of aggregate demand consisted mostly of consumption, which was linked closely to current income. On this view, the key factor determining the level of real income and output, and thereby the level of nominal income, was the strength of investment and of government spending.

Government spending

How then could the quantity equation hold? Keynes's answer was that V was so pliable that it would adjust to keep the two sides equal. Let autonomous spending increase without a change in the quantity of money, and V would simply increase in response; let the quantity of money increase without an increase in autonomous spending, and V would decline to offset the increase in M.

In the extreme form of this approach, the quantity of money simply did not matter at all for the course of prices or real output but only for the movement of V.

How did Keynes explain the plasticity of V? He did so by means of a very special explanation of the demand for money, to which he applied the phrase "liquidity preference." He regarded the quantity of money demanded as divided into two parts, one part, M_1, "held to satisfy the transactions and precautionary-motives," the other, M_2, "held to satisfy the speculative-motive." He regarded M_1 as a roughly constant fraction of income, and with respect to this part he accepted a rather rigid form of the quantity theory. He regarded M_2, however, as largely independent of income and as highly sensitive to current interest rates and to the expectations of future interest rates. This explained the plasticity of V.

According to Keynes, if current interest rates are above the level many holders of money expect to prevail in the future, people will prefer to hold their speculative balances in bonds instead of money—because they expect a fall in interest rates, which means a rise in bond prices. Conversely, if current interest rates are below the level expected to prevail in the future, they will prefer to hold money. Over short periods, he argued, these expectations are widely and strongly held at about the same level. In the extreme, with everyone holding the same expectations and everyone sensitive, liquidity preference will become, as he termed it, absolute. The interest rate measures the cost of holding money instead of bonds—it is the price, as Keynes put it, that the holder of money pays for retaining liquidity. If the interest rate is low, the cost of liquidity is low; hence people will hold a large fraction of their wealth in the form of money, and the fraction will be sensitive to small changes in the interest rate—liquidity preference being absolute in the long run as well as in the short run.

Liquidity and the interest rate

Keynes himself regarded absolute liquidity preference as a strictly "limiting case"; while it "might become practically important in future," he knew "of no example . . . hitherto." In practice, however, he treated velocity as if its behaviour frequently approximated this limiting case, and his disciples went much further than he did.

If liquidity preference was not absolute, then in the Keynesian view a change in the quantity of money would first affect interest rates in order to induce the community to hold the changed quantity of money. This change in interest rates might in turn affect autonomous spending—a decline encouraging investment and a rise discouraging investment—and in this way aggregate demand, income, and employment. The more sensitive is the quantity of money demanded to interest rates, and the less sensitive is investment to interest rates, the smaller will be the final effect of changes in the quantity of money, and conversely.

Changing views. The Keynesian revolution swept the economics profession in the late 1930s and early 1940s; by the 1960s Keynesian ideas had become deeply embedded in the thinking of intellectuals. Their analysis had predicted a great postwar depression if war spending was not replaced by other government spending. But government spending fell precipitously in the United States and elsewhere without ill effect. The analysis of the Keynesians had called for "cheap money" policies—that is, low interest rates—with a view to stimulating investment and thereby avoiding mass unemployment. Where they were adopted, however, these policies were consistently followed by inflation that could be restrained only by abandoning the cheap-money policies. A reexamination of the Great Depression of the 1930s demonstrated that, contrary to general belief, it had been a tragic testament to the great power of monetary policy, not to its impotence. The U.S. Federal Reserve System could have prevented the decline of one-third in the quantity of money that occurred from 1929 to 1933. Had it done so, the evidence indicates, the Depression would have been far milder and briefer. Most important of all, extensive empirical research demonstrated that the velocity of circulation of money, far from moving to offset changes in the quantity of money, has generally moved in the same direction and reinforced the effect of these changes.

The monetarist view. The result was a major change in the views of Keynesians. They now attribute far more importance to the quantity of money than they earlier did, regarding the quantity of money demanded as less elastic with respect to interest rates, and investment as more elastic, than they did in the first flush of enthusiasm. In addition, some economists waged a counterrevolution in the name of monetary policy, to which the name *monetarism* was attached. This doctrine made significant gains and has influenced considerably the views even of those who still regard themselves as Keynesians.

No counterrevolution ever produces a return to the status

quo. The monetarist doctrine has much in common with the quantity theory, but it has not expunged the Keynesian revolution. The Keynesian emphasis on the plasticity of velocity, for example, led to extensive work on the stability of the demand for money, and in particular on the exploration of time lags between monetary changes and economic changes and on the separate effects of monetary changes on prices, output, and interest rates.

Key propositions. For the long run, monetarism builds upon the earlier quantity theory by contributing a sophisticated analysis of short-run effects and a detailed set of empirical generalizations about these effects.

The key propositions of monetarism are as follows:

1. The rate of growth of the quantity of money is consistently, though not precisely, related to the rate of growth of nominal income. That is, if the quantity of money grows rapidly, so will nominal income, and conversely. The velocity of circulation, though not constant, is fairly predictable.

2. This relation is not obvious, mainly because it takes time for changes in monetary growth to affect income.

The time factor in monetarist theory

3. On the average, a change in the rate of monetary growth produces a change in the rate of growth of nominal income six to nine months later. But this is an average.

4. If the rate of monetary growth is reduced, then about six to nine months later the rate of growth of nominal income and also of physical output will decline, but the rate of price rise will be affected very little. There will be downward pressure on prices only as a gap emerges between actual and potential output.

5. The effect on prices comes on the average about a year after the effect on nominal income and output, so that the total delay between a change in monetary growth and a change in the rate of inflation averages roughly two years.

6. The above relationships are not invariable. There is many a slip between the monetary change and the income change.

7. Monetary changes affect output only in the short run—though "short run" may mean five to 10 years. Over the longer run the earlier quantity theory seems to hold, and the rate of monetary growth affects only prices. What happens to output in the long run depends on such "real" factors as the enterprise, ingenuity, and industry of the people; the extent of thrift; the structure of industry and government; the relations among nations; and so on.

8. Inflation is always and everywhere a monetary phenomenon, in the sense that it cannot occur without a more rapid increase in the quantity of money than in output. There are, of course, many possible reasons for monetary growth—gold discoveries, the manner in which government spending is financed, and even the manner in which private spending is financed.

9. Government spending may or may not be inflationary. It will be inflationary if it is financed by creating money—that is, by printing currency or creating bank deposits—and if the resultant rate of monetary growth exceeds the rate of growth of output. If it is financed by taxes or by borrowing from the public, the main effect is that the government spends the funds instead of someone else.

10. One of the most difficult things to explain is the way in which a change in the quantity of money affects income. Generally, the initial effect is not on income at all but on the prices of existing assets (bonds, equities, houses, and other physical capital). This is the liquidity effect stressed by Keynes; it occurs on the balance sheet, not on the income account. An increased rate of monetary growth raises the amount of cash people (or businesses) have relative to other assets. The holders of the excess cash will try to correct this imbalance by buying other assets. But one person's spending is another's receipts. All the people together cannot change the amount of cash all hold—only the monetary authorities can do that. Their attempts will tend, however, to raise the prices of assets and to reduce interest rates. These changes will in turn encourage spending to produce new assets. Thus the initial effect on balance sheets is translated into an effect on income and spending. In this connection the monetarists stress a far wider range of assets and interest rates than do the Keynesians; they emphasize such assets as durable consumer goods and other real property, and they regard market interest rates as only a small part of the whole complex of relevant rates.

11. One important feature of this mechanism is that a change in monetary growth affects interest rates in one direction at the outset and in the opposite direction later on. More rapid monetary growth at first tends to lower interest rates. But later on, as it raises spending and stimulates price inflation, it also produces a rise in the demand for loans that will tend to raise interest rates. Taking the opposite case, a slower rate of monetary growth at first raises interest rates, but later on, as it reduces spending and price inflation, it lowers interest rates. This inconsistent relation between the quantity of money and interest rates explains why monetarists insist that interest rates are not a good guide to monetary policy.

12. These propositions clearly imply that monetary policy is important and that what is important about monetary policy is its effect on the quantity of money, not on bank credit or total credit or interest rates. Wide swings in the rate of change of the quantity of money are evidently destabilizing and should be avoided.

Monetary prescriptions

Beyond this, different monetarists draw different conclusions. Some conclude that the monetary authorities should make deliberate changes in the rate of monetary growth in order to offset other forces making for instability; these changes should be gradual and small and make allowance for the lags involved. Others maintain that not enough is known about the relations between changes in the quantity of money and in prices and output to assure that a discretionary monetary policy will do good rather than harm. They believe that a wiser policy would be simply to have the quantity of money grow at a steady rate over time. Monetarism reached its peak of popularity in the 1970s. At that time, both the United Kingdom and the United States implemented monetarist policies. Keynesianism made a comeback in the final decades of the 20th century.

Conclusion. No other subject in economics has been studied longer or more intensively than the subject of money. The result is a vast amount of documented experience and a well-developed body of theoretical analysis. The extent to which the students of monetary problems agree in their basic conclusions is concealed by the tendency of laymen to exaggerate their differences. But even among professional economists there remain important disagreements, centring mainly on empirical judgments about the stability and form of some of the relations between money and other economic magnitudes.

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Mongolia

Mongolia (Mongol: Uls) is a vast highland country of eastern Asia. This independent republic, called the People's Republic of Mongolia (Bügd Nayramdah Mongol Ard Uls, from 1924 to 1992), occupies an area of 604,000 square miles (1,565,000 square kilometres). Its shape is that of an elongated oval, measuring 1,486 miles (2,392 kilometres) from west to east and, at its maximum, 782 miles from north to south. Mongolia is bounded on the north by Russia and on the south by China.

Located deep within the interior of eastern Asia far from any ocean, Mongolia has a marked continental climate, with long, cold winters and short, cool to hot summers. Its remarkable variety of scenery consists largely of upland steppes, semideserts, and deserts, although in the west and north forested, high mountain ranges alternate with dry, lake-dotted basins. Mongolia is highland country, with an average altitude of 5,200 feet (1,585 metres) above sea level. The highest peaks are in the Mongol Altai Mountains, of which Nayramadlïn Peak (also called Hüyten Peak; 14,350 feet [4,374 metres]), at the western tip of the country, is Mongolia's highest point.

Nearly four-fifths of Mongolia's area consists of pasturelands, which support immense herds of grazing livestock; the remaining area is about equally divided between forests and barren deserts, with only a tiny fraction of the land in crops. With a total population of slightly more than two million, Mongolia has one of the lowest population densities of any country in the world. However, since the 1950s the country has had one of Asia's highest rates of natural increase.

The Mongols have a long prehistory and a most remarkable history. Their ancestors were the Huns, a people who lived in Central Asia from the 3rd to the 1st century BC. A single Mongolian feudal state eventually was formed in the early 13th century AD from nomadic tribal groupings. Its leader, Genghis Khan, and his successors in the 13th century controlled a vast empire that included much of China, Russia, and Central Asia. Because of its location between China and Russia, Mongolia subsequently was dominated first by one and then the other, but mainly by the Chinese (1691–1921). Damdiny Sühbaatar, the national hero of modern Mongolia, was profoundly influenced by the October Revolution (1917) in Russia and later, with Soviet assistance, drove out both the White Russians and the Chinese. Sühbaatar's forces achieved power on July 11, 1921, traditionally the founding date of the present state.

From its independence from China in 1921, Mongolia was closely tied to the Soviet Union until the end of the 1980s. It received technical, economic, and military assistance from the Soviet Union and generally followed Soviet guidance in political and cultural matters, both domestic and international. Symbolic of the profound changes in culture and society was the replacement in the 1940s of the traditional Mongolian alphabet with a new one based on the Cyrillic letters of the Russian alphabet. In the period 1990–92, however, Mongolia moved away from a monopoly of political power by the communist party to free multiparty elections, a coalition government, a new constitution, greater cultural and religious freedom with more emphasis on national Mongol traditions, and a neutral position in international relations, as well as toward some elements of a market economy. In the 1990s the traditional script was once again taught in schools, and store signs appeared in both Cyrillic and traditional forms. (C.D.H.)

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Physical and human geography

THE LAND

Relief. Mongolia can be divided into three major topographic zones: the fingerlike mountain ridges that thrust into the northern and western areas, the basin areas that lie between and around them, and the enormous upland plateau belt that sweeps across the southern and eastern sectors. The entire country is prone to seismic movements, with some earthquakes reaching extreme limits of severity; their effects, however, are diminished by the low population density.

The mountains. The present relief of Mongolia is the result of geologically recent upheavals of the Alpine mountain-building period. There are three major mountain belts. The highest and the longest spine is the westernmost, the Altai Mountains (Mongolian: Altayn Nuruu), which sweeps in from the northwestern tip of the country and thrusts toward the southeast for 1,000 miles. The main range—the only one in the country where contemporary glaciation has developed—is the Mongolian Altai Mountains, and a lesser range splitting off to the southeast is known as the Gobi Altai Mountains. The southeastern extremities of the main range also split into a number of smaller hills, all following the same general trend, losing themselves in the expanses of the Gobi. The three major mountain belts

The Hangayn (Khangai) Mountains, also trending northwest to southeast, form a solid mountain mass near the centre of the republic, with peaks towering to more than 12,000 feet. A characteristic feature is the gentle slopes and crests, often covered with fine pastures. The higher central portions are nevertheless rugged and precipitous. To the far north, the mountains adjoin the Sayan Mountains of Siberia.

The third mountain block, the smaller and lower Hentiyn (Khentei) range, trends southwest to northeast of Ulaanbaatar; it reaches a maximum height of about 9,200 feet, but in general its elevation is between 6,000 and 8,000 feet. Ulaanbaatar lies at the southwestern base of the range. The enormous Greater Khingan Range rises along and beyond the eastern frontier with China.

The northern intermontane basins. Around and between the main ranges mentioned above lie an important series of basins. In the northwest of the country, tucked between the Altai, the Hangayn, and the mountains of the frontier with Russian Siberia, lies a scenic basin complex known as the Great Lakes region, in which are strewn more than 300 lakes. Another basin complex lies between the eastern slopes of the Hangayn Mountains and the western foothills of the Hentiyn Mountains. The southern portion (the basins of the Tuul and Orhon rivers) is a fertile region important in Mongolian history as the cradle of settled ways of life. Its landscapes are strewn with the ruins of numerous ancient communities.

Farther north, on the northern flanks of the Hangayn Mountains, lies the remarkable Khorgo region, in which as many as a dozen extinct volcanoes and numerous volcanic lakes are found in a small area. Swift and turbulent rivers have cut jagged gorges. The source stream of the Orhon River is in another volcanic region, with a cluster of lakes, deep volcanic vents, and hot springs. Near the northern border, Lake Hövsgöl is the focus of another rugged, lake-strewn region, noted for its huge subterranean caves.

The plateau and desert belt. The eastern part of Mongolia has a rolling topography of hilly steppe plains, supplanted in the extreme east by clusters of small, flat plains lying at altitudes of 2,000 to 2,300 feet. Here and there, small, stubby massifs contain the clearly discernible cones of extinct volcanoes. The Dariganga area of Mongolia's eastern tip contains some 220 such extinct volcanoes. Most of the southern part of the country is a vast rolling oasis-dotted plain, forming the northern fringe of the Gobi, which is predominantly stony. The flat relief is occasionally broken by low, heavily eroded ranges. Several spectacular natural features are found in the Gobi region. Huge, six-sided basalt columns, arranged in clusters resembling bundles of pencils, are found in the eastern and central regions. The southern Gobi contains three mountain ranges, known as the Gurvan Sayhan Mountains, and the scenic Yelyn Valley, now a national park, with deep gorges surrounded by towering rocky cliffs where condors have made their nests.

Features of the Gobi

Drainage. Mongolia lies on a continental divide: rivers in the north flow northward into the Arctic Ocean, and those in the northeast flow eastward into the Pacific. The western and southern two-thirds of the country consist of interior drainage basins, in which seasonal or intermittent streams end in salt lakes or disappear into the stones and sands of the desert. In the northern regions the turbulent mountain streams and small rivers merge into deep, well-developed rivers. In the southern areas—where there are only a few constantly flowing rivers—lakes, saltwater and freshwater springs, and wells draw on subterranean water supplies. The great divide, separating waters that flow into the oceans and into the interior basins, runs along the crest of the Hangayn Mountains. Mongolia's greatest river, the Selenge (Selenga), with its main tributary, the Orhon, drains northward across the Russian border and into Lake Baikal; the Mongolian portion of the Selenge valley is in the north-central portion of the country. Mongolia's other major rivers, the Onon and the Kerulen, run latitudinally across the eastern part of the country. The largest rivers draining into the interior are the Hovd (Kobdo), which rises from the glaciers of the Mongolian Altai Mountains, and the Dzavhan, which drains the southern slopes of the Hangayn Mountains; both flow into the Great Lakes region. A series of other rivers east of the Dzavhan run down from the southern flanks of the Hangayn, ending in salt lakes or disappearing in the Gobi expanses. Generally, the Mongolian rivers are swift and with a steep gradient, offering hydroelectric potential, as well as occasional flood dangers.

Major rivers

Mongolia has more than 3,000 lakes with areas of half a square mile or more. Many are salty, ephemeral, highly variable in area, and without outlets. The largest and deepest freshwater lake, Hövsgöl, occupies a structural depression in the northernmost part of the country. Other large lakes—all in the west—include the saline Lake Uvs, which is nearly 1,300 square miles in area, and the freshwater Lake Har Us, which drains into the saline Lake Hyargas. Many lakes are of volcanic origin, as is Lake Terhiyn Tsagaan on the Hangayn's northern slopes.

Climate. Mongolia is situated at high latitudes and high altitudes, far from the moderating influences of the ocean. As a consequence, it experiences one of the world's most pronounced continental climates with very cold winters, cool to hot summers, large annual and diurnal ranges in temperature, and generally scanty rainfall. The difference between the mean temperatures of January and July can reach 80° F (44° C), and temperature variations of as much as 55° F (30° C) can occur in a single day. Mean temperatures in the north generally are cooler than those in the south: the mean January and July temperatures for the Ulaanbaatar area are −15° F (−26° C) and 63° F (17°

M. Koene/H. Armstrong Roberts



Orhon River, north-central Mongolia.


RUSSIA
CHINA
CHINA
GOBI DESERT
Irkutsk
Lake Baikal
Baotou
Peking
Yellow R.
Hwang Ho
Amur
Onon
Ulz
Kerulen
Lake Hovsgol
Lake Uvs
Lake Hyargas
Lake Buyr
Lake Dorgon
Lake Terkhiyn
Lake Orog
Lake Ulaan
Lake Boon Tsagaan
Lake Achit
Lake Dayan
Lake Ulaan
Lake Khar Us
Lake Khyargas
Lake Airag
Lake Khar Nuur
Lake Har Us
Lake Khar
Lake Har
Lake Dorgon
Lake Terkhiyn
Lake Orog
Lake Ulaan
Lake Boon Tsagaan
Lake Achit
Lake Dayan
Lake Ulaan
Lake Khar Us
Lake Khyargas
Lake Airag
Lake Khar Nuur
Lake Har Us
Lake Khar
Lake Har
SAYAN MTS.
ALTAY MTS.
MONGOLIAN ALTAY MTS.
GOVI ALTAY MTS.
GOBI ALTAI MTS.
BOGDOHAN MTS.
BURGAN SAYHAN MTS.
HENTIY MTS.
KHANGAI RANGE
GREATER KHINGAN RANGE
HOVSGOL
UVS
BULGAN
SELENGE
DORNOD
DZAVHAN
ARHANGAY
ULAANBAATAR
HENTIY
HOVD
TOV
SUHBAATAR
GOVI ALTAY
OVORHANGAY
DUNDGOVI
BAYANHONGOR
DORNOGOVI
OMNOGOVI
Irkutsk
Ulaanbaatar
Choybalsen
Baruun-Urt
Darhan
Erdenet
Bayankhongor
Altay
Khovd
Uliastay
Mandalgovi
Sevsyhand
Dalandzadgad
Suhbaatar
Tes
Tsetserleg
Tosontsengel
Hatgal
Ulaangom
Tsagaannuur
Bayan-Ulgii
Ondorhaan
Tumentsogt
Sainshand
Choyr
Har-Ayrag
Darigang
Saynshand
Sukhbaatar
Darhan
Erdenet
Bulgan
Arvayheer
Baruun-Urt
Batshireet
Ondorhaan
Tumentsogt
Nalayh
Baganuur
Bayanzurkh
Mandalgovi
Dalandzadgad
Sainshand
Choybalsen
Sukhbaatar
Darigang
Sevsyhand
Har-Ayrag
Choyr
Khovd
Uliastay
Altay
Tes
Tsetserleg
Hatgal
Ulaangom
Tsagaannuur
Bayan-Ulgii
Arvayheer

The importance of latitudinal and altitudinal belts

are predominantly of the chestnut or brown type, but with considerable salinization in desert and semidesert areas. Latitudinal and altitudinal belts of vegetation are probably the most obvious feature of the local Mongolian landscape. There are four basic divisions running in latitude from north to south and in altitude from the mountains to the basins and plains: forest-steppe, steppe, semidesert, and desert. In addition, the higher mountains have bands of coniferous forest (taiga) and, higher yet, an Alpine zone. The steppes (grasslands) predominate, covering more than three-quarters of the national territory.

The mountain forest-steppe zone exhibits the richest diversity of plant and animal life. Forests grow thickest on the northern shady slopes, the most widely distributed tree being the Siberian larch, followed by the cedar, with a varying admixture of spruce, pine, and fir. Deciduous trees include the birch, aspen, and poplar. Steppe vegetation is found in the intermontane basins, the wide river valleys, and the sunny southern flanks of the mountains. These huge expanses of pastureland are covered with feather grass, couch grass, wormwood, and many fodder plant species. In summer the steppes are carpeted with a magnificent covering of bright violet, blue, red, and yellow flowers. On the highest mountain slopes the damp, dark taiga gives way to the thin grasses and occasional flowers of the Alpine zone, merging into the bare rocks and rugged glaciers of the summit zone.

Semideserts are found in the Great Lakes intermontane depression in the west and over the Gobi in the south, giving way to true desert conditions near the southern border. Vegetation is scarce there but heavy enough to feed camels, goats, and sheep. Tracts of saxaul (xerophytic vegetation adapted to very dry conditions) and groves of elm and poplars cluster around springs or other underground water sources. The Gobi is a typical hammada, or rock-floored desert with gravel cover; only the extreme east has small areas of sandy desert.

Animal life. The varied natural conditions, the interior location, and the sparse human population of Mongolia all contribute to a rich and diverse wildlife that has attracted international attention and has commercial importance. Lying on the borders of several distinct zoogeographic regions (the Tibetan, the Afghano-Turkistani, the Siberian, and the North-Chinese-Manchurian), the country has a fauna combining species from each of them. The northern forests harbour lynx, maral (Asiatic red deer), elk, roe deer, musk deer, brown bears, snow leopards, wolverines, wild boars, squirrels, and sables. The steppes are the home of, among others, the marmot—whose pelts are important economically—and the lithe Mongolian gazelle. Clustering around water holes in the semidesert and desert region may be found the wild sheep known as *argal,* Asiatic wild asses (*kulans*), wild camels (*khavtgays*), and the Gobi bear (*mazalai*); some of these species are extremely rare and found nowhere else in Asia. Domesticated animals include sheep, camels, cattle, the hairy highland yak, goats, dogs, and the famous Mongolian horses. Birdlife includes larks, partridges, cranes, pheasants, bustards, and falcons in the steppes; geese, ducks, gulls, pelicans, swans, and cormorants in the rivers and lakes; the snowy owl, the golden eagle, and the condor, which frequent some areas. The freshwater lakes and rivers harbour some 70 fish species, including salmon, trout, grayling, perch, and pike. Hunting and fishing, for sport and for commercial purposes, are important; but the government has introduced stringent hunting regulations and other conservationist measures, including the establishment of national parks and nature reserves. (D.Ba./O.Sh./C.D.H.)

Settlement patterns. Human beings have long been in evidence in this part of what is sometimes called High Asia; and the ruins of long-abandoned cities, as well as archaeological remains dating back to the earliest days of prehistory, have attracted the attention of Mongolian and international scholars. Settlement in modern Mongolia is characterized by sharp regional contrasts: in the better-watered northern basins of the Orhon and Selenga rivers, densities of population may reach 10 persons per square mile (4 per square kilometre), but some desert areas are devoid of inhabitants. The core of habitation lies in the north-central area between Ulaanbaatar and Sühbaatar. There are found the richest pastures, the main crop area, the largest cities, the most industrial establishments, and the best transportation.

Rural patterns. The huge rural areas of the country have their own charm. A feature distinctive of the countryside is the yurt, or *ger,* the traditional Mongolian dwelling. It is a cone-shaped, latticed structure, light, strong, and easy to assemble, transport, and reerect, which offers warmth in winter and coolness in summer. It is still used by herdsmen moving from pasture to pasture, and the clusters of white felt-and-canvas cones against a green background still dominate the landscape in many areas. As the nomadic population becomes more settled, however, the yurt clusters are becoming associated with cooperatives and state farms, often at centres with more permanent dwellings.

The yurt

Urban patterns. It is in the cities, however, that Mongolia presents its modern aspect. Cities grew rapidly in the second half of the 20th century, increasing their proportion of the total population from about one-quarter in 1950 to one-half by the early 1990s. The capital, Ulaanbaatar, by far the largest and most important urban centre, has a population of 500,000, one-fourth of the population of the entire country. It lies on the banks of the Tuul River in the north-central portion of Mongolia. Formerly known among Europeans as Urga, it was originally a nomadic princely residence and became settled on the present site in 1639. The old city—which numbered some 60,000 people in 1921—consisted mainly of monasteries, a few adobe structures, and clusters of yurts. By the late 20th century, however, the "city of felt" had been transformed into a modern city, with broad avenues and streets, apartment complexes, and massive governmental, cultural, and educational buildings. The yurt areas and the fenced-off small houses had become a diminishing feature of the peripheral regions. Two other important cities, Darhan and

M. Koene/H. Armstrong Roberts



Settlement of felt-and-canvas yurts, Mongolia.

Sühbaatar, lie between Ulaanbaatar and Mongolia's northern border. The city of Darhan is an example of planned urbanization. Its foundation stone was laid in 1961 in an existing settlement of about 1,500 people, and within 20 years the population exceeded 50,000. The new city became the centre of a major industrial complex, second only to Ulaanbaatar itself. Sühbaatar, founded in 1937, is a transportation and trade centre located at the confluence of the Orhon and Selenge rivers and on the Trans-Mongolian Railway near the Russian border. Other industrial centres include Choybalsan, on the Kerulen River in the northeast, and Erdenet, located west of Darhan.

THE PEOPLE

Ethnic and religious background. Anthropologically, the Mongols are quite homogeneous, belonging to the classic physical type to which they lent their name. Within Mongolia, Khalkha-speaking Mongols constitute almost four-fifths of the population. Other Mongolian groups—including Dörbed, Buryat, Bayad, and Dariganga—account for about one-eighth of the population. By tradition the Mongols have been Buddhists. Much of the rest of the population consists of Turkic-speaking peoples, mainly Kazakhs, who traditionally have been Muslims; located mainly in the western part of the country, they have been granted an autonomous area. A small but significant number of Russians live mainly in the cities. The Chinese, who were formerly important in cities, trade, and finance, have largely left the country.

The theocratic background

At the time of the founding of the modern state, the social composition was strongly influenced by the then-prevailing religious traditions of the lamas (monks), who followed tenets derived from Tibetan Buddhism, with a strong admixture of more primitive elements. Control lay in the hands of the head of the Mongolian Tibetan Buddhist Church (who was proclaimed the khan of all Mongolia) together with various local khans, hundreds of princes and noblemen, and the higher clergy. The new regime sought to replace feudal and religious structures with socialist and secular forms. During the 1930s the government closed monasteries, confiscated their livestock and landholdings, induced large numbers of monks to renounce religious life, and eliminated others. The number of Buddhist monks dropped from 100,000 in 1924 to 110 in 1990. Many aspects of the national cultural traditions are preserved in museums.

Demography. After a period of stagnation, the population of Mongolia increased rapidly in the second half of the 20th century, as birth rates climbed and death rates dropped. Improved health, sanitation, and medical facilities played a major role in reducing mortality, especially infant mortality. Also important was the government policy of encouraging families to have more children. Mongolia's rate of natural increase reached a peak in 1960 and declined slowly thereafter. Thus, by the late 20th century Mongolia's main demographic trend was toward a youthful, fast-growing population. (B.Gu./C.D.H.)

THE ECONOMY

Resources. In the early 1990s Mongolia experienced great economic difficulties as it moved from a command economy to a system with elements of a market economy. About one-third to one-half of the budget had previously come from the now-defunct Soviet Union. Mongolia's international debt was extremely high. The low national income per capita sank even lower as the population grew rapidly.

Mongolia possesses mineral resources. Geologic surveys have confirmed the existence of large deposits of coal and iron, tin, copper, gold, and silver ore and a number of lesser known minerals. Mongolia's biological resources consist largely of the great herds of livestock in the country. Overall livestock figures rose throughout most of the 20th century, providing a rich agricultural resource base that even enabled some exports of meat to be made. In addition, the northern rivers of Mongolia offer great potential for hydroelectric development, whereas the wildlife of the country offers potential for commercial exploitation.

Agriculture. Livestock raising—based on millions of head of sheep, goats, cattle, and horses and including a large number of camels—accounts for about 70 percent of the value of agricultural production. Livestock are widely distributed throughout the entire country. The number of horses and cattle reach their greatest concentrations in the wetter north-central regions, whereas goats and camels are proportionately more numerous in the drier west and south. Most of the livestock belong to agricultural cooperatives. Although the earliest cooperatives were formed in the 1930s, the main government campaign to organize the livestock herders (*arats*) into giant cooperatives took place in the years 1955–59.

Pastoral Mongols traditionally have shunned crop tillage. Furthermore, most of the country has a semiarid climate more suited to livestock production by grazing on the extensive natural grasslands than to cultivation. Less than 1 percent of the area of the country is used to grow crops. Crop production is largely limited to the moister northern parts of the country, particularly in the broad lower valleys of the Orhon and Selenge rivers but also along the Onon, Uldz, and Kerulen rivers in the northeast. Part of the cropland receives supplemental irrigation. Because of the long, cold winters only a single annual crop is possible. About four-fifths of the cropland is in grains—primarily in spring wheat but with some in barley or oats—and nearly all the rest is in fodder crops (hay). Yields are relatively low and vary greatly from year to year. Potatoes and other vegetables occupy only a tiny fraction of the crop area. About four-fifths of the cropland is in state farms, with the rest in cooperatives. The large state farms each average about 700 square miles in size and typically include some livestock production as well as crops.

Crops

Mining and industry. The chief minerals extracted are coal, primarily for domestic use, fluorite (fluorspar), and copper and molybdenum ores, both of which are exported. Some gold and tungsten deposits also are worked. The two main coal-mining districts are Sharin Gol, southeast of Darhan, and Nalayh, just southeast of Ulaanbaatar. To the southwest of Darhan lies the gigantic Erdenet copper- and molybdenum-mining complex, which began operation in the late 1970s.

Although the government has devoted a great amount of effort to industrializing the nation, much of Mongolia's industrial capacity is still engaged in processing raw materials or meeting basic domestic consumer needs. Thus, the principal manufactured products are processed foods (meat, beverages, dairy products, and flour); articles of clothing and footwear made from wool, hides, skins, and furs; and lumber, paper, matches, and furniture. Also important are the operation at Erdenet that concentrates copper and molybdenum ores for shipment and the construction industry. About half of the industrial employment is in Ulaanbaatar, which is the centre of light industry. Heavy industry is concentrated in Darhan, and forest products are processed in Sühbaatar.

Trade. During the 1980s minerals and ore concentrates became Mongolia's principal export, surpassing the traditional exports of livestock and their by-products. The main imports are machinery and equipment; fuels, minerals, and metals; and manufactures, particularly consumer goods.

More than three-fourths of Mongolia's trade was with the former Soviet Union, and much of the rest with former Comecon countries, but from the early 1990s Mongolia sought to increase trade with other nations. However, the development of a diversified international trade was hampered by various factors, notably the absence of direct access to the sea, the need to use Russian and Chinese transport and ports, the long distances and high transport costs, and the difficulties of competing in international markets.

Transportation. Mongolia's most important transportation artery is the Trans-Mongolian Railway, which runs north-south through the central part of the country; it links Mongolia to Russia and to China and provides the shortest overland route between Moscow and Peking. The railway is divided into northern and southern sections. The northern section extends from the Russian border to Ulaanbaatar, following several river valleys through the

The Trans-Mongolian Railway

mountainous terrain. It connects Mongolia's main urban and industrial centres and carries a substantial portion of the country's freight. The southern section, from Ulaanbaatar to the Chinese border, runs through rolling steppe and semidesert country. It was built in the mid-1950s, during the period of close Sino-Soviet cooperation. Another railway connects Choybalsan and other urban centres in the northeast with the Siberian rail system.

Roads provide connections between Ulaanbaatar and the *aymag* (provincial) centres and among smaller settlements. Nearly all the country's roads are unpaved. Trucks carry most of the nation's freight not carried by rail, particularly outside of the core area along the northern Trans-Mongolian Railway. Camels are still used in the sparsely populated desert areas of the south, and yaks and oxen still haul some goods in the rugged mountains of the west.

Air service is particularly suitable for passenger movement in Mongolia because distances between population centres are great, population density is low, and weather conditions generally are favourable for flying. Level, unobstructed terrain for landing strips is also widely available. Ulaanbaatar has an international airport, and the capital has regularly scheduled service to the province centres. Special medical and veterinary flights also are arranged.

ADMINISTRATION AND SOCIAL CONDITIONS

Government. From the founding of an independent Mongolia on July 11, 1921, the country followed Soviet leadership for nearly seven decades; it was the first Soviet satellite and remained so the longest. The Soviet army became Mongolia's main defense force, and party and governmental structures closely followed the Soviet models of a one-party political system. The economy was transformed gradually into a communist command economy with governmental ownership of the means of production and with an emphasis on mining and industry.

During the 1980s the party leadership underwent change. An era of openness permitted criticism of current and past party leadership and of economic, political, and social stagnation and resulted in the elimination of the monopoly of power by the communist party (Mongolian People's Revolutionary Party [MPRP]) in March 1990, multiparty elections in July 1990, and the subsequent formation of a coalition government. A new constitution became effective on Feb. 12, 1992, with power divided among independent legislative, executive, and judicial organs, with human rights guaranteed by law, with separation and mutual noninterference of state and religion, and with the authorization of private ownership of land, except for pastures used by nomadic herders. The lands (except those given to the citizens of Mongolia for private possession), water, forests, fauna, and underground resources are the property of the state, which also regulates the economy.

The new constitution provided for a strong, directly elected president, who nominates the prime minister and who has the power to veto legislation. That he must be at least 45 years old places the position out of the reach of young reformers. The constitution also created a unicameral legislature, the State Great Hural, with 76 members elected for four-year terms. Parliament by a two-thirds vote can overturn a presidential veto. The MPRP continues to play a leading role in the government.

The country is divided administratively into 18 *aymags* (provinces), with further local subdivisions into towns and *somons* (districts). The cities of Ulaanbaatar, Darhan, and Erdenet have independent administrative status.

Justice. Justice is administered through an independent system of courts: Supreme Court, province courts (including a capital city court), and district courts. Special courts such as criminal, civil, and administrative may be formed. Matters relating to the interpretation of the constitution are decided by an independent Constitutional Court. Amendments to the constitution require a three-fourths vote of members of the Great Hural.

Armed forces. Mongolia maintains only limited military forces, consisting of infantry divisions and support aircraft. Soviet troops were withdrawn in the early 1990s. The 1992 constitution prohibits the presence of foreign troops. (C.D.H.)

Education. From the foundation of the modern state, educational development has been regarded as important. Until 1940 the main thrust was directed at eradicating illiteracy, establishing a free system of public education, and creating a trained intelligentsia. The creation of a network of schools was undertaken first. From the 1940s on, the main educational emphasis passed to establishing institutions of higher education and expanding elementary and secondary facilities. There are now several hundred general schools (offering primary and secondary education), many special vocational schools, and several institutions of higher education—the Mongolian State University (established 1942) and teachers' training, medical, and agricultural institutes.

General schools

Most children attend school for at least 8 years; those in larger urban centres receive 10 years of schooling. Illiteracy has been almost eradicated. The Academy of Sciences coordinates research institutions, experimental stations, and other scientific establishments and supervises scholarly work.

Health and welfare. Health services were similarly expanded over the republic's first half century. Medical treatment is free, and the state also maintains a network of sanatoriums and holiday rest homes.

Among other social services, the provision of housing has been greatly emphasized. The yurt remains the main traditional dwelling in the countryside. Increasing urbanization, as well as the introduction of more settled ways in the country, has necessitated the building of modern apartment blocks in the cities and an increasing number of permanent rural structures. Motor-transport mail links date from 1924, shortwave communications from 1934–36, and national radio broadcasting from 1934. A trunk telephone-telegraph link connecting Ulaanbaatar with all the province centres was established in the late 1940s. In the 1960s, satellite communication systems were used, and television broadcasts began in 1967.

(B.Sv./D.Dn./C.D.H.)

CULTURAL LIFE

Contemporary cultural life in Mongolia is a unique amalgam of traditional elements—the heritage of centuries—and a growing modern element.

Traditional elements. Mongolian literature evolved a wealth of traditional genres: heroic epics, legends, tales, *yurol* (the poetry of good wishes), and *magtaal* (the poetry of praise), as well as a host of proverbial sayings. These genres are infused by what Mongols regard as a national characteristic—a good-humoured love of life, with particular fondness for witty sayings and jokes, particularly evident in the image of Dalan Khuldalchi, the hero of humorous folktales, and in the stories about the *badarchins*, clever but wily wandering monks. The *baatar*—the popular hero of folk legend—is also a symbolic figure. *Khurchins*—folk poets and singers—carried down the oral epics and ballads; and their mime and gesture gave rise to the popular trenchant satirical vaudevilles, *Sumya Noyon* and *Dunkher Da-Lam*. The religious mysteries, *tsam* and *maidari*, were formerly staged as mass spectacles. Other folk arts include the making of *shirdeg*, richly ornamented felt carpets noted as adorning the entrances to yurts by 13th-century European travelers. The Mongolian form of chess, *shatar*, with a stern khan for king, a dog—the cattle breeder's traditional honoured friend—as queen, and a camel as a bishop, has very deep roots and has produced some finely carved chess sets. The ancient faience decoration of glazed earthenware, with exquisite motifs, has been revived. A complicated and dignified ritual still accompanies the traditional offering and acceptance of hospitality in a country where traveling is all-important, and the seating arrangements in the yurt are likewise carefully arranged. When conversing, Mongolians traditionally place the right palm on that of the left hand, a symbol of mutual esteem, and the same gesture, together with a light bow, expresses gratitude, greeting, or farewell.

The most famous celebration of traditional ways, however, is the annual Naadam festival of the Three Games of Men, beginning each year on July 11, National Day, and held in all provinces and counties. The festival has

The Naadam festival of the Three Games of Men

recorded roots going back 2,300 years or more. The first sport is wrestling, prominent in ancient times at religious festivals, and the ritual entry into the arena of several hundred participants, clad in the bright colours of a special tight-fitting costume known as the Dzodog Shudag and simulating the flight of the mythical Garudi bird, is a spectacular sight. The contests themselves also are conducted with great ceremony. Titles awarded at the national Naadam festivals are those of Titan, Lion, Elephant, and Falcon. A three-time winner becomes a Darkhan Avraga ("Invincible Titan"). The second sport is archery; and bowmen vie for the title of Merghen, or "Supermarksman," in individual and group contests, shooting at a leather-covered target with weapons of ancient design. Exceptional winners are characterized as Miraculous Archer, Most Scrupulous Archer, and similar names. The third sport, horse racing, is in many ways the most spectacular because all the competitors are children, ranging in age from 7 to 12. They are highly skilled and wear fine ornamental dresses as they race for about 20 miles across country. National horse-riding competitions for all ages are held during January and February, the Mongolian New Year, and are claimed to date back to the Bronze Age. Marco Polo, visiting in the 13th century, described a gathering of not fewer than 10,000 white horses held at the behest of the Great Khan.

Modern elements. Modern sports range from freestyle wrestling (introduced 1962) to motorcycling, rifle shooting, table tennis, boxing, and gymnastics. A growing number of economic enterprises cater to the various folk arts. The Palace Museum has a superb collection of folk art housed in the former winter palace of the khan, built in 1898. The architectural ensemble contains temples housing the famous sculptures of the goddess Tara made by the 17th-century artist Zanabazar. The State Central Museum and related exhibits portray the rich archaeological and paleontological remains of the country. Buddhist relics are exhibited in the Temple Museum, built 1903–05. The Erdene-Dzuu Monastery Museum on the site of Karakorum (Har Horin), Mongolia's ancient capital, is also noteworthy. Each province now has its own museum of regional studies. The State Public Library contains works of great variety and historical value.

In literature, the poems and short stories of Dashdorjiyn Natsagdorj became particularly significant in the 1930s. The literature of the 1940s was more varied in theme and genre, and the autobiographical "Old Scribe's Story" by G. Navaannamzhil was popular. Younger writers in the 1950s and '60s injected a more contemporary note, attempting to balance psychological and social imagery. The realistic epic novel continues in popularity.

Performing arts

The State Drama Theatre, founded in 1931, shows both Mongolian and classical works, and the State Opera and Ballet Theatre has a deserved reputation. There is a puppet theatre in the capital and internationally known song and dance companies. Practically every community has its own amateur art group, and the State Circus is also very popular. The Mongolkino film studio in the late 20th century was making an increasing impact at international festivals: its productions are assisted by the magnificent landscapes and clear air of the country, which help the production of wide-screen epics. Mass radio and television services are of importance because of the great distances in the country and are now aided by satellite links. The vast majority of households have radios, and the ownership of televisions has spread. There are about a dozen central and nearly two dozen local newspapers. The leading newspapers are *Unen* ("Truth") and *Pionyeriyn Unen* ("Pioneers' Truth"). There are also several dozen popular and specialist periodicals. (Sh.Bi./C.D.H.)

For statistical data on the land and people of Mongolia, see the *Britannica World Data* section in the BRITANNICA BOOK OF THE YEAR.

History

The Mongols constitute one of the principal ethnographic divisions of Asian, or Oriental, peoples. Their traditional homeland is centred in Mongolia, a vast plateau in Central Asia now divided politically into an autonomous region of the People's Republic of China (Inner Mongolia) and Mongolia (Outer Mongolia), which lies at the eastern end of what was a great corridor of migration between Northeast China (Manchuria) and Hungary throughout history. It is unfortunate, because confusing, that 19th-century physical anthropologists introduced the terms Mongol and Mongolian as descriptive of racial type. The Mongols exhibit a wide range of physical characteristics and should be considered not as a race but as a group of peoples bound together by a common language and a common nomadic tradition.

The geographic origin of the Mongols themselves is the northeast corner of present-day Mongolia. To the east, the ancient tribal history is mostly that of the Tungus peoples (including the ancestors of the Manchu) and to the west, that of the Hsiung-nu, or eastern Huns, and their Turkic-speaking successors, whom the Mongols eventually displaced and in part absorbed. As a result of later wars and migrations Mongols are now found in Mongolia; southern Russia; in the Inner Mongolia Autonomous Region (which includes a large portion of Northeast China), the Hui Autonomous Region of Ningsia, the Uighur Autonomous Region of Sinkiang (Chinese Turkistan), and the northern part of the Tibet Autonomous Region of China; and in Afghanistan.

ETHNOGRAPHY AND EARLY TRIBAL HISTORY

All Mongols recognize their kinship to each other in varying degrees through legend, written history, and especially language. Dialects vary from east to west more than from north to south, but few are unintelligible to other Mongols. Historical change in the language is indicated by the fact that reading *The Secret History of the Mongols* (mid-13th century), the oldest major document written in Mongol, is for the Mongols of today like reading the work of Chaucer for the modern English. Pan-Mongolism, the desire to reunite politically all the Mongols, was always more a romantic than a practical idea, and is now a dead issue.

Nomadic tradition

The Mongols have always been nomads, though there has also always been some cultivation. However, nomadism is the seasonal movement of livestock and camps from one pasture to another, not unfettered wandering. Nomads have a clear concept of the possession of territory, though they sometimes interpret this in socially conflicting ways. Legend and folklore show that among the premodern Mongols the common people considered livestock to be private property and land to be the collective property of the tribe, while the families of ruling chiefs tried to claim the land as well as individual subjects as their property.

Traditional society was based on blood relationship traced through the common male ancestor who gave his name to the clan, though evidence exists of a more ancient system of matrilineal descent. Marriage was forbidden between members of the same clan, giving rise to complicated marriage alliances (and also feuds) among the clans. As clans grew and merged into tribes (often inventing a fictitious common ancestor), the most successful families tended to arrogate to themselves claims to "real" ancestry and, at the same time, to control of the tribal territory, while lesser families could claim ancestry only in a vaguer, tribal sense. In this process weak clans fell to a subordinate but not servile status: they owned their own cattle and had their own headmen but paid tribute to the ruling clan and moved, camped, pastured, and fought under its orders.

Political and military organization was matched to the family-clan-tribe pattern. Every man who could ride and bear arms was both a herdsman and a soldier according to the need of the moment. Raiding other tribes to capture cattle, women, and prisoners was a recognized method of property accumulation. When, however, a tribe rose to notable power, as in the time of Genghis (Chinggis) Khan in the 13th century, a decimal form of military organization was adopted, with units of 10, 100, 1,000, and 10,000. Commanders of large units were assigned territories from which they drew the tribute to the supreme khan and mustered their quotas of troops. Mongol history fluctuates between such periods of feudal concentration and those of tribal dispersion.

The first mention in the Chinese chronicles of tribes that can be identified with Mongolia goes back in a shadowy way to the 2nd millennium BC. The first inhabitants of whom there is certainty, however, are the Hsiung-nu, in about the 5th or 4th century BC. It was once thought that they were Turks, or at least Turkic speaking, but the opinion has grown that they spoke a paleo-Asiatic language, represented today by the Ket dialects of the Yenisey River valley in Siberia. The Hsiung-nu created a great tribal empire in Mongolia while China was being unified as an imperial state under the Ch'in (221–206 BC) and Han (206 BC–AD 220) dynasties. After several centuries of war with the Chinese, complicated by civil wars among themselves, the Hsiung-nu confederation broke up. Some of the southern tribes surrendered to the Chinese and were settled within China, where they were eventually absorbed. Some of the northern tribes migrated westward, where descendants—together with the members of other tribes—appeared in Europe in the 5th century AD as the Huns of Attila. By then, of course, these people were considerably more mixed ethnically.

The Huns

In Mongolia the Hsiung-nu were succeeded both by Turkic-speaking peoples and by others identified by some scholars as Mongols, or Mongol speakers. There is a lack of convincing archaeological or historical evidence that these groups came to Mongolia from some distant region to fill a void left by the Hsiung-nu departure. Probably they were there all the time as the subjects of the Hsiung-nu, until the breakup of that confederation gave them the opportunity to assert themselves. Among the peoples who have been considered possibly Mongol, the most important tribal names are Sienpi (Hsien-pi), who may however have been Tungus (modern Evenk) rather than Mongol, recorded in Han dynasty annals, and the Juan-juan (Joujan, or Geougen) of the 4th to 6th centuries. The latter have been identified by some scholars with the Avars, who migrated into Europe along the plains of the Danube and were nearly annihilated in Hungary by Charlemagne in the late 8th century.

According to a legend recorded by the Chinese, the Turks of Mongolia, whose name is recognizable under its Chinese transcription "T'u-chüeh," were a subject tribe ruled by the Juan-juan. The Turks overthrew their masters and soon were in control of all Mongolia, centring their power in the Orhon valley in the northern part of the country. The Orhon (Orkhon) Turks were contemporaries of the T'ang dynasty (618–907) in China, and their fortunes rose and fell in counterpoint to periods of T'ang strength and weakness. Comparison of archaeological and historical data, moreover, shows that power in Mongolia was at this time not based simply on levies of nomad horsemen. The khans and great men had fixed headquarters, surrounded by cultivated land that enabled them to breed large, stable-fed horses capable of carrying a man in armour. This situation emphasized a class distinction between the aristocrat on his charger and the herdsman-warrior-archer on his smaller horse. Agriculture also became an element in the economy, and the Uighurs, who came to power after the fall of the Orhon Turks, enter history as an oasis-centred people.

In the welter of tribes the name Mongol first appears in a tribal list recorded under the T'ang dynasty. It then vanishes, to reappear only in the 11th century, when the Khitan (Khitai, from which comes the word Cathay) ruled in Northeast and North China and controlled most of Mongolia. The Khitan, who established the Chinese dynasty of Liao (907–1125), were themselves a Mongol people, but their homeland was in Northeast China rather than in what is now Mongolia. Like other Chinese dynasties, the Liao exercised its power in Mongolia by playing off the tribes against one another. Liao sources record the existence of a rather shadowy tribal power known in Mongol tradition as Khamag Mongol Uls ("Nation of all the Mongols"), which did not, however, include all of the population who spoke the Mongol language.

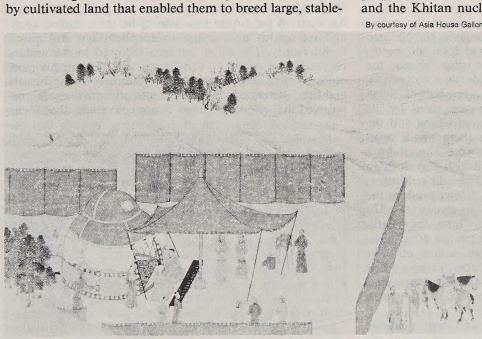
When the Khitan fell, their power in China was taken over and extended by the Juchen (Jurched), a Tungus people based farther north in northeastern China. They took the Chinese name of Chin ("Golden"). In their tribal policy they switched their favour from "All the Mongols" to the Tatars (known in the West as Tartars, from a medieval pun on *tartarus*, Latin for "hell"). Although Mongols, the Tatars were not part of the tribal league of All the Mongols, centred in the Onon and Kerulen valleys in the eastern half of North Mongolia; the Tatars lived to the east and south of them.

The Tatars

On the whole, though chastened occasionally by punitive expeditions, All the Mongols had been transfrontier allies or auxiliaries of the Khitan-Liao. A contingent of 50,000 Mongols (large for that time) fought on the Khitan side in the last battles of the Khitan empire. Presumably, this was one reason why the Juchen-Chin transferred their favour to the Tatars, nearer to their frontier. Such alternations, between using the more distant and using the nearer transfrontier and frontier tribes, were frequent in the policies of dynasties in China, and this one had the desired effect of creating a feud between Mongols and Tatars.

Before the era of Genghis Khan, a defeated Khitan army had migrated westward at the fall of their Liao dynasty. It was led by a prince of the Khitan imperial line but must have included heterogeneous tribal elements. Moving westward through Mongolia, it reached what is now Kazakhstan and created a new and briefly powerful empire, the Karakitai. It ruled primarily over Turkic-speaking peoples, made up of nomads and city dwellers in the oases, and the Khitan nucleus had the opportunity to apply its

By courtesy of Asia House Gallery, New York



A Mongol encampment, showing a central yurt surrounded by felt screens, beside which stand three Mongolian horses. Detail from the "Wen Chi Scroll," a Chinese hand scroll of the Southern Sung period (1127–1279), which illustrates the story of Wen Chi, a Chinese lady captured by the steppe nomads. In a private collection.

knowledge of how to deal with nomads and its ability in the administration of a bureaucracy.

THE RISE OF GENGHIS KHAN

Such was the setting in Mongolia when Genghis Khan (his given name was Temüjin) was born, about 1162 (the date accepted by contemporary Mongol scholars). Genghis was born into a clan that had a tradition of power and rule, being the great-grandson of Khabul (Qabul) Khan, who had been the greatest ruler of All the Mongols. Genghis inherited a feud against the Juchen-Chin dynasty and another against the Tatars, who had betrayed a collateral ancestor of his to the Juchen. His own father was poisoned by Tatars. He also inherited feuds among the ruling clans of All the Mongols and a feud with the powerful Merkit (Mergid) tribe, from whom his father had stolen his mother.

Genghis was even more deeply a political man than a warrior, and he resorted to war only as an extension of policy by other means. He was orphaned in his teens; his family fell on bad times, and power among the Mongols passed to other clans. Even in such apparently primitive practices as camp raiding and horse thieving, he skillfully used ancient customs: marriage alliances; putting himself under the patronage of a stronger prince; making an alliance with Jamuka (later his dangerous rival) by the oath of *anda,* under which men became as if blood brothers; and recruiting *nökhör* (the modern Mongol term for "comrade"). Unlike the institution of *anda,* which created a fictitious kinship and harboured the possibility of deadly rivalry, a man who became a *nökhör* forswore all loyalties of kinship and tribe and declared himself solely "the man" of his chosen leader. Genghis later fell out with his *anda,* but he was never betrayed by a *nökhör,* and his most brilliant generals were *nökhör.*

Genghis broke alliances and betrayed loyalties, but only when he could seem to be acting in "the common cause." By 1206 his success in tribal warfare caused him to be proclaimed ruler of All the Mongols with the rank of khan and the title of Genghis (Chinggis)—a word deriving probably ultimately from the Turkic *tengiz,* meaning "a large body of water, the ocean"; although this explanation has not convinced all Mongol scholars, it is consistent with the belief that the ocean symbolized breadth and depth of wisdom, and later the equivalent Mongol word of *ta-le* (Anglicized as "dalai") was applied to the supreme lama of Tibet. Previous nomads had invaded China, but none had yet ruled the whole of it, chiefly because they had invaded prematurely, leaving other nomads on their flanks and in their rear. Genghis, however, first united all the "dwellers in felt-walled tents" (*tuurgatan*), probing far back, away from China, to make sure that he controlled all potential nomadic rivals.

Ruler of All the Mongols

His first move was to bring under control the major tribal groups to the west of him in Mongolia, the Naiman and Kereit (Kerait) with whom he had been alternately in alliance and rivalry, as well as the tribes fringing the northern Mongolia-Siberia frontier. He then turned toward China, where at this time the eastern half of North China, south almost to the Yangtze, was ruled by the Juchen-Chin. In the northwest corner of China and the western extension of Inner Mongolia there was a small state, that of the Hsi Hsia: its rulers were Tangut from Tibet, and under them there were Turkish and Sogdian merchants who exploited the caravan trade, the cultivators of the oases being Turks and Chinese. China south of the Yangtze was ruled by the Southern Sung dynasty (1127–1279). Although they had lost North China, the Southern Sung were expanding southward toward Indochina, bringing rich new land under cultivation. Among all these states there was an interplay of diplomacy, alliances made and broken, and open warfare. The Mongols themselves, far from being ignorant barbarians, understood the game and played it skillfully.

Between 1207 and 1215 the armies of Genghis probed deep into North China. Genghis made good use of the Khitan in northern and northeastern China, whose Liao dynasty the Juchen-Chin had overthrown and who were now discontented subjects of the Chin. In 1215 the Chin capital Chung-tu (modern Peking), from which the Chin emperor had withdrawn southward, was taken and sacked. Realizing, however, that it was premature to commit his main strength to the conquest of China, Genghis withdrew to Mongolia, leaving one of his best generals, Mugali, to ravage and weaken the country. He himself turned westward. When he had defeated the Naiman, the last of the powerful tribes in Mongolia proper, the son of the last ruler of that tribe, Küchlüg, fled to Karakitai and married the daughter of its last ruler, whom he then overthrew. In that variegated kingdom, which included Semirechiya in Russian Turkistan and the Kashgarian Oases in Chinese Turkistan (Uighur Autonomous Region of Sinkiang), he favoured the Buddhist minority and persecuted Islām, the majority religion. This situation made it easy for the Mongols to defeat him. The Mongol general Jebe (Jeb) proclaimed freedom of religion and forbade massacre and plunder. This policy indicates that the Mongols did not massacre out of sheer savagery but only when they thought it necessary to break the power of an opponent.

Sack of Peking

Taking over the lands of the Karakitai opened the way for Genghis to Khwārezm, the land of the oases along the Syr Darya and Amu Darya in northern Iran. For drawing on the resources of a higher civilization this gave him an alternative to China, and it also secured him against the danger of any other nomadic power organizing, on his flank and rear, a military striking force backed by agricultural and urban resources. This done, he turned back toward China, leaving further campaigning into Russia and the eastern fringes of Europe to his generals and sons. He would not, however, commit his main forces in China until he had dealt with the wealthy Tangut state of Hsi Hsia; it was on this successful campaign in 1227 that he died.

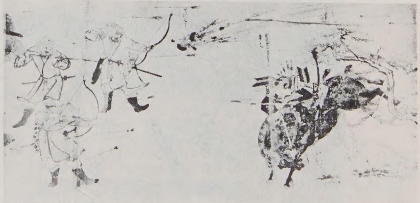
THE SUCCESSOR STATES OF THE MONGOL EMPIRE

Genghis had already dealt with the problem of succession. Each of his four sons was to hold a vassal kingdom: Jöchi, the eldest, was given the land from the Yenisey River and the Aral Sea westward "as far as the hooves of Mongol horses have reached"—a wording attributed to Genghis himself; the second son, Chagatai (Tsagadai), received Kashgaria (now the southern part of Sinkiang) and most of Mavrannakhar between the Amu Darya and Syr Darya; the third son, Ögödei (Ogadai), received western Mongolia and the region of Tarbagatai (now the northwestern corner of Sinkiang); the youngest, Tolui, inherited the ancient Mongol homeland of eastern Mongolia. Two years later, in 1229, a great Mongol assembly confirmed the succession of Ögödei as the great khan (khagan).

Tradition of succession

These dispositions made skillful use of ancient traditions. It was the custom among prosperous families that the eldest son, on reaching manhood, was given a wife and his share of the future inheritance; he then moved away and set up his own camp, independent but still allied to his family. The other brothers followed in due order, but each one nearer to the "home camp" than his next older brother. The youngest, as "guardian of the hearth and fire," remained with his parents until their death and received the residual heritage. It was convenient that Jöchi

By courtesy of the International Society for Educational Information, Tokyo



The Japanese champion Takezaki attacking Mongol archers, a detail from the "Mongol Invasion Scroll," c. 1293. In the Imperial Household Collection, National Museum, Tokyo.

could in this way be placed at the greatest distance from the ancient homeland because he got on poorly with his brothers, who considered him illegitimate, conceived while his mother was the captive of a hostile tribe. The election of Ögödei as great khan over the head of his elder brother Chagatai (Jöchi had already died) did not do violence to nomadic tradition; it was quite acceptable in wartime for the dying ruler to nominate as his successor the son who was considered ablest and most acceptable to his brothers.

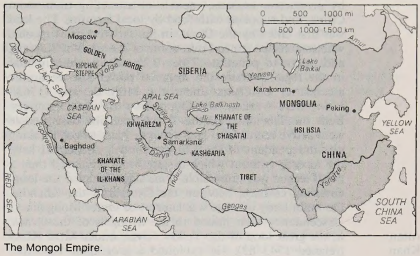
With this first division, further fission was inevitable. Under Batu, the successor of Jöchi, there began the formation of the Golden Horde, which ruled, or rather, drew tribute from the city-states of Russia. In this khanate the Mongols were greatly outnumbered by Turks; the Turkish language soon displaced Mongol, and Islām became the prevailing religion. Because its reservoir of nomad power was in the Kipchak Steppe, the Golden Horde is sometimes known as the Kipchak khanate. By its methods of collecting taxes and tribute it contributed to the rise of the grand dukes of Muscovy; and it was eventually a Moscow-led alliance that broke the power of the Mongols (by then more frequently called Tatars), at the Battle of Kulikovo in 1380. Partly by treachery and partly by guile the Golden Horde was still able to take and sack Moscow two years later, but its power soon disintegrated—an important factor being attacks by Timur (Tamerlane), coming from Turkistan.

House of Chagatai

To the east were the khanates of the House of Chagatai and the Il-Khans of Iran (Persia). Like the rulers of the Golden Horde, the rulers of the House of Chagatai considered themselves senior, in genealogy, to the House of Ögödei; they were frequently at odds with the great khan, with each other, and with the Il-Khans. On the other hand, the Il-Khans (the title itself implies subordination) accepted and supported the authority of the great khans. Like the Golden Horde, again, the House of Chagatai controlled wide pastures and therefore retained a strong nomadic base, while the Il-Khans, like the great khans (especially after Kublai [Khubilai] moved his capital into China), were directly affected by the urban influences of an old, highly developed civilization with a rich literary tradition. As in China, this situation led rather rapidly to the passage of real administrative control from Mongol hands into the hands of their subjects. The greatest of the Il-Khans was Hülegü (Khulagu, Hulagu), a brother of Kublai Khan of Mongolia and China, who began the Il-Khan tradition of supporting Peking against the House of Chagatai and the Golden Horde.

This brief review of the outer khanates helps to explain the subsequent history of the Mongols in Mongolia and the Mongol dynasty in China. As great khan, Ögödei authorized the continuation of Mongol campaigns in Russia and the west and also in China, where the disintegration of the Juchen-Chin dynasty in 1234 had brought the Mongols face to face with the surviving Sung dynasty in the Yangtze valley. Ögödei was also able to maintain a system of imperial representatives in the appanages of his imperial kinsmen in Central Asia and Iran but was less able to control the always insubordinate Golden Horde. He died in 1241 and was succeeded, after a stormy regency under his widow, Töregene, by his son Güyük (Kuyug) who had already quarreled with his cousin Batu of the Golden Horde. Güyük died at Samarkand in 1248, while preparing an attack on Batu.

A major change then occurred in the succession. At the next great assembly of the descendants of Genghis Khan, enlarged by the presence of powerful commanders and officials, the great khan chosen (again after much intrigue) was not a son of the House of Ögödei but Möngke (Mungke, Manga), a son of Tolui, the "guardian of the fire and hearth" of the Mongol homeland. This choice was favoured by Batu Khan, and Möngke responded by trying to stabilize and pacify relations among the khanates. Of his brothers he sent Kublai (later Great Khan) to continue the conquest of Sung China and Hülegü to subdue the Assassins (Nizārī Ismā'īliyūn); on this campaign Hülegü also took Baghdad, a rich and powerful city and seat of the 'Abbāsid caliphate. Möngke was aware of the desire of some of the crusaders for a Mongol alliance against the Saracens, but like Ögödei and Güyük he would not consider this except on terms of the submission of the European rulers and the pope. He himself campaigned deep into southwest China and there died of a fever in 1259.



The Mongol Empire.

Adapted from *Muir's Historical Atlas: Medieval and Modern*, R.F. Treharne and H. Fullard (eds.), 9th ed. (1967); George Philip & Son Ltd., London

The succession was then disputed between Möngke's second brother, Kublai, and his youngest brother, Arigböge (Ariböx, Arikböge). A third brother, Hülegü, supported Kublai. The dispute was more than a brawl over spoils among barbarian warriors; ideology was involved. Genghis Khan's concept of conquest and rule had been clear: the "people of the felt-walled tents" should remain in the steppes and continue their ancient warrior way of life, drawing tribute from the world of farms, cities, and caravan trade. Kublai and Hülegü, however, favoured moving into the conquered countries and there becoming the new ruling class—even if this meant mingling with the remnants of the conquered ruling class.

Kublai Khan

In this respect Arigböge was closer to the concept of Genghis than was Kublai, but Kublai prevailed and Arigböge died in honourable captivity. Kublai had himself proclaimed great khan in Mongolia in 1260. Kublai's reign has been romanticized in the West ever since Marco Polo. Kublai Khan moved the capital from Karakorum (Kharakhorum), which had been built by Ögödei (not Genghis Khan, as is often said), to a new city that he had built on the site of Chung-tu, naming it Ta-tu ("Great Capital"). He used Mongolia as his base for ascendancy over the other Mongol khanates, but drew his main revenue directly from China. He used foreigners (including Marco Polo and his family) to lessen his dependence on Chinese bureaucrats, but the administrative structure was essentially on the Chinese model; and consequently the Mongols, because they no longer held the real keys to power, lost the throne to the native Chinese Ming dynasty in 1368, only a century after the accession of Kublai and within a decade or two of the end of the Golden Horde and the Il-Khanate.

Internecine strife. Although in the first vigour of reconquest the Chinese penetrated deeply into Mongolia and destroyed Karakorum, they never succeeded in establishing control. Mongol unity was shattered, but Mongols in different regions began to recover. Mongol fission followed several lines. In western Mongolia there arose new lines of chieftains who did not claim descent from Genghis Khan. As a group, these were the Oyrat (Oirat), but at times the names of subgroups or individual tribes, such as the Dzungar (Jüüngar) or the Dörbed (Dörböd), predominated. In the centre, both in Outer and Inner Mongolia, the ruling princes claimed descent from Genghis Khan. In northeastern China were princes whose ancestor was Khasar, a brother of Genghis Khan. Because there had been bad blood between the two, these princes and the Chingiside princes were always suspicious of each other.

The Oyrat

What followed, in the renewed tribal wars and pressure on the frontiers of China in the 15th and 16th centuries, was much more than a resurgent "wave of barbarian invasions." A distinct new period was opening in which all concerned understood that in order to have real power outside the Great Wall of China it was necessary to coordinate nomadic military mobility with towns inhabited

by productive artisans, capable of attracting trade from China, and supplied with food by local farming. The lead was first taken by the Oyrat, in the far west of Mongolia, who established control over some of the oases of Sinkiang and began to penetrate Tibet. This advance meant that in the regions where the Imperial power and economic ascendancy of China under the Ming dynasty (1368–1644) were weakest, the Oyrat drew on new resources. Both the Tibetans and the Turkic-speaking oasis people were active merchants, had a literate class whose thinking was independent of the Chinese model, and could keep the records without which a state more advanced than a tribal league was impossible. This stage initiated the long-enduring cleavage between the Oyrat and the Khalkha, the main body of what was later to be Outer Mongolia.

Altan Khan

Ascendancy then passed to the Mongols of the Ordos, in the great loop of the Yellow River, under Altan Khan (reigned 1543–83). He exploited a geographic base that enabled him to develop agriculture and trade, to challenge the Oyrat in Tibet, and to pressure the Chinese. Meanwhile, the Mongols of the centre, Khalkhas in the north, and Chahars (Chakhars) in the south (there was as yet no "Outer" and "Inner" Mongolia) had lagged behind for lack of a suitably diversified geographic base. The best that they could achieve was a tribal league unification under Dayan Khan, a descendant of Kublai and grandfather of Altan Khan, who was proclaimed khan in 1470 at the age of five and died in 1543. After this, and after the death of Altan Khan, the supremacy over the Mongols of the centre passed to the south to another descendant of Dayan, Ligdan (Legdan, Lingdan) Khan of the Chahars. Using the geographic advantages of the modern Chinese frontier province of Chahar, close to the Great Wall, he tried during his reign (1604–34) to build up a power comparable to that which had been held by Altan Khan. He was too late, however, because of the rise of the Manchu.

Revival of Buddhism. During this period there was a second flowering of Buddhism among the Mongols. In the reign of Kublai, Buddhism in its Tibetan form had been fashionable at court and among some of the Mongol aristocracy, but the people as a whole had not been converted. The new entry of Buddhism was promoted by political considerations. A number of Mongol princes saw that for the kind of power that was now advantageous it was necessary to have not only a religious ethos higher than that of shamanism (whose priests used magic to cure the sick, to divine what was hidden, and to control events) but also a literate class to provide a bureaucracy. To use the Chinese language meant the risk—as had been proved under the Mongol empire in China—of the absorption of the Mongol ruling class into the Chinese ruling class. Tibet was not strong enough to dominate Mongolia, and the Tibetan monastic system had already produced able clerical bureaucrats. Moreover, Tibetan alphabetic writing was easier to use than Chinese ideographs.

Establishment of the Dalai Lama

Thus it was that Altan Khan invited from Tibet a prelate who had claims to primacy in Tibet, but also rivals, and proclaimed him Dalai Lama. Moreover, a way was found to link church and state. A son of the line of the Tüshētü Khans of Khalkha was conveniently found to be the first "reincarnation" of the line of Jabtsandamba Khutagt (Khutukhtus) of Urga. The significance of this device is underlined by the fact that, as soon as the Manchu controlled Mongolia, they ruled that no man of the lineage of Genghis Khan could be "discovered" to be a reincarnation or "living Buddha," and also that the Khutagt of Urga must always be discovered in Tibet. In their rule of Mongolia they thus separated church and state and used them against each other.

At the beginning of the revival of Buddhism in Mongolia there was a great burst of translation of the scriptures from Tibetan (and Sanskrit) into Mongol. The Mongols wanted to use Buddhism as a unifying principle in a new nationalism. When the Manchu won control, however, they threw their support to the use of Tibetan as the "Latin" of the church, further widening the cleavage between clerical and secular authority and bureaucracy. By the end of the Manchu regime there were many monks in Mongolia who were literate in Tibetan but not in their own language.

THE ASCENDANCY OF THE MANCHU

The rise of the Ch'ing, or Manchu dynasty, which had such profound effects on the fate of Mongolia, began long before 1644, the year a Manchu emperor was first seated on the throne in Peking. In the late 16th century it was becoming clear that a new barbarian conquest of China was again possible. In competition with the various Mongol princes and tribes already mentioned, the Manchu had the advantage that in the southern part of Northeast China (Manchuria), but outside the Great Wall of China, there was a large Chinese population with a number of urban centres and a flourishing trade that, instead of passing by land through the Great Wall, went largely by sea to the Shantung Peninsula—to the rear, that is, of the rulers in Peking. These Chinese were somewhat alienated from other Chinese. They had for centuries been accustomed to trading with the barbarians and to farming under the patronage of barbarian princes, and they did not like Peking's periodic attempts to maintain a "closed frontier" along the Great Wall.

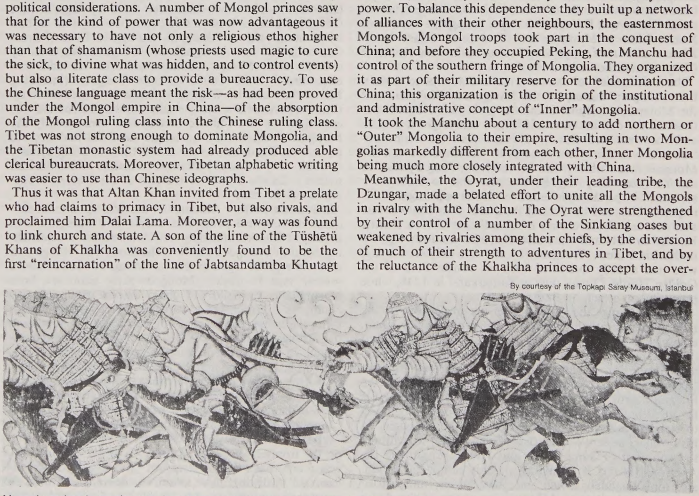
The Manchu not only subjugated these Chinese but also cultivated their loyalty and were soon heavily dependent on them, not only economically but for military manpower. To balance this dependence they built up a network of alliances with their other neighbours, the easternmost Mongols. Mongol troops took part in the conquest of China; and before they occupied Peking, the Manchu had control of the southern fringe of Mongolia. They organized it as part of their military reserve for the domination of China; this organization is the origin of the institutional and administrative concept of "Inner" Mongolia.

It took the Manchu about a century to add northern or "Outer" Mongolia to their empire, resulting in two Mongolias markedly different from each other, Inner Mongolia being much more closely integrated with China.

Attempt at Mongol revival

Meanwhile, the Oyrat, under their leading tribe, the Dzungar, made a belated effort to unite all the Mongols in rivalry with the Manchu. The Oyrat were strengthened by their control of a number of the Sinkiang oases but weakened by rivalries among their chiefs, by the diversion of much of their strength to adventures in Tibet, and by the reluctance of the Khalkha princes to accept the over-

By courtesy of the Topkapi Saray Museum, Istanbul



Mongol warriors in cavalry pursuit wearing lamellar armour, which covers them from the neck to the elbow and to the lower leg. Miniature from *Jami'at-tawarikh* by Rashīd od-Dīn, 14th century. In the Topkapi Saray Museum, Istanbul.

lordship of princes not descended from Genghis Khan. Led by such warriors as Galdan (Dga'-ldan), the Oyrat made sweeping campaigns far to the east in Mongolia but were never quite able to consolidate their gains. In trying to make the Oyrat a recognizably distinct nation, the great religious leader, the Jaya Pandita, revised the Mongol alphabet, making it phonetically more accurate, and originated an independent literary tradition.

Unwilling to accept submission to the Oyrat as the price of unification, the Khalkha princes rallied more and more to the Manchu, who guaranteed their aristocratic privileges and titles in a great convention at Dolon Nor (To-lun), in Inner Mongolia, in 1691. With the added resources of Khalkha, the Manchu were then able to mount a long series of military campaigns in which they annihilated the Oyrat power with tremendous slaughter on the scale of genocide.

This conquest, however, was not completed until 1759, and it was complicated by many events, particularly a major revolt against Manchu rule in western Khalkha in the 1750s led by a noble named Chingunjav. Chingunjav was a coconspirator with an Oyrat leader named Amursana, who in turn had first submitted to the Manchu and then rebelled against them. But this was the last period of general warfare involving the Mongols, and it ended with a considerable redistribution of the tribes. Several Khalkha groups that had fled from the Oyrat into Inner Mongolia never returned; a few Chahars from Inner Mongolia were settled in Sinkiang as garrisons; numbers of the Oyrat group were included in the western part of Khalkha geographically but not within the tribal organization; some ended their migrations in Ala Shan, at the western end of Inner Mongolia, but not within the Inner Mongolian organization; and some ended theirs far away in the Kokonor-Tsaidam region of Tibet. The most distant Oyrat wanderers (mostly Torgut and Dörbed) migrated in the early 17th century from the Altai to the Volga, where they took service under the tsars and took part in the Russian conquest of the Caucasus. In 1771 about 70,000 families migrated all the way back to Sinkiang, where they were accepted under Manchu rule and allotted pastures for grazing. The descendants of those who remained on the Volga were known as the Kalmyk (Kalmuck).

Mongol dispersion

The ensuing period of peace degenerated into stagnation and economic decline. Chinese camp followers had accompanied the Manchu conquest, and from this grew Chinese control of the caravan trade and of a barter trade exploiting usurious terms of credit. Because Mongol troops were of decreasing use for the control of China, there was no incentive for the Manchu to protect, economically, this source of manpower, and the Manchu authorities relied increasingly on the potentates of the Lama Buddhist Church, who were themselves increasingly corrupt, for the control of Mongolia. Chinese colonization began to encroach on the pasturelands of Inner Mongolia, and at the end of the 19th century an attempt was made to plant a screen of Chinese colonists along the frontier between Siberia and Outer Mongolia.

THE 20TH CENTURY

In the Russo-Japanese War of 1904–05 both Russians and Japanese enlisted Mongol mercenaries as auxiliaries; from this time on there were Japanese army officers who dreamed of a new Mongol nationalism that could be used against both Russia and China. The Russians were more restrained and were satisfied with Buryatia (Buryat Mongolia). By secret treaties after the war Inner Mongolia east of the meridian of Peking was recognized by Russia as a Japanese sphere of interest.

By 1911, when the Chinese Revolution broke out, unrest was widespread in Mongolia. At the time, the Mongol language and Mongol sources being little known outside Mongolia, most observers thought of Mongolia only in terms of Russian and Japanese intrigue. But the rich documentation that later became available proved that the unrest was both social and political. The Mongols by this time identified the Manchu with the Chinese, the Chinese with usurious debt, and their own clerical and secular rulers as people who lived in luxury on Chinese loans and passed on the usurious interest to their subjects. The rulers, for their part, saw both the chance of a new government they could control and the danger that if they did not act, they would not be able to control the people.

Under the leadership of the Jabtsandamba Khutagt, the Mongols declared their independence. Uncertain of themselves in world politics, however, they sought to replace Manchu Imperial patronage with that of the tsar; but the Russians, because of the secret treaties with Japan and an understanding with Britain about Tibet and Mongolia (which, though not secret, could hardly be comprehended by the Mongols), would go no further than support of "autonomy," not "independence." This status was ratified after difficult negotiations between the Mongols, the Russians, and the new Republic of China. Union between Inner and Outer Mongolia was similarly frustrated. Some leaders in Inner Mongolia saw themselves as the future elite of a united Mongolia because they could draw on an intelligentsia with a knowledge of the language and politics of China, but for the same reason they were distrusted in Outer Mongolia as being too Chinese.

Independence

This uneasy situation endured with increasing economic distress and social unrest until the Russian Revolution. A Japanese-controlled clique in the Chinese government then sent a military expedition into Mongolia that forced the Mongols to sign a "request" to be taken over by the Chinese Republic. Almost immediately afterward, defeated anti-Bolshevik troops began to retreat into Mongolia. Their most important leader was Baron Roman von Ungern-Sternberg, known as the "Mad Baron," who defeated the Chinese occupation forces and treated the Mongols with unfeeling savagery.

In this period of terror and confusion two secret revolutionary groups, which later merged, were formed by Damdiny Sühbaatar, a former trooper and machine gunner in the Mongol forces disbanded by the Chinese, and Khorloghiyin Choibalsan, who had been a boy runaway from a monastery and later a student in Siberia. Choibalsan, though not the principal leader during the lifetime of Sühbaatar, was in touch with underground Bolsheviks—hiding there as refugees—later massacred by Ungern-Sternberg. Memoirs of the Mongol partisans enlisted by these two show that quite apart from Russian propaganda there was already in Mongolia a geographically widespread and socially embittered demand for radical social and political change. The traditional leaders had been discredited by their inability to handle either the Chinese intervention or the incursions of the antirevolutionary Russians.

The revolutionaries took the initiative in going to the Bolsheviks for help, which was quickly granted. The remnants of the Chinese warlord forces were driven out, and Ungern-Sternberg was handed over to the Bolsheviks for execution. Urga, the capital (now Ulaanbaatar), was taken by a joint Mongol-Russian column in July 1921, and this is now considered the date of the founding of the present republic, though the first measures of the revolutionary victors were surprisingly moderate. The Jabtsandamba Khutagt (the living Buddha of Urga) was continued in office, but as a "constitutional monarch," meaning he could sign only documents prepared for him by the new regime.

Sühbaatar died in 1923 and the Khutagt in 1924. In the Soviet Union Lenin also died in 1924, and in China Sun Yat-sen died in 1925. Mongolia was engaged in a revolutionary process also going forward at different rates of speed in the Soviet Union and in China. The problem of the Khutagt was easily solved; no successor was found, and on Nov. 26, 1924, Mongolia was proclaimed a People's Republic—using a wording that exactly follows the Chinese, not the Soviet, model. The government, and the controlling People's Revolutionary Party, was a coalition of conservative and nationalistic revolutionary elements. Shifts between "rightist" and "leftist" policy ensued, closely affected by the rise of Joseph Stalin in the Soviet Union and by the defeat of the Chinese communists (for the time being) by Chiang Kai-shek. Increasingly important, too, was the Japanese invasion of Northeast China (Manchuria) in 1931, followed by Japanese encroachment on Inner Mongolia and North China and all-out invasion of China in 1937.

Proclamation of the People's Republic

The uncertainty, both internal and external, engendered cliques and conspiracies—some real and others imagined—resulting in an atmosphere of suspicion and fear that cost many lives. The situation began to clear after 1939, when the Japanese, in a thrust toward Siberia, invaded the northeastern corner of Mongolia, testing the Soviet-Mongol alliance. The Mongol border troops fought ferociously, holding the heights of Nomynkhan (Nomonhan) and the line of the Khalkyn River until Soviet troops came up. The Japanese defeat was shattering, and it undoubtedly played a major part in their fateful decision not to honour the "Berlin-Tokyo Axis" with Hitler but to make their major effort in the Pacific and Southeast Asia. In Mongolia the victory dispelled fears that elements of the army might go over to the Japanese; on the contrary, many Inner Mongolian troops recruited by the Japanese went over to the Mongols. The military alliance with the Soviet Union was reconfirmed when the Mongols took part in the Soviet campaign in Inner Mongolia and Manchuria in the last two weeks of World War II.

At this time, refugees from Inner Mongolia swarmed into the Mongolian People's Republic. The Japanese had organized a puppet government of Inner Mongolia under Teh Wang (Prince Teh, Demchukdongrub). He had, however, tried to minimize Japanese control and to promote Mongol nationalism. When the Chinese communists came to power in Inner Mongolia, he was condemned as a war criminal but later released.

Under an agreement made by U.S. President Franklin D. Roosevelt at the Yalta Conference (February 1945), Chiang Kai-shek consented to a plebiscite in Mongolia after the war. The result was overwhelmingly in favour of independence over "autonomy." Full diplomatic recognition did not follow, however, because of a border dispute. Mongolian membership in the United Nations was at first sponsored by Chiang Kai-shek but later opposed by him and by the United States, and it was not until 1961 that Mongolia gained membership. In the meantime, Inner Mongolia was reorganized as an autonomous region within the People's Republic of China. (O.La.)

Foreign relations

For many years the relations of the Mongolian People's Republic with China were strained because of the former's unswerving loyalty to the Soviet alliance. Nevertheless, its long frontier with China was amicably redemarcated. Tensions eased considerably in the 1980s, leading to the establishment of diplomatic relations between the two countries in 1986. On Jan. 27, 1987, diplomatic relations also were established between the United States and the Mongolian People's Republic for the first time in the history of the two countries.

A series of events in the middle and late 1980s led to the failure of the social and economic system constructed by the Mongolian People's Revolutionary Party. The ouster from power of Yumjaagiyn Tsedenbal in 1984, and the introduction by his successor, Jambyn Batmönh, of Mongol versions of glasnost and perestroika, led to economic stagnation and demands for further social reform. Public demonstrations in December 1989 by a number of newly formed opposition groups forced the entire leadership of the MPRP to resign in 1990 and call for new elections. Prior to the elections in July 1990, the constitution was amended to provide for multiparty balloting, and the MPRP was denied its previous position as sole party and "guiding force" in Mongolia.

A new constitution put into effect in February 1992 swept away the last remaining vestiges of the previous socialist system, and the People's Republic was renamed simply Mongolia. The constitution established the single-chamber Mongolian Great Hural. Elections to the Great Hural in 1992 produced a strong majority for the MPRP. In 1993, however, the opposition candidate Punsalmaagiyn Ochirbat was elected president of Mongolia.

Laws abolishing the socialist economic system were passed in 1990, 1991, and 1992. These laws included regulations pertaining to banking, foreign investment, and privatization of state property. In order to guarantee fair access for all Mongols to available resources, every citizen was issued coupons to be used to buy at public auction any property designated for privatization. A special commission makes the determination of property to be auctioned, which to date has included pastureland, herds of animals, and factories. Collective farms have been abolished, as has party control over all state assets.

After the dissolution of the U.S.S.R. in 1991, relations between Mongolia and Russia were initially strained, as disagreements arose over the extent of Mongolia's debt to the U.S.S.R. and over the pace of withdrawal of Soviet military forces. The remaining Russian troops left in 1992, however, and the two countries signed a treaty of friendship and cooperation the following year. Mongolia concluded a similar treaty with China in 1994.

The painful process of historical reassessment of the revolutionary era has resulted in rehabilitation of some victims of past purges and the condemnation of such leaders as Tsedenbal. Continued revisions of past interpretation of the events that led to the revolution of 1921 and to the policies of the next seven decades are expected to alter the currently accepted picture of 20th-century Mongolia and its prerevolutionary past. (L.W.M./Ed.)

For later developments in the history of Mongolia, see the BRITANNICA BOOK OF THE YEAR.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, sections 932, 933, and 975.

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Montaigne

Michel Eyquem de Montaigne wrote, in his *Essais* (*Essays*), one of the most captivating and intimate self-portraits ever written, on a par with Augustine's and Rousseau's. Living, as he did, in the second half of the 16th century, he bore witness to the decline of the intellectual optimism that had marked the Renaissance. The sense of immense human possibilities, stemming from the discoveries of the New World travelers, from the rediscovery of classical antiquity, and from the opening of scholarly horizons through the works of the humanists, was shattered in France when the advent of the Calvinistic Reformation was followed closely by religious persecution and by the Wars of Religion (1562–98). These conflicts, which tore the country asunder, were in fact political and civil as well as religious wars, marked by great excesses of fanaticism and cruelty. At once deeply critical of his time and deeply involved in its preoccupations and its struggles, Montaigne chose to write about himself—"I am myself the matter of my book," he says in his opening address to the reader—in order to arrive at certain possible truths concerning man and the human condition, in a period of ideological strife and division when all possibility of truth seemed illusory and treacherous.

Giraudon—Art Resource/EB Inc.



Montaigne, portrait by an unknown French artist, 16th century. In the Condé Museum, Chantilly, Fr.

Life. Born on Feb. 28, 1533, in the family domain of Montaigne, in Périgueux, southwestern France, Michel Eyquem spent most of his life at his château and in the city of Bordeaux, 30 miles to the west. The family fortune had been founded in commerce by Montaigne's great-grandfather, who acquired the estate and the title of nobility. His grandfather and his father expanded their activities to the realm of public service and established the family in the *noblesse de robe,* the administrative nobility of France. Montaigne's father, Pierre Eyquem, served as mayor of Bordeaux.

As a young child Montaigne was tutored at home according to his father's ideas of pedagogy, which included the creation of a cosseted ambience of gentle encouragement and the exclusive use of Latin, still the international language of educated people. As a result the boy did not learn French until he was six years old. He continued his education at the College of Guyenne, where he found the strict discipline abhorrent and the instruction only moderately interesting, and eventually at the University of Toulouse, where he studied law. Following in the public-service tradition begun by his grandfather, he entered into the magistrature, becoming a member of the Board of Excise, the new tax court of Périgueux, and, when that body was dissolved in 1557, of the Parliament of Bordeaux, one of the eight regional parliaments that constituted the French Parliament, the highest national court of justice. There, at the age of 24, he made the acquaintance of Étienne de la Boétie, a meeting that was one of the most significant events in Montaigne's life. Between the slightly older La Boétie (1530–63), an already distinguished civil servant, humanist scholar, and writer, and Montaigne an extraordinary friendship sprang up, based on a profound intellectual and emotional closeness and reciprocity. In his essay "On Friendship" Montaigne wrote in a very touching manner about his bond with La Boétie, which he called perfect and indivisible, vastly superior to all other human alliances. When La Boétie died of dysentery, he left a void in Montaigne's life that no other being was ever able to fill, and it is likely that Montaigne started on his writing career, six years after La Boétie's death, in order to fill the emptiness left by the loss of the irretrievable friend.

Étienne de la Boétie

In 1565 Montaigne was married, acting less out of love than out of a sense of familial and social duty, to Françoise de la Chassaigne, the daughter of one of his colleagues at the Parliament of Bordeaux. He fathered six daughters, five of whom died in infancy, whereas the sixth, Léonore, survived him.

In 1569 Montaigne published his first book, a French translation of the 15th-century *Natural Theology* by the Spanish monk Raymond Sebond. He had undertaken the task at the request of his father, who, however, died in 1568, before its publication, leaving to his oldest son the title and the domain of Montaigne.

In 1570 Montaigne sold his seat in the Bordeaux Parliament, signifying his departure from public life. After taking care of the posthumous publication of La Boétie's works, together with his own dedicatory letters, he retired in 1571 to the castle of Montaigne in order to devote his time to reading, meditating, and writing. His library, installed in the castle's tower, became his refuge. It was in this round room, lined with a thousand books and decorated with Greek and Latin inscriptions, that Montaigne set out to put on paper his *essais,* that is, the probings and testings of his mind. He spent the years from 1571 to 1580 composing the first two books of the *Essays,* which comprise respectively 57 and 37 chapters of greatly varying lengths; they were published in Bordeaux in 1580.

Although most of these years were dedicated to writing, Montaigne had to supervise the running of his estate as well, and he was obliged to leave his retreat from time to time, not only to travel to the court in Paris but also to intervene as mediator in several episodes of the religious conflicts in his region and beyond. Both the Roman Catholic king Henry III and the Protestant king Henry of Navarre—who as Henry IV would become king of France and convert to Roman Catholicism—honoured and respected Montaigne, but extremists on both sides criticized and harassed him.

After the 1580 publication, eager for new experiences and profoundly disgusted by the state of affairs in France, Montaigne set out to travel, and in the course of 15 months he visited areas of France, Germany, Switzerland, Austria, and Italy. Curious by nature, interested in the smallest details of dailiness, geography, and regional idiosyncrasies, Montaigne was a born traveler. He kept a record of his trip, his *Journal de voyage* (not intended for publication and not published until 1774), which is rich in picturesque episodes, encounters, evocations, and descriptions.

Journal de voyage

While still in Italy, in the fall of 1581, Montaigne received the news that he had been elected to the office his father had held, that of mayor of Bordeaux. Reluctant to accept, because of the dismal political situation in France

and because of ill health (he suffered from kidney stones, which had also plagued him on his trip), he nevertheless assumed the position at the request of Henry III and held it for two terms, until July 1585. While the beginning of his tenure was relatively tranquil, his second term was marked by an acceleration of hostilities between the warring factions, and Montaigne played a crucial role in preserving the equilibrium between the Catholic majority and the important Protestant League representation in Bordeaux. Toward the end of his term the plague broke out in Bordeaux, soon raging out of control and killing one-third of the population.

Montaigne resumed his literary work by embarking on the third book of the *Essays.* After having been interrupted again, by a renewed outbreak of the plague in the area that forced Montaigne and his family to seek refuge elsewhere, by military activity close to his estate, and by diplomatic duties, when Catherine de Médicis appealed to his abilities as a negotiator to mediate between herself and Henry of Navarre—a mission that turned out to be unsuccessful—Montaigne was able to finish the work in 1587.

The year 1588 was marked by both political and literary events. During a trip to Paris Montaigne was twice arrested and briefly imprisoned by members of the Protestant League because of his loyalty to Henry III. During the same trip he supervised the publication of the fifth edition of the *Essays,* the first to contain the 13 chapters of Book III, as well as Books I and II, enriched with many additions. He also met Marie de Gournay, an ardent and devoted young admirer of his writings. De Gournay, a writer herself, is mentioned in the *Essays* as Montaigne's "covenant daughter" and was to become his literary executrix. After the assassination of Henry III in 1589, Montaigne helped to keep Bordeaux loyal to Henry IV. He spent the last years of his life at his château, continuing to read and to reflect and to work on the *Essays,* adding new passages, which signify not so much profound changes in his ideas as further explorations of his thought and experience. Different illnesses beset him during this period, and he died after an attack of quinsy, an inflammation of the tonsils, which had deprived him of speech. His death occurred while he was hearing mass in his room, on Sept. 13, 1592.

The Essays. Montaigne saw his age as one of dissimulation, corruption, violence, and hypocrisy, and it is therefore not surprising that the point of departure of the *Essays* is situated in negativity: the negativity of Montaigne's recognition of the rule of appearances and of the loss of connection with the truth of being. Montaigne's much-discussed skepticism results from that initial negativity, as he questions the possibility of all knowing and sees the human being as a creature of weakness and failure, of inconstancy and uncertainty, of incapacity and fragmentation, or, as he wrote in the first of the essays, as "a marvelously vain, diverse, and undulating thing." His skepticism is reflected in the French title of his work, *Essais,* or "Attempts," which implies not a transmission of proven knowledge or of confident opinion but a project of trial and error, of tentative exploration. Neither a reference to an established genre (for Montaigne's book inaugurated the term essay for the short prose composition treating a given subject in a rather informal and personal manner) nor an indication of a necessary internal unity and structure within the work, the title indicates an intellectual attitude of questioning and of continuous assessment.

Skepticism

Montaigne's skepticism does not, however, preclude a belief in the existence of truth but rather constitutes a defense against the danger of locating truth in false, unexamined, and externally imposed notions. His skepticism, combined with his desire for truth, drives him to the rejection of commonly accepted ideas and to a profound distrust of generalizations and abstractions; it also shows him the way to an exploration of the only realm that promises certainty: that of concrete phenomena and primarily the basic phenomenon of his own body-and-mind self. This self, with all its imperfections, constitutes the only possible site where the search for truth can start, and it is the reason Montaigne, from the beginning to the end of the *Essays,* does not cease to affirm that "I am myself the matter of my book." He finds that his identity, his "master form" as he calls it, cannot be defined in simple terms of a constant and stable self, since it is instead a changeable and fragmented thing, and that the valorization and acceptance of these traits is the only guarantee of authenticity and integrity, the only way of remaining faithful to the truth of one's being and one's nature rather than to alien semblances.

Yet, despite his insistence that the self guard its freedom toward outside influences and the tyranny of imposed customs and opinions, Montaigne believes in the value of reaching outside the self. Indeed, throughout his writings, as he did in his private and public life, he manifests the need to entertain ties with the world of other people and of events. For this necessary coming and going between the interiority of the self and the exteriority of the world, Montaigne uses the image of the back room: human beings have their front room, facing the street, where they meet and interact with others, but they need always to be able to retreat into the back room of the most private self, where they may reaffirm the freedom and strength of intimate identity and reflect upon the vagaries of experience. Given that always-available retreat, Montaigne encourages contact with others, from which one may learn much that is useful. In order to do so, he advocates travel, reading, especially of history books, and conversations with friends. These friends, for Montaigne, are necessarily men. While none can ever replace La Boétie, it is possible to have interesting and worthwhile exchanges with men of discernment and wit. As for his relations with women, Montaigne wrote about them with a frankness unusual for his time. The only uncomplicated bond is that of marriage, which reposes, for Montaigne, on reasons of family and posterity and in which one invests little of oneself. Love, on the other hand, with its emotional and erotic demands, comports the risk of enslavement and loss of freedom. Montaigne, often designated as a misogynist, does in fact recognize that men and women are fundamentally alike in their fears, desires, and attempts to find and affirm their own identity and that only custom and adherence to an antiquated status quo establish the apparent differences between the sexes, but he does not explore the possibility of overcoming that fundamental separation and of establishing an intellectual equality.

Friendship and love

Montaigne extends his curiosity about others to the inhabitants of the New World, with whom he had become acquainted through his lively interest in oral and written travel accounts and through his meeting in 1562 with three Brazilian Indians whom the explorer Nicolas Durand de Villegagnon had brought back to France. Giving an example of cultural relativism and tolerance, rare in his time, he finds these people, in their fidelity to their own nature and in their cultural and personal dignity and sense of beauty, greatly superior to the inhabitants of western Europe, who in the conquests of the New World and in their own internal wars have shown themselves to be the true barbarians. The suffering and humiliation imposed on the New World's natives by their conquerors provoke his indignation and compassion.

Involvement in public service is also a part of interaction with the world, and it should be seen as a duty to be honourably and loyally discharged but never allowed to become a consuming and autonomy-destroying occupation.

Montaigne applies and illustrates his ideas concerning the independence and freedom of the self and the importance of social and intellectual intercourse in all his writings and in particular in his essay on the education of children. There, as elsewhere, he advocates the value of concrete experience over abstract learning and of independent judgment over an accumulation of undigested notions uncritically accepted from others. He also stresses, throughout his work, the role of the body, as in his candid descriptions of his own bodily functions and in his extensive musings on the realities of illness, of aging, and of death. The presence of death pervades the *Essays,* as Montaigne wants to familiarize himself with the inevitability of dying and so to rid himself of the tyranny of fear, and he is able to accept death as part of nature's exigencies, inherent in life's expectations and limitations.

Montaigne seems to have been a loyal if not fervent Roman Catholic all his life, but he distrusted all human pretenses to knowledge of a spiritual experience which is not attached to a concretely lived reality. He declined to speculate on a transcendence that falls beyond human ken, believing in God but refusing to invoke him in necessarily presumptuous and reductive ways.

Although Montaigne certainly knew the classical philosophers, his ideas spring less out of their teaching than out of the completely original meditation on himself, which he extends to a description of the human being and to an ethics of authenticity, self-acceptance, and tolerance. The *Essays* are the record of his thoughts, presented not in artificially organized stages but as they occurred and reoccurred to him in different shapes throughout his thinking and writing activity. They are not the record of an intellectual evolution but of a continuous accretion, and he insists on the immediacy and the authenticity of their testimony. To denote their consubstantiality with his natural self, he describes them as his children, and, in an image of startling and completely nonpejorative earthiness, as the excrements of his mind. As he refuses to impose a false unity on the spontaneous workings of his thought, so he refuses to impose a false structure on his *Essays*. "As my mind roams, so does my style," he wrote, and the multiple digressions, the wandering developments, the savory, concrete vocabulary, all denote that fidelity to the freshness and the immediacy of the living thought. Throughout the text he sprinkles anecdotes taken from ancient as well as contemporary authors and from popular lore, which reinforce his critical analysis of reality; he also peppers his writing with quotes, yet another way of interacting with others, that is, with the authors of the past who surround him in his library. Neither anecdotes nor quotes impinge upon the autonomy of his own ideas, although they may spark or reinforce a train of thought, and they become an integral part of the book's fabric.

Form of the *Essays*

Montaigne's *Essays* thus incorporate a profound skepticism concerning the human being's dangerously inflated claims to knowledge and certainty but also assert that there is no greater achievement than the ability to accept one's being without either contempt or illusion, in the full realization of its limitations and its richness.

Readership. Throughout the ages the *Essays* have been widely and variously read, and their readers have tended to look to them, and into them, for answers to their own needs. Not all his contemporaries manifested the enthusiasm of Marie de Gournay, who fainted from excitement at her first reading. She did recognize in the book the full force of an unusual mind revealing itself, but most of the intellectuals of the period preferred to find in Montaigne a safe reincarnation of stoicism. Here started a misunderstanding that was to last a long time, save in the case of the exceptional reader. The *Essays* were to be perused as an anthology of philosophical maxims, a repository of consecrated wisdom, rather than as the complete expression of a highly individual thought and experience. That Montaigne could write about his most intimate reactions and feelings, that he could describe his own physical appearance and preferences, for instance, seemed shocking and irrelevant to many, just as the apparent confusion of his writing seemed a weakness to be deplored rather than a guarantee of authenticity.

In the 17th century, when an educated nobility set the tone, he was chiefly admired for his portrayal of the *honnête homme,* the well-educated, nonpedantic man of manners, as much at home in a salon as in his study, a gentleman of smiling wisdom and elegant, discreet disenchantment. In the same period, however, religious authors such as Francis of Sales and Blaise Pascal deplored his skepticism as anti-Christian and denounced what they interpreted as an immoral self-absorption. In the pre-Revolutionary 18th century the image of a dogmatically irreligious Montaigne continued to be dominant, and Voltaire and Denis Diderot saw in him a precursor of the free thought of the Enlightenment. For Jean-Jacques Rousseau, however, the encounter with the *Essays* was differently and fundamentally important, as he rightly considered Montaigne the master and the model of the self-portrait. Rousseau inaugurated the perception of the book as the entirely personal project of a human being in search of his identity and unafraid to talk without dissimulation about his profound nature. In the 19th century some of the old misunderstandings continued, but there was a growing understanding and appreciation of Montaigne not only as a master of ideas but also as the writer of the particular, the individual, the intimate—the writer as friend and familiar. Gustave Flaubert kept the *Essays* on his bedside table and recognized in Montaigne an alter ego, as would, in the 20th century, authors such as André Gide, Michel Butor, and Roland Barthes.

The *Essays* were first translated into English by John Florio in 1603, and Anglophone readers have included Francis Bacon, John Webster, William Shakespeare, Lord Byron, William Makepeace Thackeray, Ralph Waldo Emerson, Virginia Woolf, T.S. Eliot, and Aldous Huxley.

Today Montaigne continues to be studied in all aspects of his text by great numbers of scholars and to be read by people from all corners of the earth. In an age that may seem as violent and absurd as his own, his refusal of intolerance and fanaticism and his lucid awareness of the human potential for destruction, coupled with his belief in the human capacity for self-assessment, honesty, and compassion, appeal as convincingly as ever to the many who find in him a guide and a friend.

MAJOR WORKS

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(T.A.Sa.)

Montreal

Montreal (French: Montréal), the largest city of Quebec province and the second most populous metropolitan area of Canada, is uniquely situated. The present city proper occupies about one-third of Île de Montréal (Montreal Island), the largest of the 234 islands of the Hochelaga Archipelago, one of three archipelagos near the confluence of the Ottawa and St. Lawrence rivers. The city was built around and up Mont-Royal, which rises 763 feet (233 metres) above sea level (some 660 feet above the island shores). The city proper occupies an area of 61 square miles (158 square kilometres); and several independent cities and towns constitute the 1,087-square-mile metropolitan area that covers Montreal and other islands, as well as both shores of the St. Lawrence. Montreal is the major seaport on the St. Lawrence River and Seaway, lying between the navigable waters of the open Atlantic Ocean to the east and of the Great Lakes to the west.

Along with New York City and San Francisco, Montreal is one of North America's most cosmopolitan cities. It is often said to be the second largest French-speaking city in the world (after Paris), a boast that is sometimes disputed. English and French are Canada's two official languages but, in accordance with a law passed for Quebec province in 1977, the use of English in schools and in government and commercial activity is restricted. Yet, in several areas of Montreal, one must still express oneself in English to be understood fully. This phenomenon reflects decades of dominance over Montreal's economic life by the English-speaking minority. With the advent to power in 1976 of the Parti Québécois—which advocates political independence from and economic association with the rest of Canada—"normal" tensions between French- and English-speaking communities have fluctuated.

In spite of politics and unrest, Montreal remains a city of great charm, of vivacity, and of gaiety, one of the most appealing in North America, as well as one of unquestioned modernity in its physical appearance and way of life. Thus it was chosen as the site of the International World Exposition in 1967—Expo 67. No great objections were raised when the event was perpetuated for the public each summer under the title Terre des Hommes (Man and His World).

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Physical and human geography

THE LANDSCAPE

The city layout. The layout of Montreal has been affected throughout its history by the river and the natural rises of the terrain from it, including the slopes of Mont-Royal. These factors produced a general southwest–northeast pattern of growth, and since its incorporation the city has been divided by Boulevard Saint-Laurent (St. Lawrence Street) into western and eastern sections. Such designations as street, avenue, and boulevard are virtually interchangeable in Montreal, and the ensuing confusion is enhanced by the use of both French and English placenames for thoroughfares and other city and suburban sites.

Modernization of the city

The city centre. Since about 1958 the centre of Montreal has been transformed significantly, abetted by post-World War II prosperity, by preparations for Expo 67 and the exposition itself, and by an administration intent upon grand designs. Built with the aid of U.S. capital and developers, Place Ville-Marie comprises a cruciform building more than 40 stories tall and many underground shops, restaurants, and theatres, linked to which are nearby skyscrapers with similar underground complexes. Together, this downtown area provides the Canadian metropolis with an answer to New York City's Rockefeller Center, with an underground commercial, culinary, and artistic life among the most advanced in the Western Hemisphere. Similar change has spread throughout the city, often obliterating historic landmarks, but the city has preserved the historic centre known as Vieux-Montréal (Old Montreal). There, seekers after nostalgia stroll amid reminiscences of the past that are in striking contrast to the city's overall momentum into the vanguard of urban modernity.

THE PEOPLE

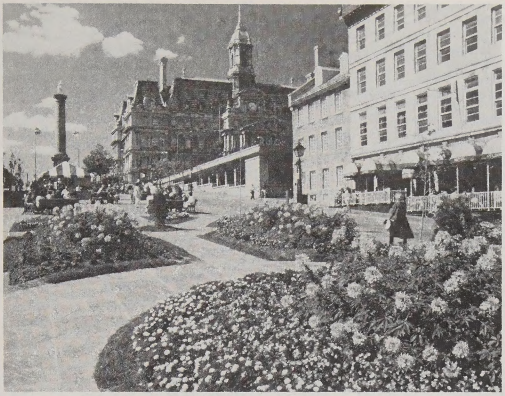
The 1871 population of Montreal proper—about 133,000—increased 10-fold in the following century, and the pace of metropolitan planning promises ongoing growth in addition to annexation of adjacent areas. Immigration from abroad practically ceased during World War I, but a steady flow of people continued from other parts of Canada and from the United States. Although the birth rate among Canadians of French descent dropped markedly, immigration from the Continent reduced the percentage of Montrealers of British descent after World War II. French-speaking citizens account for about two-thirds of the population, with the English-speaking proportion increasingly eroded by immigrants from all over the world. Religious affiliations generally follow ethnic traditions, with Roman Catholicism by far the dominant faith.

Social and political tensions

On the other hand, newcomers to Montreal quickly learn that English is the more practical tongue, for in Montreal as in most of Canada—except Quebec city and smaller centres of Quebec province—English is the primary language of commerce and industry. The economic upper classes are mostly old Montreal-bred English-speaking families, with a sprinkling of French and others. The middle classes are more mixed, whereas the lower economic stratum continues to be made up mainly of French- and Irish-Canadians and of new immigrants. Thousands of blacks have immigrated from the United States, most of them settling in the lower part of Montréal-Ouest. The instabilities of Montreal and of Quebec province as a whole are largely the result of the continuing sociolinguistic separateness of and economic disparity between the two major ethnic groups. Majority political power has been achieved by the French community, but equivalent weight in other areas has been slower to arrive.

THE ECONOMY

Trade and industry. Montreal suffered in the 1970s from a "Go West" trend, to the benefit of Ontario and the western provinces rich in oil and natural gas. It remains, however, the headquarters of most of the largest Canadian banks, railroad lines, and insurance companies, as well as for the International Civil Aviation Organization, an agency, affiliated with the United Nations, that sets the rules and standards for international air traffic. The city is also an important shipping and industrial centre. The



Place Jacques-Cartier in the Vieux-Montréal (Old Montreal) section of Montreal.
Milt and Joan Mann—CAMERAMANN INTERNATIONAL

centuries-long colonial fur trade that penetrated the new continent to its westernmost territories formed the city's earliest commercial ventures, while soapmaking, brewing and distilling (among John Molson's main civic legacies), and wood and leather fabrication are longtime Montreal industries. Innumerable other products of a modern manufacturing economy emanate from the city's factories, along with millions of gallons of processed petroleum each day from Montréal-Est refineries.

Shopping areas abound throughout the city, in the more remote residential sections as well as throughout the supermodern underground city of streets and shops that has aided Montrealers to carry on in spite of the five to 10 feet of snow dumped on the city each winter. This deluge of snow from November through April is among the most significant factors in Montreal's life, costing the city millions of dollars annually to remove it from the streets.

Transportation. The perennial grumbling of Montrealers about municipal transportation is more an exercise of democratic rights than a reflection of reality. Compared with those in other large cities, bus and subway lines allow easy movement throughout the area at relatively low cost. The subway, called the Métro, has three lines running under the city and to Longueuil on the south shore of the St. Lawrence River. Each station is different in architectural design and artistic decor. Public transportation dates from 1847, and by 1868 buses mounted on sleighs replaced rail cars during the winter. By 1894 the entire system had been electrified and the last horsecars withdrawn from service. Montreal is also served by two airports (both under the same authority): Montreal International–Dorval handles domestic and U.S. flights, and Montreal International–Mirabel handles all other international flights.

The modern Métro

ADMINISTRATIVE AND SOCIAL CONDITIONS

Government. From the present city hall, sixth in the city's history, Montreal is governed by a mayor and a 56-member council, all elected for four years, and a six-member executive committee selected by the council. A Montreal Urban Community replaced the Montreal Metropolitan Corporation in 1969. Its responsibilities, for the whole of Montreal Island and Bizard Island to the north, include assessment and tax collection, traffic control, water and sewage services, police and fire protection, and antipollution activities. It is governed by a general council and an executive committee.

The metropolitan area embraces numerous cities (including Montreal), towns, villages, and parishes. The changes in the region's economic structure and increasing business and white-collar employment, intensified by the growing modernization of the city, have brought about some of the main administrative problems. The French-speaking majority, most of whom were relegated to blue-collar jobs for decades, reacted against this historical pattern with some success, attributable in part to legislation and to the goodwill of the more moderate elements of the two communities.

Education. As throughout Quebec, a dual school system for Roman Catholic and Protestant students is supported from the public treasury. The language of instruction—French or English, respectively—rigidly follows the religious division.

Montreal is probably the outstanding city of Canada in terms of higher education. McGill University (founded 1821) and Concordia University (1974; formed by the merger of Sir George Williams University, founded 1929, and Loyola College, founded 1899) offer mainly English-language instruction, whereas the Université de Montréal (1876) and the Université du Québec à Montréal (1968) serve the French-speaking population.

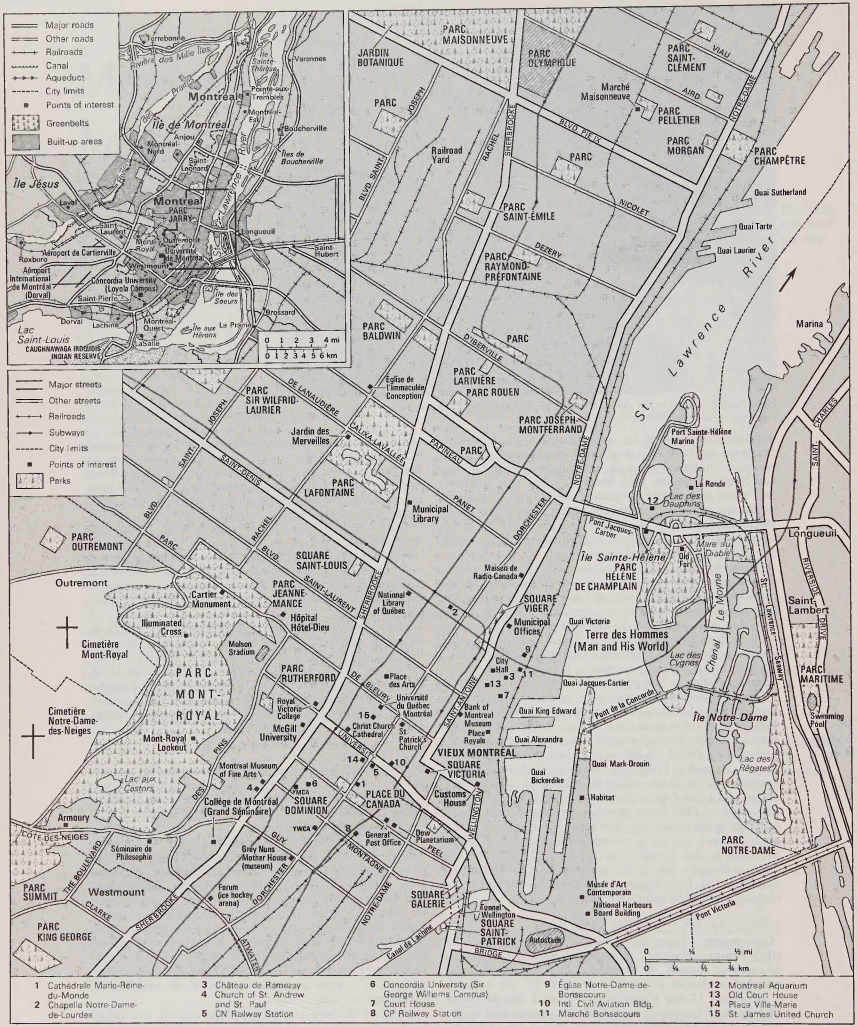
CULTURAL LIFE

With its Place des Arts, museums, public libraries, art galleries, bookshops in most European languages, symphony orchestra, publishing houses, theatre companies, and free public lectures at the universities, Montreal must be accounted a major culture centre.

The Place des Arts is a complex of concert and theatre halls in downtown Montreal. The nearby Place Desjardins is an exciting example of modern architecture; the complex, with its multilevel terraces, balconies, mezzanines, and sunken plaza, comprises three office towers, a public square, a hotel, and several restaurants and retail stores. Art instruction is given, among other places, at the Museum of Fine Arts. Besides a conservatory of music, faculties or schools of music offer instruction at the universities. The Terre des Hommes exhibition, which draws millions of visitors yearly, is the site of the Museum of Contemporary Art.

In the 1930s only a few bookshops existed, but today bookshops can be found in all districts and shopping centres; and "new Canadians," as new immigrants are called, can buy books, reviews, and magazines in their native languages. The Municipal Library has several branches, and special libraries are located throughout the city. Publishing houses, both English and French, prosper.

Montrealers are great sports enthusiasts. Hockey and baseball are foremost, but other indoor and outdoor sports


Major roads
Other roads
Railroads
Canal
Aqueduct
City limits
Points of interest
Greenbelts
Built-up areas
Major streets
Other streets
Railroads
Subways
City limits
Points of interest
Parks
Montreal
Île de Montréal
Île Jésus
Île des Soeurs
Île aux Hérons
Île Sainte-Hélène
Île Notre-Dame
Lac Saint-Louis
St. Lawrence River
Lac des Deux Montagnes
Lac des Dauphins
Lac des Cygnes
Lac des Régates
Mare au Diable
Le Moyne
Cheval
Aéroport de Cartierville
Aéroport International de Montréal (Dorval)
Concordia University (Loyola Campus)
Jardin Botanique
Parc Maisonneuve
Parc Olympique
Parc Saint-Clément
Marché Maisonneuve
Parc Pelletier
Parc Morgan
Parc Champêtre
Parc Saint-Émile
Parc Raymond-Préfontaine
Parc Baldwin
Parc Larivière
Parc Rouen
Parc Joseph-Montferrand
Parc Sir Wilfrid-Laurier
Jardin des Merveilles
Parc Lafontaine
Parc Outremont
Square Saint-Louis
Parc Jeanne-Mance
Parc Rutherford
Parc Mont-Royal
Parc Summit
Parc King George
Parc Maritime
Parc Notre-Dame
Square Victoria
Square Dominion
Square Saint-Patrick
Square Galerie
Place du Canada
Place d'Armes
Place Royale
Place Ville-Marie
Place Jacques-Cartier
Vieux Montréal
Terre des Hommes (Man and His World)
Municipal Library
Municipal Offices
City Hall
Police Station
Court House
Customs House
Bank of Montreal Museum
Maison de Radio Canada
Église de l'Immaculée Conception
Cathédrale Marie-Reine-du-Monde
Chapelle Notre-Dame-de-Lourdes
Château de Ramezay
Church of St. Andrew and St. Paul
CN Railway Station
Christ Church Cathedral
St. Patrick's Church
Notre Dame Basilica
Collège de Montréal (Grand Séminaire)
Séminaire de Philosophie
Grey Nuns Mother House (museum)
Forum (ice hockey arena)
Concordia University (Sir George Williams Campus)
CP Railway Station
Église Notre-Dame-de-Bonsecours
Ind. Civil Aviation Bldg.
Marché Bonsecours
Montreal Aquarium
Old Court House
Place Ville-Marie
St. James United Church
Musée d'Art Contemporain
National Harbours Board Building
Tunnel to Victoria Bridge
Autoroute
Pont Victoria
Pont Jacques Cartier
Pont de la Concorde
Quai Jacques-Cartier
Quai King Edward
Quai Alexandra
Quai Mark-Drouin
Quai Bickerdike
Habitat
Quai Victoria
Quai Sutherland
Quai Tarte
Quai Laurier
Marina
Port Sainte-Hélène Marina
La Ronde
Longueuil
Saint-Lambert
Swimming Pool
Outremont
Westmount
Mont-Royal
Lachine
Dorval
Laval
Boucherville
Varennes
Terrebonne
Repentigny
Mascouche
Saint-Eustache
Deux-Montagnes
Saint-Hubert
Brossard
Roxboro
Pierrefonds
Saint-Laurent
Saint-Léonard
Montréal-Nord
Montréal-Est
Pointe-aux-Trembles
Rivière des Mille Îles
Rivière des Prairies
Lac des Deux Montagnes
Lac Saint-Louis
Caughnawaga Iroquois Indian Reserve
Boulevard Métropolitain
Autoroute Bonaventure
Autoroute Ville-Marie
Autoroute Décarie
Autoroute Métropolitaine
Autoroute Jacques-Cartier
Autoroute Chomedey
Autoroute Laurentienne
Autoroute Papineau-Leblanc
Autoroute Dorchester
Autoroute Bonaventure
Autoroute Champlain
Autoroute Louis-Hippolyte-Lafontaine
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Autoroute Laurentienne
Autoroute Papineau-Leblanc
Autoroute Dorchester
Autoroute Bonaventure
Autoroute Champlain
Autoroute Louis-Hippolyte-Lafontaine
Boulevard Saint-Joseph
Boulevard Saint-Laurent
Boulevard Saint-Michel
Boulevard Saint-Denis
Boulevard Saint-Hubert
Boulevard Saint-Charles
Boulevard Saint-Jean-Baptiste

The founding fathers

the New World. More than 1,000 Indians welcomed him on the slope of the mountain that he named Mont Réal, or Mont-Royal. More than 50 years elapsed before other Frenchmen returned, this time with Samuel de Champlain, the founder of Quebec city. Hochelaga had disappeared, replaced on the shores of the St. Lawrence by a settlement that Champlain called Place Royale.

It was not until May 1642 that Paul de Chomedey, sieur de Maisonneuve, founded today's Montreal. He built dwellings, a chapel, a hospital, and other structures, protecting the settlement against Indian attack with a stockade. He named the aggregate Ville-Marie.

The community was granted its first civic charter by King Louis XIV in 1644, and Chomedey became its first governor. The first hospital, the Hôtel-Dieu, was founded in 1644 by Jeanne Mance and the first school for girls in 1653 by Marguerite Bourgeoys. Almost immediately a society of priests, Les Messieurs de Saint-Sulpice, took charge of education for boys.

The real development of Montreal began during the first half of the 18th century. Land grants were made, and farming was developed outside the original fortifications. Colonization was initiated under the French seigniorial system, in which a landowner leased portions of his holdings to numerous farming families. For many years, Montreal was a base for explorers and traders, and by the end of the 18th century outlying settlements—Saint-Henri and Lachine to the west and Longue-Pointe and Pointe-aux-Trembles to the east—had taken root, later to become part of the city or of the Montreal Urban Community.

By 1672 the population of Montreal had reached 1,500, but it did not obtain city status for another 120 years and was not incorporated until 1833. The city surrendered peacefully to British forces in 1760 and, with all of New France, became part of the British North American empire in 1763. In November 1775 Montreal was occupied by American Revolutionary forces, who retreated in the spring following the abortive siege of the city of Quebec by Benedict Arnold and thus failed to secure Canada for the new United States. In 1796 Canada's first public library was opened in Montreal, and in the following year daily postal service was established between Montreal and the United States.

EVOLUTION OF THE MODERN CITY

Sequence of civic firsts

In 1809 John Molson—entrepreneur, brewer, banker, and carrier—linked Montreal and Quebec by water with the first Canadian steamship. Canada's first bank, the Bank of Montreal, was founded in 1817, and the Lachine Canal, forerunner of the St. Lawrence Seaway, was started in 1821. In 1825 Molson, the "Montrealer par excellence," provided his city with a splendid theatre, and gas lighting appeared by 1838. A Committee of Trade, forerunner of the Board of Trade (1842), was founded in 1822, and from 1844 to 1849 Montreal was the capital of Canada. On April 25, 1849, a mob put fire to the Parliament building, possibly on the ground that it had lost its vocation. In 1847 telegraph links were made with the cities of Quebec and New York; in 1853 a shipping service between Montreal, Liverpool, and the Continent was begun; in 1856 a railroad to Toronto opened; in 1858 a transatlantic cable to Europe was laid; and in 1861 the city's first horse-drawn tramways began operation.

Fires destroyed hundreds of buildings in the early 1850s, and an economic slump provoked numerous bankruptcies in 1857. The Confederation of Canada was proclaimed in 1867, and 10 years later the city had its first labour strike and first telephone conversation with Quebec. It had its first electric lighting in 1882, electric tramways in 1892, and the first automobile along its streets and movie houses along its sidewalks in 1903.

By 1900 Montreal's population reached 270,000, and it began to annex several cities, towns, and villages on its outskirts. It purchased Île Sainte-Hélène (St. Helen's Island) in 1908, the site, with two neighbouring man-made islands, of Expo 67. Montreal's famous ice-hockey team, the Canadiens, was founded in 1909 (and has since won more world championships than any other professional team). In 1922 several mergers gave birth to the Canadian National Railways Company (CNR), which, like the Canadian Pacific in 1881, established its head office in Montreal.

The world wars gave impetus to the economic life of Montreal, as they did to most industrial centres of North America, and in January 1947 the U.S. Congress began to consider a joint venture with Canada for building the St. Lawrence Seaway. In 1959 the need for a Montreal Metropolitan Corporation was recognized by the Quebec provincial government (which, like others in Canada, has exclusive jurisdiction over municipalities). In 1960 the Metropolitan Boulevard, a throughway encircling Montreal, was opened. In 1962 construction was started on the Métro, supervised by engineers from the Paris Métro; the system was inaugurated six months before the opening of Expo 67. With the growing recognition of Montreal as a major world centre following this universally acclaimed exposition, it became the first non-U.S. city to be awarded a major-league baseball franchise. Its players first took the field in 1969 as the Montreal Expos. (C.Fe./W.J.C.)

Montreal was host of the 1976 Summer Olympic Games, a venture that was a financial disaster for the city. The high cost of building and maintaining facilities, including a stadium with a 552-foot (168-metre) tower (now the home of the Expos), placed a burden of debt on the province. Beginning in the 1960s, Quebec separatist groups engaged in occasional violence in the city, and during the 1970s and '80s many corporations that had their headquarters in Montreal moved to Toronto, partly in response to enforcement of French-language usage guidelines. In 1995 the province narrowly voted against secession from Canada.

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Moscow

One of the world's great cities, Moscow (Russian Moskva) is the capital of Russia. Since it was first mentioned in chronicles of 1147, Moscow has played a vital role in Russian history; indeed the history of the city and of the Russian nation are closely interlinked. Today Moscow is not only the political centre of Russia but also the country's leading city in population, in industrial output, and in cultural, scientific, and educational importance. For more than 600 years Moscow has been the spiritual centre of the Russian Orthodox Church.

The capital of the Union of Soviet Socialist Republics (U.S.S.R.) until its dissolution in 1991, Moscow attracted world attention as a centre of Communist power; the name of the seat of the former Soviet government and successor Russian government, the Kremlin (Russian Kreml), became a synonym for Soviet authority. The dissolution of the U.S.S.R. brought economic and political change, along with a degree of uncertainty over the future, to the city.

Moscow covers an area of about 386 square miles (1,000 square kilometres), its outer limit being roughly delineated by the Moscow Ring Road. Most of the area beyond this highway has been designated as a Forest-Park Zone, or greenbelt.

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Physical and human geography

THE LANDSCAPE

Site and relief. Moscow stands on the Moskva River, a tributary of the Oka and thus of the Volga, in the centre of the vast plain of European Russia. The city and its surrounding area, the Moscow oblast (administrative region), lie in the northwest corner of the most highly developed and densely populated part of Russia. Moscow lies in the broad, extremely shallow valley of the Moskva and its tributaries. The valley itself overlies a deep syncline of the Russian Platform of very ancient crystalline rocks, a granitic basement more than a mile below the present-day surface. The trough in the platform has been filled through long geologic time by sedimentary rocks, mostly of Devonian and Carboniferous age, with Jurassic series and some Cretaceous rocks nearest the surface. Hardly anywhere is the bedrock exposed on the surface.

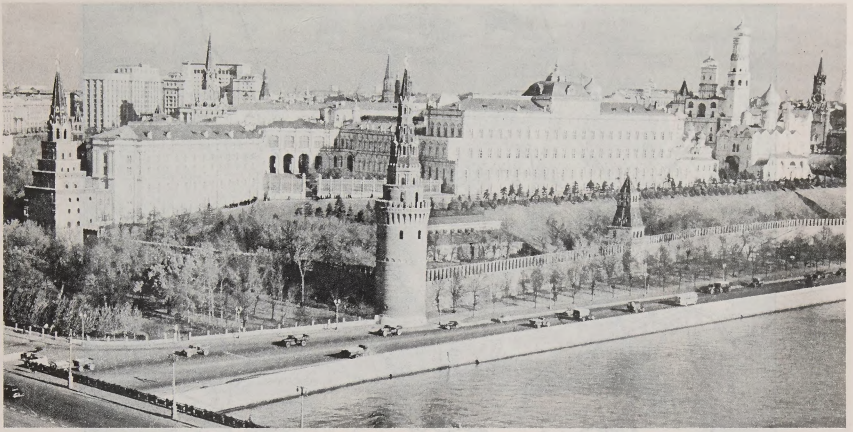
The advances and retreats of Pleistocene glaciers deposited a thick mantle of boulder clays and morainic sands and gravels into which the sinuous Moskva River cut its wide valley in successive stages, marked by four corresponding levels. Geologically recent alluvial deposits cover their surfaces. Beside the river itself is a narrow belt of floodplain; a few feet above this is the first terrace, which yields to the successively higher second and third levels. The last of these terraces, rising up to 100–115 feet (30–35 metres) above the river, is the most extensive, and much of Moscow is built on it. Northward the third terrace merges imperceptibly with a plain of clays and sands, which slopes up very gradually to the Klin-Dmitrov morainic ridge some 40 miles (64 kilometres) north of the city. Eastward and southeastward the surface equally gradually merges into the vast, almost completely flat and very swampy clay plain of the Meshchera Lowland, which extends far beyond the city limits.

Almost everywhere surface relief is minor. The legend that Moscow is built on seven hills is an exaggeration, although there are a few small hills in and around the city centre. Only in the southwest of the city is there an upland area on Cretaceous rocks, covered by glacial morainic material. This is the Teplostanskaya Upland, which rises more than 400 feet above the Moskva River and on which is the highest elevation within Moscow's limits, 830 feet above sea level. One of the sweeping bends of the Moskva has cut into the edge of the Teplostanskaya Upland a steep cliff, the Lenin Hills (also known as the Sparrow Hills), from the top of which there are fine panoramic views of the city.

The human imprint. Long occupation has extensively altered the natural setting. The "cultural layer," consisting of debris of buildings demolished long ago and of other materials deposited by humans, is up to 50 feet deep in some parts of central Moscow. Almost all the small rivers and streams that once flowed into the Moskva through the city area have now been put into underground conduits or filled in. The only tributaries still visible are the Yauza on the left (northern) bank and, on the right bank, the Gorodnya and Kotlovka. The Yauza, the largest of these, and the Moskva itself are controlled by stone embankments for most of their winding courses through the city. The Moskva has been diverted in places, with cuts made through the necks of its loops, and it has also been both widened and deepened; in places it is 800 feet wide. In the past the river was icebound from November to April, but a channel is now kept open throughout the winter. The Yauza receives additional water from the Volga, by way of the Moscow Canal and its branch, the Likhobory Canal. Two dams on its lower course have raised the level of the Yauza and made the lower reaches navigable.

Rivers

Part of Moscow's water supply comes from some 1,000 deep bores in the city that tap the artesian water of the underlying Carboniferous beds. Overuse has greatly lowered the levels of these underground waters, and most water needs are now met by surface sources, from the reservoirs north of the city built in connection with the Moscow Canal, in particular the Ucha Reservoir. Water is also drawn from the Moskva and pumped into underground storage reservoirs. The discharge of untreated sewage and industrial effluents had polluted the Moskva and the adjacent groundwater, until in the mid-1960s a major effort to correct it by heavy investment in antipollution and water purification measures brought great improvement. Slow but steady progress has also been made in controlling the



The Kremlin in Moscow, on the Moskva River, with the Water Tower in the foreground and (from the left) the Borovitskaya Tower, the Armoury Palace, the Kremlin Great Palace, and the Archangel Cathedral.
Novosti Press Agency

discharge of industrial effluents into the river and into bore wells, and the discharge of untreated sewage has ended.

Climate. The climate of Moscow is continental, modified by the temperate influence of westerly winds of Atlantic origin. Precipitation is moderate, 23 inches (581 millimetres) a year, with a marked summer maximum that reaches a peak in July. A considerable part of the precipitation falls as snow; beginning usually about mid-October—though permanent snow cover is not normally established before the beginning of November—it lasts generally until mid-April. Winters are thus long and dark, although southerly airstreams occasionally bring days with temperatures above freezing. Conversely, northerly winds from the Arctic bring very sharp drops in temperature, often accompanied by clear, brisk weather with low relative humidity. December, January, and February are the driest months. Thus, although the January average temperature is 14° F (−10° C), there can be considerable variation; the minimum recorded temperature is −44° F (−42° C). Moscow employs a large number of workers and a fleet of mechanical devices to keep the streets clear of snow. Spring is relatively brief, and the temperature rises rapidly during late April. Summers are warm, and July, the warmest month, has an average temperature of 65° F (18° C); a maximum temperature of 99° F (37° C), however, has been recorded in August. Rainy days are not uncommon, but the summer rainfall often comes in brief, heavy downpours and thunderstorms. Autumn, like spring, is short, with rapidly falling temperatures.

Urban climate

Human activity has modified the climatic conditions as well as the relief and hydrology. The vast number of buildings creates the so-called urban heat-island effect, causing the average annual temperature in the central city to be up to 3° F (2° C) higher than the temperature in open country outside the city. Plants in central parks and gardens blossom a week or more earlier than those in the outer suburbs. The temperature differential is most marked on clear winter nights, when the buildings radiate heat; it can be as much as 18° F (10° C) or more. The city centre also receives heavier rainfall than the surrounding countryside and averages about 100 hours less sunshine per year.

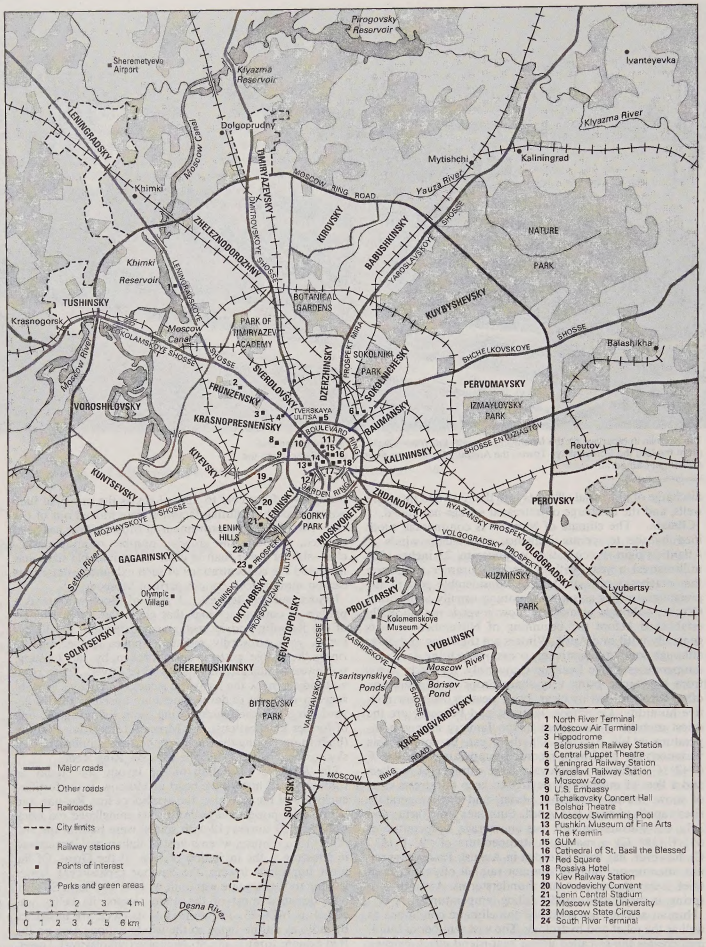
Until the late 1950s there was increasing air pollution in Moscow. Smog was common, often with heavy concentrations of sulfur dioxide. A major campaign to control noxious emissions was launched, assisted greatly by a changeover from coal to natural gas as the principal fuel. Some seriously polluting factories were moved out of the city. The resulting improvement in Moscow's air has been marked, although the growing number of motor vehicles—still far fewer than in cities of comparable size—has increased the concentrations of such exhaust pollutants as carbon monoxide in certain parts of Moscow.

Layout and architecture. A map of Moscow presents a pattern of concentric rings that circle the rough triangle of the Kremlin and its rectangular extension, the Kitay-gorod, with outwardly radiating spokes connecting the rings, the whole pattern being broken by the twisting, northwest–southeast-trending Moskva River. These rings and radials mark the historical stages of the city's growth: successive epochs of development are traced by the Boulevard Ring and the Garden Ring (both following the line of former fortifications), the Moscow Little Ring Railway (built in part along the line of the former Kamer-Kollezhsky customs barrier), and the Moscow Ring Road.

The Kremlin. The hub of the layout, and today as throughout its history the heart of Moscow, is the fortified enclosure of the Kremlin, the symbol of first Russian and later Soviet power and authority. Its crenellated red brick walls and 20 towers (19 with spires) were built at the end of the 15th century, when a host of Italian builders arrived in Moscow at the invitation of Ivan III the Great. Of the most important towers, the Saviour (Spasskaya) Tower leading to Red Square was built in 1491 by Pietro Solario, who designed most of the main towers; its belfry was added in 1624–25. The chimes of its clock are broadcast by radio as a time signal to the whole nation. Also on the Red Square front is the St. Nicholas (Nikolskaya) Tower, built originally in 1491 and rebuilt in 1806. The two other principal gate towers—the Trinity (Troitskaya) Tower, with a bridge and outer barbican (the Kutafya Tower), and the Borovitskaya Tower—lie on the western wall.

Kremlin gate towers

Within the Kremlin walls is one of the most striking and beautiful architectural ensembles in the world: a combination of churches and palaces, which are open to the public and are among the city's most popular tourist attractions, and the highest offices of the state, which are surrounded by strict security. Around the central Cathedral Square (Sobornaya Ploshchad) are grouped three magnificent cathedrals, superb examples of Russian church architecture at its height in the late 15th and early 16th



The city of Moscow.

centuries. These and the other churches in the Kremlin ceased functioning as places of worship after the Revolution and are now museums. The white stone Cathedral of the Assumption (Uspensky Sobor) is the oldest, built in 1475–79 in the Italianate-Byzantine style. Its pure, simple, and beautifully proportioned lines and elegant arches are crowned by five golden domes. The Orthodox metropolitans and patriarchs of the 14th to the 18th century are buried there. Across the square is the Cathedral of the Annunciation (Blagoveshchensky Sobor), built in 1484–89 by craftsmen from Pskov; though burned in 1547, it was rebuilt in 1562–64. Its cluster of chapels is topped by golden roofs and domes. Inside are a number of early 15th-century icons attributed to Theophanes the Greek and to Andrey Rublyov, considered by many to be the greatest of all Russian icon painters. The third cathedral, the Archangel (Arkhangelsky), was rebuilt in 1505–08; in it are buried the princes of Moscow and tsars of Russia (except Boris Godunov) up to the founding of St. Petersburg.

Just off the square stands the splendid, soaring white bell tower of Ivan the Great; built in the 16th century and damaged in 1812, it was restored a few years later. At its foot is the enormous Tsar Bell (Tsar-Kolokol), cast in



The Cathedral of St. Basil the Blessed (from the back) on Red Square. At the left is the State Department Store, GUM.

© Robert Houser/Comstock

1733–35 but never rung. Nearby is the Tsar Cannon (Tsar-Pushka), cast in 1586. Beside the gun are located the mid-17th-century Cathedral of the Twelve Apostles (Sobor Dvenadtsati Apostolov) and the adjoining Patriarchal Palace.

On the west of Cathedral Square is a group of palaces of various periods; the Palace of Facets (Granovitaya Palata)—so called from the exterior finish of faceted, white stone squares—was built in 1487–91. Behind it is the Terem Palace of 1635–36, which incorporates several older churches, including the Resurrection of Lazarus (Voskreseniye Lazarya), dating from 1393. Both became part of the Kremlin Great Palace, built as a royal residence in 1838–49 and formerly used for sessions of the Supreme Soviet of the U.S.S.R.; its long, yellow-washed facade dominates the riverfront. It is connected to the Armoury Palace (Oruzheynaya Palata), built in 1844–51 and now the Armoury Museum, housing a large collection of treasures of the tsars. Along the northeast wall of the Kremlin are the Arsenal (1702–36), the former Senate building (1776–88), and the School for Red Commanders (1932–34). The only other Soviet-period building within the Kremlin is the Palace of Congresses (1960–61), with a vast auditorium used for political gatherings and as a theatre.

Kremlin Great Palace

The Kitay-gorod. Along the east wall of the Kremlin lies Red Square (Krasnaya Ploshchad), the ceremonial centre of the capital and scene of holiday parades. The modest Lenin Mausoleum blends into the wall, which itself contains the graves of most of the U.S.S.R.'s past leadership. At the southern end of Red Square is the Church of the Intercession (Pokrovsky Sobor), better known as the Cathedral of St. Basil the Blessed. Built in 1554–60 to commemorate the defeat of the Tatars (Mongols) of Kazan and Astrakhan by Ivan IV the Terrible, it is a unique and magnificent architectural fantasy, each of its 10 domes differing in design and colour. Along Red Square facing the Kremlin is the State Department Store—usually called by its Russian acronym, GUM—with its long aisles, iron bridges linking the upper floors, and great skylights. The slightly earlier State Historical Museum (1875–83) closes off the northern end of the square.

GUM

Many old churches survive in the Kitay-gorod. Of particular note are the Church of the Trinity (1628–34) in Nikitniki, the 15th-century Church of St. Anne of the Conception, and the Epiphany Cathedral (1693–96). The Kitay-gorod was for centuries the commercial centre of Moscow, and its narrow, crowded streets still contain former banks, the stock-exchange building, and warehouses. Many of the old buildings near the river, however, were demolished in the 1960s to make room for the huge Rossiya Hotel. Along the northern front of the hotel is a row of preserved buildings, including the 16th-century house of the Romanov boyars and Old English Embassy and the 17th-century Monastery of the Sign.

The inner city. In the remainder of the central part of Moscow, within the Garden Ring (Sadovoye Koltso), are buildings representative of every period of Moscow's development from the 15th century to the present day. Scattered through the inner city are several fine examples of 17th-century church architecture, notably the Church of All Saints of Kulishki, built in the 1670s and '80s to replace a 14th-century edifice, and the Church of the Nativity of Putniki (1649–52). This was the period of development of the Moscow Baroque style; one of the best examples of this style, the Church of the Intercession at Fili (1693), is outside the city centre. Buildings of the classical period—beginning about the latter half of the 18th century and covering the rebuilding of Moscow after the fire of 1812—abound within the Garden Ring and the Boulevard Ring (Bulvarnoye Koltso), the latter forming a rough horseshoe north of the Moskva around the Kremlin and Kitay-gorod, and Zamoskvoreche, a largely residential district south of the Moskva. Notable examples are the old university and the former assembly of nobles with its Hall of Columns (now the House of Trade Unions), both built by Kazakov in the 1780s; the elegant Pashkov House (1785–86), now part of the Lenin State Library; the Lunin House (1818–23), now the Museum of Oriental Art; the Manezh (Riding School; 1817), which is now used as an exhibition hall; and the magnificent Bolshoi Theatre (1821–24), rebuilt in 1856 after a fire. Toward the end of the 19th century and continuing into the early 20th, buildings in the revivalist Old Russian style were built, including the State Tretyakov Gallery (1906) and—just outside of the Garden Ring—the Yaroslavl railway station (1902–04).

In the Soviet period many of the old buildings of the inner city were replaced by large office and apartment buildings. Side by side with the old appeared new buildings in the modern, functional style of the 1920s, in the ponderous, often over-ornate style of the later Stalin period (1930s to '50s), and in the high-rise concrete and glass predominant since the 1960s. Cheek by jowl with the Pashkov House stands the main building of the Lenin State Library (1927–29). Among more imaginative exam-

ples of later architecture is the Taganka Theatre (1983).

In the Soviet period much more open space was created, especially by constructing large squares such as Manezhnaya Square (formerly known as the Square of the 50th Anniversary of October). Many streets have also been widened, in particular Gorky Street (Gorkogo Ulitsa), now one of Moscow's principal radial roads, lined with large shops, hotels, and offices. The Garden Ring itself has been widened to form a broad highway with multiple lanes in each direction and with overpasses where it is intersected by the main radial routes. In the 1960s a new radial street, Prospekt Kalinina, was built through an area of older housing westward from the Kremlin to the Moskva River; it is lined by high-rise office and apartment buildings, linked at street and second-floor levels by a shopping mall. At its outer end rises a lofty, three-winged building overlooking the river that for many years housed offices of Comecon (Council for Mutual Economic Assistance, disbanded in 1991). Yet, just next to this bustling thoroughfare is Arbat Street (also called Old Arbat), one of the most picturesque streets of Moscow and now closed to vehicular traffic. Most of the historic buildings of central Moscow have been preserved—since the 1960s much careful restoration and repair work has been undertaken—but some architectural monuments disappeared in the early Soviet period. Where before the Revolution the Cathedral of the Saviour stood, near the river just above the Kremlin, there is now a vast open-air swimming pool.

Prospekt Kalinina

Inner Moscow has the functions typical of a central business district. In this area are concentrated most of the government offices and administrative headquarters of state bodies, most of the hotels and larger shops, and the principal theatres, museums, and art galleries. But its function as a residential area has not been lost; the many large apartment buildings of modern times have ensured that a large population continues to live in the centre, and there are still many quiet residential neighbourhoods within the Garden Ring.

Nikolai Ignatiev



The interior of the State Department Store, GUM.

The middle zone. Beyond the Garden Ring and approximately as far as the Moscow Little Ring Railway lies a zone mostly of late 18th- and 19th-century development. Within it are many factories and the principal railway stations and freight yards. The Likhachyov Automobile Works, with its associated housing, occupies much of the southeastern sector. Enveloped within this zone are further examples of the best of classical Moscow, such as the 18th-century palace that houses the Presidium of the Academy of Sciences of Russia on Leninsky Prospekt. Also to the southwest, on the banks of the Moskva, are the most important of the fortified monasteries, the 16th-century Novodevichy Convent, with its beautiful Smolensk Cathedral, whose tall bell tower (1690) dominates the churches and buildings within the crenellated walls and towers of the convent. The cathedral now houses the Novodevichy Convent Museum, and the complex includes a cemetery where, among other prominent figures of Soviet history, Nikita Khrushchev is buried. Just south of Novodevichy, within the large loop of the Moskva and facing the Lenin Hills, is the sports complex known as Luzhniki Park, dominated by the huge Central Lenin Stadium (1955–56).

Novodevichy Convent

The middle zone underwent the most urban renewal in Soviet times. Among the features of the present Moscow skyline are the ornate "wedding cake" skyscrapers along the Garden Ring, built in the late 1940s and early 1950s. In the same Stalin-period style are the Ukraina Hotel across the river and the gigantic building in the Moscow State University complex on the Lenin Hills. Most of the renewal that has taken place since 1960 consists of extensive neighbourhoods of wide streets lined with rows of apartment buildings. A number of areas still have narrow streets of 19th-century housing and smaller factories.

Outer Moscow. Beyond the Garden Ring is the zone of modern factory development and of extensive housing construction. Closer to the centre are the micro-regions, or neighbourhood housing units, of the Khrushchev period, typically five- to nine-story apartment buildings built predominantly of yellowish brick. Farther out, the neighbourhoods are characterized by high-rise buildings (20 or more stories), made of standardized, prefabricated concrete sections. Commonly the street levels of the buildings are occupied by shops. Streets are broad and tree-lined. Between the densely populated micro-regions are wedge-shaped areas of open land, notably the extensive Izmaylovsky Park in the east, Sokolniki Park and large forest tracts to the northeast, and on the north the grounds of the permanent Exhibition of National Economic Achievements. Nearby, in Dzerzhinsky Park at Ostankino, is the 1,758-foot television tower.

In the sea of new building, individual monuments of the past, such as the 17th-century Church of the Intercession in Medvedkovo, survive. Moscow's growth has engulfed a number of former country estates, the mansions of which date mostly from the period of classical architecture. On the east side of the city is Kuskovo, once the estate of the Sheremetyev family, its palace built in the 1770s, a church, hermitage, and Baroque grotto. To the south is the Uzkoe mansion, formerly belonging to the Trubetskoy family; to the north are the Petrovsky Palace (built by Kazakov in 1775–82) and, best known of all, the Ostankino Palace (1790–98). In the southeastern suburbs is the former village of Kolomenskoye, once a summer residence of the princes of Moscow. Its most remarkable architectural ensemble of buildings is dominated by the tower of the Church of the Ascension (1532). The Kazan Church and the gatehouse both date from the later 17th century. The surrounding park has a collection of examples of early Russian wooden architecture, brought from various parts of the country. In the nearby village of Dyakovo is the ornate Church of St. John the Baptist, built in 1557.

Beyond the newest suburbs are remaining areas of open land and forest within the Ring Road, together with the satellite industrial towns and dormitory suburbs that were included within the extended boundaries of the city of Moscow in 1960. The principal satellites are Babushkin to the north, with textile mills and a large number of

Satellite towns

commuters, Perovo to the east, with major marshaling yards and engineering and chemical factories, Lyublino to the southeast, Kuntsevo to the west, and Tushino to the northwest. In the mid-1980s several areas outside the Ring Road—including the suburban city of Solntsevo (now the Solntsevsky District [*rayon*]) to the southwest—were added to Moscow. Another part of Moscow, the new town of Zelenograd, established in 1963, is several miles north of the Ring Road.

THE PEOPLE

The inhabitants of Moscow are overwhelmingly of Russian nationality, the largest minority groups being Jews, Ukrainians, Belorussians, and Tatars. It is possible, however, to meet people on the streets of Moscow who belong to any of numerous nationalities, including Georgians and Armenians from the Caucasus Mountains and Uzbeks and Kazakhs from Central Asia.

A considerable percentage of the residents were not born in Moscow but migrated there during the rapid growth of the city. Some of the older generation have lived through the Stalinist purges and the deprivations of World War II. There is no typical Muscovite, but to some visitors the residents seem guarded in their relations with others. With the coming of summer, however, this seems less true as people shed their winter clothes and mingle more freely. Among the more common scenes are those in the courtyards of apartment buildings, where the children play while their elders gossip on benches and play chess, and young people congregate to listen to music.

The great increase in the amount of housing since the late 1950s has brought a fundamental change in the Muscovites' way of life as many have moved farther from the central city. For most of them, living in the suburbs has involved lengthier travel to and from work. The subway system has been extended to many suburban housing districts, but most working Muscovites must spend at least two hours a day commuting. The new housing pattern has also inevitably led to the breakup of the close communities that existed in the old central areas, such as the so-called intelligentsia district around Kropotkinskaya and the Arbat. The degree of change has been marked: in 1926 more than one-third of the population lived within the Garden Ring, but by 1967 fewer than 9 percent of the people lived there. The population density of central Moscow, however, is still much higher than in the suburbs.

THE ECONOMY

Since the dissolution of the Soviet Union in 1991 and the free-market reforms of the early 1990s, Moscow's economy has undergone a dramatic transformation. The manufacturing and engineering sectors that had dominated the Soviet capital's economy shrank dramatically, partly because their products could not compete on the world market and partly because rapid privatization left many industrial plants in the hands of owners who chose to invest their earnings abroad rather than in modernizing their plants to compete with foreign producers. At the same time, the city's financial and service sectors have grown rapidly to meet the demands of investors and consumers. While this transformation has brought hardship to many of the city's workers, it has also ended the retail shortages and lack of services that once characterized the city.

Moscow's labour force is one of the most highly skilled and educated in Russia, and the city's financial, engineering, and manufacturing sectors are among the country's most advanced. Women make up more than half of the workforce. They form the vast majority of workers in the textile and food-processing industries, and they predominate in the teaching and medical professions.

Industry. Despite the decline of industry in the post-Soviet period, Moscow remains the largest industrial centre of Russia. It dominates an industrial region that extends east and northeast to the Volga between Yaroslavl and Nizhny Novgorod (formerly Gorky). Moscow's industries generally rely more on the city's skilled labour force than on raw materials.

Moscow's most important industries are engineering and metalworking, which together employ more than half of the industrial workforce. There is significant production of automobiles and trucks. The largest plant in the city is the Likhachyov Automobile Works, followed by the Lenin Komsomol Automobile Plant. Closely linked with these two plants are a number of factories producing component parts, both elsewhere in Moscow and in other towns of the region. Ball bearings are manufactured both for the vehicle industry and for other purposes. The manufacture of machine tools is another major branch of engineering, particularly grinding lathes, precision cutting tools, and machinery for the textile industry.

Precision engineering

Precision engineering is highly developed and is noted for measuring and other instruments (especially at the Kalibr and Frezer factories), as well as for watches. In addition, Moscow is an important centre of electrical, electronic, and radio engineering; the wide range of items made includes transformers, computers, radio and video equipment, refrigerators, vacuum cleaners, and electric motors. Aerospace design and manufacture is one of Moscow's most important engineering sectors.

Some of the specialized, high-grade steels required by this formidable array of engineering industries are made in the city; specialized steels also come from the satellite town of Elektrostal, 36 miles east of Moscow.

Moscow is the nation's leading textile centre, and the numerous branches of its textile industry are the city's second leading employer. All types of natural and synthetic cloth are manufactured.

Chemical industry

Moscow's large chemical industry was originally geared to producing dyestuffs for the textile industry. The industry's product line has been expanded, however, to include synthetic industrial rubber and rubber tires, paints, plastics, pharmaceutical goods, and perfumes. Many of its chemical products are derived from Moscow's oil refinery, which processes petroleum piped from the Volga–Urals oil field.

Nikolai Ignatiev



Housing in southwestern Moscow.

Food processing avoided the sharp decline in output that characterized other industrial sectors and became one of the city's most developed industries in the 1990s. Its most important products include processed meat and dairy items, confectionery, and alcoholic beverages. Among the city's most successful firms is the Kristall Distillery, which produces the renowned Stolichnaya vodka.

Apart from food processing, Moscow's consumer goods sector suffered in the early 1990s when the market was opened to inexpensive, higher-quality imports. Still, the city produces a wide range of consumer goods for the city and its wider hinterland. Furniture making is part of a varied timber-processing industry, which also makes pulp and paper. Some of the timber is used in the vast construction industry, the workers of which include not only the large numbers actually employed in building but also those engaged in making building materials, such as reinforced concrete sections, glass, and bricks. Moscow's printing industry is the nation's largest supplier of books, journals, and newspapers. Many of Moscow's factories are small, long-established works that make highly specialized items.

Moscow draws on a wide area for its power supply. Electrical generating stations in the city are fired by natural gas, which is piped via a grid system from fields in Siberia and elsewhere. Large gas storage facilities have been constructed near Moscow, and a linking pipeline rings the city. Electrical power also comes from nuclear plants, the nearest of which is about 37 miles to the south, and from the hydroelectric stations on the Volga. Other sources are the large thermal stations at Konakovo to the northwest and Kashira to the south. A by-product of the power industry is hot water, which is piped from the district central stations to apartment buildings for heating and domestic use.

Services. *Commerce and finance.* As the capital and largest city of Russia, Moscow not surprisingly is the country's chief commercial and financial centre. The privatization of the Russian economy spurred the development of a substantial financial sector, including several banks and securities exchanges. Most foreign investment in the Russian economy passes through Moscow's financial institutions. As the hub of Russia's transportation network, Moscow also enjoys unchallenged supremacy as the country's centre for domestic and foreign commerce.

Moscow is Russia's leading educational and research centre, and its educational institutions furnish skilled workers for its important engineering and aerospace sectors. It is also the centre of Russia's publishing industry.

The city's retailing facilities are heavily used, not only by the inhabitants of Moscow itself and its satellite towns but also by people throughout the nation. Its shops offer a wide range of goods and are always crowded with customers. Many of the stores are fairly large, particularly the department stores (*univermagy*). The most important of the department stores are Children's World (Detsky Mir); the Central Department Store (TsUM); the Moscow (Moskovsky) Department Store, close to three main railway stations; and, best known and most heavily patronized, GUM, the direct descendant of the medieval trading rows. An important part of Moscow's retail trade is carried on at farmers' markets, where farmers and small-scale traders sell fruit, vegetables, meat, liquor, and other goods to the populace.

Tourism. As a world-renowned capital, Moscow is a principal focus for foreign visitors. Free-market reforms have encouraged the construction of new, modern hotels and the modernization of existing hotels in the city. The government also opened new tourist offices and refurbished many cultural attractions.

Moscow has thousands of eating places, many of them inexpensive cafeterias serving the city's workers. The city's more exclusive dining venues include Chinese, Indian, American, Italian, and other ethnic restaurants that opened during the 1990s.

Transportation. *Rail.* Russia is heavily dependent for freight transport on its railways. The hub of this network is the capital. Trunk lines radiate out from the city in all directions. The first in operation was the St. Petersburg (formerly Leningrad) line, opened in 1851. Others include the Savyolovo line, running north to the Volga and on as a secondary route to St. Petersburg; the Yaroslav line, which is connected by way of the Trans-Siberian route to Vladivostok; the Nizhny Novgorod line, linked to Kirov; the Kazan line, the most direct route to the Urals and Siberia; the Ryazan line, leading to Central Asia and the Caucasus; the Pavelets line, a secondary route to the European south and the Caucasus; the Kursk line, the main route south to the Crimea; the Kiev line to the southwest; the Smolensk line to Minsk, Warsaw, and Berlin; and the Riga line to the Baltic. The most heavily used of these lines are now electrified—notably those to St. Petersburg, Kiev, the Donbass, and the Trans-Siberian—as are all suburban-zone lines, which carry the heavy commuter traffic. To link the radial lines the Moscow Little Ring Railway was built in 1908 within the city; this has been supplemented by the Greater Moscow Ring Railway at a distance of some 25 to 40 miles from the city.

Waterways. Moscow is a major river port. The canalized Moskva can take only smaller craft, but the Moscow Canal, built by forced labour in 1932–37, can take ships of seagoing size. The canal runs from the Moskva, upstream of the city, northward to the Khimki and Ucha reservoirs and, continuing northward, through the Klin-Dmitrov Ridge to the Volga at Ivankovo. The Volga's various canal links open up Moscow to all the seas bordering European Russia. The capital has three large river ports mainly for freight and two terminals for passengers that are part of the urban transit system.

Moscow Canal

Air. Moscow is similarly the hub of the Russian airline network, and the number of passengers rises steadily each year. Four airports operate in the Moscow area. Sheremetyevo-2 to the north is the main airport for international flights, with direct links to most European capitals and to Havana, New York City, Montreal, Tokyo, and other foreign cities. Sheremetyevo-1 handles mostly domestic flights, as does Vnukovo, 15 miles to the southwest. Other domestic airports are Bykovo, 20 miles to the southeast, and Domodedovo, 28 miles to the south.

Intracity transport. Compared with other large cities in most developed countries, Moscow has few privately owned cars, although their number is steadily increasing. There are, however, a considerable number of officially owned cars, which have added to the increase in traffic congestion. At the same time, there is heavy reliance on public transport, and in this respect Moscow is generally well served.

The most important element in Moscow's city transport is the Metropolitan (Metro) subway. The system, begun in 1935, is renowned for the elaborate architecture of its stations, especially the older ones, which are highly decorated with marble, stained glass, statuary, and chandeliers. Trains usually arrive at three-minute intervals, although the interval is less during rush hours. The network copies the city street pattern, with a series of radial lines linked by a single ring subway. Although the lines extend to most parts of the city, the stations are spaced far apart so that it is usually necessary to use them in conjunction with bus, trolley, and streetcar lines.

Subway system

The inflexibility of fixed-line forms of transport poses a potential problem as traffic gradually increases. Many streetcar lines, consequently, have been replaced by bus routes. On the positive side, fares on all forms of transport are very low regardless of distance.

ADMINISTRATION AND SOCIAL CONDITIONS

Government. In the period after the 1917 Revolution, Moscow was divided into 11 administrative districts, or wards. With the expansion of the municipal limits in 1960 the number of administrative units was increased to 17 *rayony* (districts; singular *rayon*). The subsequent huge building program and redistribution of population from central areas to the suburbs necessitated the creation of new divisions in 1968 and again in 1976, when the number reached 30. Further annexations caused an increase by the mid-1980s to 32 *rayony*, a figure that would rise as the city continued to grow. The *rayony* vary in population, the inner *rayony* usually being somewhat smaller in area and

population than the outer. The *rayony* elect delegates to a city council, which has its headquarters on Gorky Street. The council handles the city's annual budget, which is derived chiefly from central government funds. The city council is responsible to the government of Russia rather than to a smaller administrative unit.

Although the centre of national government is the Kremlin, the buildings of various ministries and government departments are scattered fairly widely over the inner city. The Ministry of Foreign Affairs is in a skyscraper of the Stalin period on the Garden Ring. Several ministries are housed in the new tower buildings on Prospekt Kalinina, and a number of foreign embassies have been transferred to the southwestern suburbs on the Lenin Hills, although many are still located in the city centre. Moscow also serves as headquarters of most national bodies and organizations.

Education. Even considering its size and political importance, Moscow has an exceptionally large concentration of educational establishments. At the pre-university level, schools serving the city's own population include those for handicapped children, special foreign language schools, and boarding schools. For children below school age (six years old in Russia) there are nurseries and kindergartens; many are attached to individual places of employment, which permits parents more freedom to work. Moscow's higher educational institutions draw students from throughout the nation. A large percentage of the students are registered for correspondence courses. Although the students are predominantly Russians, they include representatives of several ethnic groups together with a number of overseas students.

Moscow M.V. Lomonosov State University

Higher education. The leading institution of higher learning is the Moscow M.V. Lomonosov State University, which was founded in 1755. Some of the humanities departments are still housed in the old university buildings facing Manezhnaya Square, near the Kremlin. Science departments are located in the complex of buildings on the Lenin Hills, which date from the early 1950s and are dominated by a 34-story skyscraper in the Stalin-period style; this building houses the central administration, the Museum of Earth Science, and accommodations for thousands of students. In 1970–78 two other humanities buildings were constructed on the Lenin Hills site. Moscow's second university, the Patrice Lumumba People's Friendship University, was founded in 1960 to serve students from the world's developing nations.

Among the specialist higher educational foundations are the Moscow Timiryazev Academy of Agriculture in the north of Moscow and the Moscow P.I. Tchaikovsky State Conservatory, where some of the world's finest musicians have received their training. Also important are the Moscow D.I. Mendeleyev Institute of Chemical Technology, the Moscow N.E. Bauman Higher Technical School, and the A.V. Lunacharsky State Institute of Dramatic Art. Many institutes, among them the Moscow Institute of Aviation Technology and an institute for railway engineers, produce specialists for particular industries.

Research. In addition to the large volume of research undertaken in the university and in other teaching establishments, there is a formidable array of scientific research institutions. Between them they constitute the second largest employer in Moscow after industry. A large proportion of those Russian citizens holding the doctor of science degree are employed in Moscow. The main focus of research is the Academy of Sciences of Russia, the Presidium of which is located in a building on Leninsky Prospekt south of Gorky Park. There are also national academies of arts and medical, pedagogical, and agricultural sciences.

Many scientific institutes, such as the Experimental Research Institute of Metal-Cutting Machine Tools, are concerned with highly specialized industrial research. These are often connected closely with Moscow's own industries, as in the case of the Central Research Institute of Automobile Engineering. Linked to the research bodies are many design bureaus, including an institute that designs hydroelectric power projects and an institute for the planning of metallurgical plants.

Lenin Library

Foremost among Moscow's libraries is the V.I. Lenin State Library, one of the world's largest. There are also a number of specialty libraries in the arts and sciences and in other fields.

Health. The health of the Muscovites is attended to at the neighbourhood level by hundreds of clinics, giving medical, dental, and maternity services. Perhaps the most prominent of the city's numerous hospitals is the Botkinskaya, founded in 1911. Among specialist institutions are maternity, mental, and tuberculosis hospitals, supported by a number of specialist medical research institutions.

CULTURAL LIFE

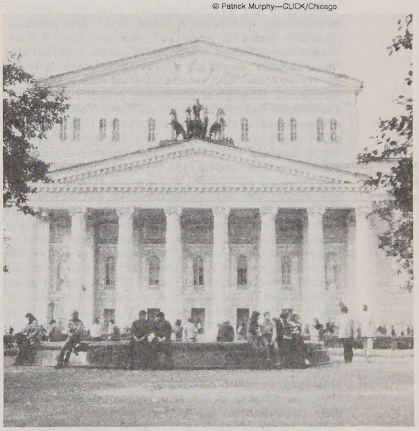
Moscow has numerous theatres, headed by the renowned State Academic Bolshoi (Great) Theatre, which was founded in 1825, though its present splendid building facing Theatre (formerly Sverdlov) Square dates from 1856. Also on Theatre Square is the Maly (Little) Theatre. The city's principal drama theatre, the Moscow Art Theatre, was founded in 1898 by the actor, director, and producer Konstantin Stanislavsky and the playwright-producer Vladimir Nemirovich-Danchenko; in its early days it was especially noted for its performances of the plays of Anton Chekhov. Also of worldwide fame are the State Central Puppet Theatre and the Moscow State Circus, which in 1971 acquired new quarters on the Lenin Hills. The repertory companies of these theatrical groups tour frequently both in Russia and abroad. There are several concert halls, notably the Tchaikovsky Concert Hall and the two halls of the Conservatory. The national orchestra has won international repute, as have a number of Moscow-based folk dance and choral ensembles.

Motion pictures are a popular form of entertainment in Moscow, and the city's many cinemas are augmented by facilities for showing films in numerous clubs and cultural institutions. The October and Rossiya cinemas are the largest in Russia. Several studios in the city produce motion pictures, notable among which is Mosfilm. The television and radio broadcasting networks also have headquarters in Moscow; programs produced there are received throughout the country.

Museums and galleries

The museums and art galleries in the capital include several of international rank. Foremost among these are the State Pushkin Museum of Fine Arts, with a fine international collection, and the State Tretyakov Gallery. The latter, which began in 1856 as the private collection of a connoisseur, Pavel Tretyakov, is noteworthy for its superb collection of icons, including several by Andrey Rublyov.

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The State Academic Bolshoi (Great) Theatre.

Other notable museums are the Armoury Museum in the Kremlin, the State Historical Museum on Red Square, and the nearby Central Lenin Museum on Revolution Square.

Although many places of worship were closed, converted into museums, or destroyed after the Revolution, Moscow retained a number of functioning Russian Orthodox churches in addition to a few other Christian churches and Jewish and Muslim places of worship. Beginning in the late 1980s with the Soviet policy of *glasnost* and continuing with the Russian successor government in the early 1990s, religious repression gave way to policies endorsing religious freedom, and houses of worship in Moscow underwent renovation and returned to use. The Russian Orthodox patriarch has a residence in Moscow.

The Luzhniki Park complex is the leading Moscow facility for sports and was one of the main arenas for the 1980 Olympic Games. The Central Lenin Stadium, accommodating 103,000, is flanked by a smaller arena, swimming pool, and the indoor Sports Palace. There are many stadiums and swimming pools in the area, including a large, heated, open-air pool that is in use all year round. In addition there are a large number of soccer fields, gymnasiums, and volleyball and basketball courts; most of these are attached to individual places of work or to sports clubs.

Parks

Outside the Garden Ring, Moscow is well provided with parks and open spaces. Gorky Central Park of Culture along the right bank of the Moskva is the closest to the centre and, with its amusement park, is very popular. A large green area, covering nearly 3,000 acres (1,200 hectares), is Izmaylovsky Park on the east side. To the northeast is the more formal Sokolniki Park, which leads to an extensive tract of forest called Moose Island. North of the city centre are the Botanical Gardens of the Academy of Sciences, one of several such gardens in the city, and the grounds of the Moscow Timiryazev Academy of Agriculture. Bittsevsky Park, also of considerable size, has been established adjacent to the Ring Road south of the city centre. The Moscow Zoo, one of the world's leading zoos, is a popular attraction west of the city centre. The Khimki Reservoir is used for boating and aquatic sports, but even more popular are the other reservoirs to the north, just outside Greater Moscow. The surrounding forest-park zone provides extensive space for recreation.

History

THE EARLY PERIOD

Foundation and medieval growth. The first documentary reference to Moscow is found in the early monastic chronicles under the year 1147, when on April 4 Yury Vladimirovich Dolgoruky, prince of Suzdal, was host at a "great banquet" for his ally the Prince of Novgorod-Seversky "in Moscow." This is the traditional date of Moscow's foundation, although archaeological evidence shows that a settlement had existed on the site since Neolithic times. Archaeological work has also revealed the remains of corduroy roads and evidence of iron and leather working dating from the 11th century. The disturbed times made defense essential, and in 1156 Prince Dolgoruky built the first fortifications—ditches and earthen ramparts topped by a wooden wall with blockhouses. This was the Kremlin. The origin of the word *kremlin* is disputed; some authorities suggest Greek words for "citadel" or "steepness," others the early Russian word *krem,* meaning a conifer providing timber suitable for building. The Kremlin was sited on the relatively high spit of land between the Moskva River and a small tributary, the Neglinnaya. The triangular piece of land between the rivers was protected on the eastern side by a moat joining them. The Neglinnaya now flows through an underground conduit, but part of its course is traced by a street of the same name.

First fortifications

Moscow soon developed as one of the more important towns of the principality of Vladimir-Suzdal. A trading settlement, or *posad,* grew up to the east of the Kremlin, along the Moskva in the area known as Zaradye. Like most other Russian towns, Moscow was captured and burned by the Mongols in their great invasion of 1236–40, and its princes had to accept Mongol suzerainty. It soon recovered, though the Mongols sacked it once again in 1293. Three years later the Kremlin was strengthened with a new earthen wall and oak palisade. Thereafter Moscow grew in importance, in trading and artisan activity, and in size, overtaking the older and previously more important centres of Suzdal and Vladimir. The town was fairly centrally placed in the system of rivers and portages that formed the trade routes across European Russia. The area east of Moscow between the Oka and Volga rivers moreover had rather better soils than most of northern Russia and formed a region of more developed agriculture and prosperous towns. Moscow's authority was greatly enhanced when in 1326 the metropolitan of the Russian Orthodox Church transferred his seat from Vladimir to Moscow. Thereafter the town was to remain the centre of Russian Orthodoxy, and after the fall of Constantinople to the Turks (1453) it claimed the title of the Third Rome. Under Ivan I Kalita the principality of Vladimir was incorporated into that of Moscow. Gradually the princes of Moscow extended their rule over the other surrounding Russian princedoms, and the town became the leader in the long struggle against Mongol hegemony.

Seat of the metropolitan

The struggle at first fluctuated. In 1378 a Muscovite army repulsed a Mongol attack on the Vozha River south of the town, and in 1380 Prince Dmitry of Moscow inflicted a crushing defeat on the Mongols under the great khan Mamai at Kulikovo on the Don River, for which victory he was thereafter known as Dmitry Donskoy ("of the Don"). The Kremlin had been enlarged and given walls and towers of white limestone in 1367, but the new fortifications were unable to withstand a renewed Mongol attack in 1382, when, despite a heroic defense, the khan Tokhtamysh captured and plundered Moscow. Yet another attack in 1408 under Khan Yedigei, however, was beaten off. Moscow grew steadily in size and importance as it continued to absorb the surrounding princedoms. Within the Kremlin the first stone cathedral, the Assumption, was built in 1326. Palaces for the prince and leading boyars, monasteries, and churches were erected. Outside the Kremlin walls, the trading and artisan quarter to the east grew in size and became known as the Kitay-gorod; this name, which originated in the 16th century, probably derives from the word *kita,* a binding of poles used in the fortifications before stone walls were built, and does not mean "Chinese City" as it is sometimes translated.

The rise of Moscow as capital. By the second half of the 15th century, especially after the annexation of Novgorod in 1478, Moscow had become the undisputed centre of a unified Russian state. During the reign of the grand prince of Moscow Ivan III the Great, the Kremlin was again enlarged and given brick walls more than a mile in length and in places up to 60 feet high. From this period also date the rebuilt Cathedral of the Assumption and the equally beautiful Annunciation and (also rebuilt) Archangel cathedrals, the Palace of Facets, and the bell tower of Ivan III. In 1534–38 the Kitay-gorod, previously protected only by earth banks and palisades, was also surrounded by a brick wall, with 12 towers. The town continued to grow and spread outside the walls to form what became known as the Bely Gorod ("White City") in a semicircle around the Kremlin and Kitay-gorod.

Despite its new fortifications, Moscow remained subject to disaster and attack. In 1547 two fires destroyed much of the town. In the mid-16th century Ivan IV the Terrible conquered the Tatar (Mongol) khanates of Kazan (1552) and Astrakhan (1556), but in 1571 the Crimean Tatars captured Moscow, burning everything but the Kremlin. The annals record that only 30,000 of 200,000 inhabitants survived. A further attack was launched by the Crimean Tatars in 1591, but they failed to overcome Moscow's stubborn resistance. The defense was helped by the new walls, built between 1584 and 1591 to protect the Bely Gorod, made of stone and some five miles long. The walls' lines are marked today by the strip of parkland and tree-lined streets of the Boulevard Ring. In 1592 an outer earth rampart with 50 towers was thrown up around the city, including an area on the right bank of the Moskva. This encompassed a further extension of Moscow that had grown up beyond the Bely Gorod; known at first as Sko-

Zemlyanoy Gorod

rodom, this outer sector came to be called the Zemlyanoy Gorod, or Earthen City. The Garden Ring traces the line of its fortifications. As an outermost line of defense, a chain of strongly fortified monasteries was established beyond the ramparts to the south and east, principally the Novodevichy Convent and Donskoy (Don), Danilovsky, Simonov, Novospassky, and Andronikov monasteries, most of which now house museums.

With much improved security, trade and craft manufacture flourished. Distinct quarters were occupied by particular trades; for example, the suburbs of Bronnaya by armour makers, Kuznetskaya by blacksmiths, and Kotelniki by kettle makers. Across the Moskva was the weavers' suburb. These artisan sectors are commonly commemorated today by street or quarter names. State workshops cast cannon and made weapons and gunpowder. The tsar's court and its attendant nobility provided patronage for luxury crafts. Increasingly the boyars took over the Kitay-gorod, with artisans and traders moving to the outer parts; the Kremlin became solely the seat of temporal and ecclesiastical authority. The centre of commercial activity was the market in Red Square between the Kremlin and the Kitay-gorod, where there were rows of stalls, each handling a specific variety of goods; the Russian word for "red" (*krasnaya*) also means "beautiful," which was the original name for the square. Trade with western Europe (especially England and Holland), as well as with Central Asia, Transcaucasia, Persia, and the Black Sea coast, was brisk, furs forming a major staple in this international commerce. Foreign merchants lived in the Nemetskaya Sloboda ("German suburb"), and a flourishing cultural life was marked by the growth of the book trade and the founding in 1553 of the first printing house.

At the turn of the 17th century Moscow, like the rest of Russia, suffered severely during the Time of Troubles. In the reign of Boris Godunov there were severe famines from 1601 to 1603. After Boris' death in 1605, the first False Dmitry seized Moscow with Polish help, and, though he was killed in 1606 and the Poles were driven out, they reoccupied Moscow with a second False Dmitry in 1608–10. In May 1611 the Muscovites attacked the Poles, and the invaders retreated into the Kremlin. Under the energetic leadership of a boyar, Prince Dmitry Mikhaylovich Pozharsky, and a merchant, Kuzma Minin, the Russians forced the Poles to surrender in October 1612.

With the establishment in 1613 of the Romanov dynasty under Michael, relative peace returned to Moscow and with it further economic advance. Nevertheless the conditions of the poor of the town often led to riots and uprisings; similar events had occurred also in 1382, 1445, and 1547. In 1648, as a result of an increase in the salt tax, and again in 1662 (the so-called Copper Riots) there were disturbances by artisans, labourers, and tradesmen. The great revolt of Stenka Razin in southern Russia (1667–71) was echoed by unrest in the capital, and in 1671 Razin was executed in Moscow as a warning to its inhabitants. The revolts were put down by the hereditary militia, the *streltsy,* who in 1698, early in the reign of Peter I the Great, themselves revolted and were suppressed only with great slaughter. Despite the frequent upheavals, however, culture flourished. Russia's first higher educational institution, the Slavonic-Greek-Latin Academy attached to the Zaikonospassky Monastery in the Kitay-gorod, dates from 1687. In 1701 Peter founded a School of Mathematics and Navigation. The first newspaper in Russia began publication in Moscow in 1703.

Riots and uprisings

EVOLUTION OF THE MODERN CITY

The 18th and 19th centuries. In 1703 Peter I began constructing St. Petersburg on the Gulf of Finland, and in 1712 he transferred the capital to his new, "westernized," and outward-looking city. Members of the nobility were compelled to move to St. Petersburg; many merchants and artisans also moved. Both population growth and new building in Moscow languished for a time, but even during Peter's reign the city began to recover from the loss of capital status. Peter himself stimulated economic growth by establishing new industries, and private entrepreneurs followed suit. By 1725 there were some 32 new factories employing 5,500 workers; more than 20 of the factories were textile mills, including a crown enterprise making sailcloth. At the same period there were about 8,500 craft workers.

During the 18th century Moscow retained its major role in the cultural life of Russia. In 1755, on the initiative of the great man of letters and science Mikhail Vasilyevich Lomonosov, Moscow University (now Moscow M.V. Lomonosov State University) was founded, the first university in Russia; a medical and surgical college was opened in 1786. Although serious fires did much damage in 1737, 1748, and 1752, many splendid new buildings appeared, designed by such architects as Giacomo Quarenghi, Vasily Bazhenov, Matvey Kazakov, and Vasily Stasov. In 1741 Moscow was surrounded by a barricade 25 miles long, the Kamer-Kollezhsky barrier, at whose 16 gates customs tolls were collected; its line is traced today by a number of streets called *val* ("rampart") and by place-names such as Kaluga Zastava (Customs Gate). Industry flourished, and by the end of the 18th century there were about 300 factories in Moscow, more than half of them textile mills. The population had grown to 275,000 by 1811.

Moscow University

In 1812 Napoleon invaded Russia; after a bitter 15-hour battle on September 7 at Borodino on the approaches to Moscow, the Russian commander in chief, Gen. M.I. Kutuzov, evacuated troops and civilians from the city, which was occupied by the French a week later. A fire broke out and spread rapidly, eventually destroying more than two-thirds of all the buildings. Looting was rife. The lack of supplies and shelter and continual harassment by Russian skirmishing forces made it impossible for Napoleon to winter in Moscow, however, and on October 19 the French troops began their catastrophic retreat.

In 1813 a Commission for the Construction of the City of Moscow was established. It launched a great program of rebuilding, which included a partial replanning of the city centre. Among many buildings constructed or reconstructed at this time were the Kremlin Great and Armoury palaces, the university, the Manezh (Riding School), and the Bolshoi Theatre. Industry also recovered rapidly and continued to develop through the 19th century. In 1837 the Moscow stock exchange was established. The emancipation of the serfs in 1861 and the beginning of the railway era with the opening of the line to St. Petersburg in 1851 greatly increased labour mobility, and large numbers of peasants from the villages began moving into Moscow. The population, which had reached 336,000 in 1835, had almost doubled, to 602,000, in 1871 and by 1897 had reached 978,000. Moscow became the hub of Russia's railways, with trunk lines to all parts of European Russia. A ring of main line termini was built, mostly on or near the Kamer-Kollezhsky barrier at the limits of the built-up area. Outside the barrier many new factories, particularly those concerned with textiles, began operation. In the 1890s heavy engineering and metalworking industries also developed. Between 1897 and 1915 Moscow yet again doubled in size, to a population of 1,983,700.

The later 19th century was a period of ostentatious building by public bodies and wealthy private persons, in various imitative "Old Russian" styles and the so-called modern style. From this period date the old Town Hall (meeting place of the Gorodskaya Duma, now the Central Lenin Museum), the State Historical Museum, and the Upper Trading Rows (now GUM).

The growth of an industrial proletariat in Moscow, together with the generally low living standards of the workers, brought growing unrest and strikes. Various revolutionary groups were active. In the Revolution of 1905 a small-scale insurrection took place in Moscow, and an attempt was made to seize the Nikolayev (now St. Petersburg) station; the revolt was ruthlessly crushed. In 1917, although a Council of Workers' and Soldiers' Deputies was set up in Moscow, the city remained relatively quiet until after the Bolshevik seizure of power in Petrograd (St. Petersburg) on October 25 (November 7, New Style), which was immediately followed by fighting in Moscow. Military cadets held out for a time in the Kremlin, but by November 3 (16, N.S.) they were overcome and Bolshevik power was firmly established.

The Bolshevik Revolution

Moscow in the Soviet period. In March 1918 Lenin and the Soviet government moved to Moscow, which thereby resumed its former status as capital. This status was formally ratified on Dec. 30, 1922, when the first All-Union Congress of Soviets met in the Bolshoi Theatre and passed the legislation setting up the Union of Soviet Socialist Republics. In the civil war period Moscow, like other Soviet cities, suffered greatly, with grave food shortages, loss of population (falling to 1,027,300 in 1920), and reduction of industry. In the years following the final establishment of Soviet power and peace, recovery was swift, and the beginning of the series of five-year plans in 1928 brought great industrial progress. The city's existing plant and labour force formed one of the main springboards for industrialization elsewhere in the U.S.S.R. Between the censuses of 1926 and 1939, Moscow once more doubled its population, from 2,029,425 to 4,182,916 (within the 1959 boundaries). Priority in investment went to industry, and housing construction was very limited; as a consequence, exceptional overcrowding of existing housing developed, with extremely high population densities.

During World War II, the Germans in late 1941 reached the outskirts of Moscow, less than 25 miles from the Kremlin. Many factories were evacuated, together with much of the government. From October 20 the city was declared to be in a state of siege. Its remaining inhabitants built and manned antitank defenses, while the city was bombarded from the air. A desperate counterattack on December 6 threw the German forces back from the outskirts and saved Moscow. Recovery was quick after the war, with further growth of the city's economy. Two major events have marked the city's progress: in 1947, two years after the war's end, Moscow celebrated its 800th anniversary, and in 1980 it hosted the Summer Olympic Games.

In the postwar period, immigration to Moscow caused a housing shortage that reached grave proportions in the 1950s; the population density within the Garden Ring surpassed 132,000 persons per square mile (51,000 per square kilometre) by 1959. Under Khrushchev a major construction program was initiated. Much of the old housing, often single storied and made of wood, was cleared, and extensive new tracts of large apartment buildings sprang up around the historic core of the city. Considerable urban renewal took place in the central areas, and high-rise buildings now dominate the skyline.

In 1935 a far-reaching development plan for Moscow was formulated; but the plan devised in 1960, in which adjacent satellite towns were incorporated into the city, was even more ambitious than the earlier plan. Under this plan urban growth was to be contained within the Moscow Ring Road, and residential and industrial zones and greenbelts were carefully designated. Implementation of this plan was instrumental in alleviating housing shortages, reducing traffic congestion, and improving air quality in the city centre. By the late 1970s, however, urban growth had outstripped original predictions, and in the 1980s planned urban expansion was initiated beyond the Ring Road.

In August 1991 Moscow was the scene of a coup attempt by hard-line Communists against a reform-minded president, Mikhail Gorbachev. The coup failed but was followed within months by the dissolution of the U.S.S.R.

Post-Soviet Moscow. As the capital of post-Soviet Russia, Moscow was at the centre of the nation's historic transformation. As in other parts of Russia, industrial output dropped sharply, unemployment and underemployment increased, and living standards fell for many. Moscow remained Russia's chief financial and research centre, and its service sector expanded rapidly, but not enough to compensate for the industrial decline. Meanwhile, the criminal activity, including organized crime, increased.

In October 1993 violence broke out in the city when members of the Russian parliament launched an armed revolt against the government of President Boris Yeltsin. Many lives were lost when the rebels attempted to occupy the television tower and studios at Ostankino. The Russian military bombarded the parliament building and eventually put down the revolt. In 1999 bombings in Moscow and other cities killed dozens of people. The government attributed the bombings to Chechen separatists.

Meanwhile, a financial crisis in 1998 caused bank failures in Moscow and a devaluation of the Russian currency. Economic hardship continued into the 21st century for many, and the city faced the continuing challenges of improving living standards for a majority of its residents and fighting organized crime. (R.A.F./K.B.M./Ed.)

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Moses

Moses (Hebrew: Moshe) was the gifted Hebrew leader who, in the 13th century BCE (before the Common Era, or BC), delivered his people from Egyptian slavery. In the Covenant ceremony at Mt. Sinai, where the Ten Commandments were promulgated, he founded the religious community known as Israel. As the interpreter of these Covenant stipulations, he was the organizer of the community's religious and civil traditions. In the Judaic tradition, he is revered as the greatest prophet and teacher, and Judaism has sometimes loosely been called Mosaism, or the Mosaic faith, in Western Christendom. His influence continues to be felt in the religious life, moral concerns, and social ethics of Western civilization, and therein lies his undying significance.

By courtesy of Staatliche Museen Preussischer Kulturbesitz Gemaldegalerie, Berlin



"Moses Showing the Tables of the Law to the People," oil painting by Rembrandt, 1659. In the Staatliche Museen Preussischer Kulturbesitz, Berlin.

THE HISTORICAL PROBLEM

Historical views of Moses. Few historical figures have engendered such disparate interpretations as has Moses. Early Jewish and Christian traditions considered him the author of the Torah ("Law," or "Teaching"), also called the Pentateuch ("Five Books"), comprising the first five books of the Bible, and some conservative groups still believe in Mosaic authorship.

Opposing this is the theory of the German scholar Martin Noth, who, while granting that Moses may have had something to do with the preparations for the conquest of Canaan, was very skeptical of the roles attributed to him by tradition. Although recognizing a historical core beneath the Exodus and Sinai traditions, Noth believed that two different groups experienced these events and transmitted the stories independently of each other. He contended that the biblical story tracing the Hebrews from Egypt to Canaan resulted from an editor's weaving separate themes and traditions around a main character Moses, actually an obscure person from Moab.

View of Martin Noth

This article, following the lead of the biblical archaeologist and historian W.F. Albright, presents a point of view that falls somewhere between these two extremes. While the essence of the biblical story (narrated between Exodus 1:8 and Deuteronomy 34:12) is accepted, it is recognized that, during the centuries of oral and written transmission, the account acquired layers of accretions. The reconstruction of the documentary sources of the Pentateuch by literary critics is considered valid, but the sources are viewed as varying versions of one series of events (see BIBLICAL LITERATURE AND ITS CRITICAL INTERPRETATION). Other critical methods (studying the biblical text from the standpoint of literary form, oral tradition, style, redaction, and archaeology) are equally valid. The most accurate answer to a critical problem is therefore likely to come from the convergence of various lines of evidence. The aid of critical scholarship notwithstanding, the sources are so sketchy that the man Moses can be portrayed only in broad outline.

The date of Moses. According to the biblical account, Moses' parents were from the tribe of Levi, one of the groups in Egypt called Hebrews. Originally the term Hebrew had nothing to do with race or ethnic origin. It derived from Habiru, a variant spelling of Ḫapiru (Apiru), a designation of a class of people who made their living by hiring themselves out for various services. The biblical Hebrews had been in Egypt for generations, but apparently they became a threat, so one of the pharaohs enslaved them. Unfortunately, the personal name of the king is not given, and scholars have disagreed as to his identity and, hence, as to the date of the events of the narrative of Moses. One theory takes literally the statement in I Kings 6:1 that the Exodus from Egypt occurred 480 years before Solomon began building the Temple in Jerusalem. This occurred in the fourth year of his reign, about 960 BCE; therefore, the Exodus would date about 1440 BCE.

This conclusion, however, is at variance with most of the biblical and archaeological evidence. The storage cities Pithom and Rameses, built for the pharaoh by the Hebrews, were located in the northeastern part of the Egyptian delta, not far from Goshen, the district in which the Hebrews lived. It is implicit in the whole story that the pharaoh's palace and capital were in the area, but Thutmose III (the pharaoh in 1440) had his capital at Thebes, far to the south, and never conducted major building operations in the delta region. Moreover, Edom and Moab, petty kingdoms in Transjordan that forced Moses to circle east of them, were not yet settled and organized. Finally, as excavations have shown, the destruction of the cities the Hebrews claimed to have captured occurred about 1250, not 1400.

Inasmuch as tradition figured about 12 generations from Moses to Solomon, the reference to 480 years is most likely an editorial comment allowing 40 years for each generation. Since an actual generation was nearer 25 years, the most probable date for the Exodus is about 1290 BCE. If this is true, then the oppressive pharaoh noted in Exodus (1:2–2:23) was Seti I (reigned 1318–04), and the pharaoh during the Exodus was Ramses II (*c.* 1304–*c.* 1237). In short, Moses was probably born in the late 14th century BCE.

YEARS AND DEEDS

The formative years. One of the measures taken by the Egyptians to restrict the growth of the Hebrews was to order the death of all newborn Hebrew males. According to tradition, Moses' parents, Amram and Jochebed (whose other children were Aaron and Miriam), hid him for three months and then set him afloat on the Nile in a reed basket daubed with pitch. The child, found by the pharaoh's daughter while bathing, was reared in the Egyptian court. While many doubt the authenticity of this tradi-

tion, the name Moses (Hebrew Moshe) is derived from Egyptian *mose* ("is born") and is found in such names as Thutmose ([The God] Thoth Is Born). Originally, it is inferred, Moses' name was longer, but the deity's name was dropped. This could have happened when Moses returned to his people or possibly even earlier, because the shortened form Mose was very popular at that time.

The young prince or courtier

Moses' years in the court are passed over in silence, but it is evident from his accomplishments later that he had instruction in religious, civil, and military matters. Since Egypt controlled Canaan (Palestine) and part of Syria and had contacts with other nations of the Fertile Crescent, Moses undoubtedly had general knowledge of life in the ancient Near East. During his education he learned somehow that he was a Hebrew, and his sense of concern and curiosity impelled him to visit his people. According to the biblical narrative, Moses lived 120 years and was 80 when he confronted Pharaoh, but there is no indication how old he was when he went to see the Hebrews. Later Jewish and Christian tradition assumed 40-year periods for his stay in the Egyptian court, his sojourn in Midian, and his wilderness wanderings.

Most likely Moses was about 25 when he took the inspection tour among his people. There he saw the oppressive measures under which they laboured. When he found an Egyptian taskmaster beating a Hebrew, probably to death, he could control his sense of justice no longer. After checking to make sure that no one was in sight, he killed the tough Egyptian overlord. As a prince in the court, Moses was probably in excellent physical condition, and apparently he knew the latest methods of combat.

The flush of victory pulled Moses back the next day. He had removed one threat to his people and was determined to assist them again. This time, however, he found two Hebrews fighting. After parting them, he questioned the offender in an attempt to mediate the disagreement. Two questions jolted him: "Who made you a prince and a judge over us? Do you intend to kill me as you killed the Egyptian?" The confidence of the self-appointed deliverer turned into fear. One of his own knew his "secret" and soon Pharaoh would, too. Realizing that he would have to flee, he went to Midian (mainly in northwest Arabia).

Moses in Midian. In noting the flight to Midian the narrative says nothing of the difficulties involved. Like Sinuhe, the Egyptian court official whose flight in about 1960 BCE was narrated in a famous story, Moses undoubtedly had to filter through the "Wall of the Ruler," a series of forts at the eastern border, approximately where the Suez Canal is now located. From there he made his way southeast through very desolate country. Unfortunately, the Bible does not specify the part of Midian in which Moses resided. Midian proper was east of the Gulf of Aqaba, in the northern section of Hejaz in Arabia, but there is evidence that some of the Midianite clans crossed over the Arabah (the great valley south of the Dead Sea) and settled in the eastern and southern sections of the Sinai Peninsula.

While Moses was resting at a well, according to the biblical account, seven daughters of the Midianite priest Jethro came to water their father's flocks. Other shepherds arrived and drove the girls away in order to water their own flocks. Again Moses showed his courage and prowess as a warrior because he took on the shepherds (perhaps with the girls' help) and routed them. Moses stayed on with Jethro and eventually married Zipporah, one of the daughters. In assuming the responsibility for Jethro's flocks, Moses roamed the wilderness looking for pasture.

The burning bush

One day at the base of a mountain, his attention was attracted by a flaming bush, but, oddly, it was not consumed. He had seen bushes brilliant with flamelike blossoms, but this phenomenon was different, and so he turned aside to investigate it. Before he could do so, he was warned to come no closer. Then he was ordered to remove his sandals because he was standing on holy ground.

Regardless of how one interprets the burning bush, the important fact is that Moses was conscious of an encounter with Deity. This God, who claimed to be the God of Abraham, Isaac, and Jacob, was calling him to deliver the Hebrews from Egypt. Although on his own he had previously been zealous to help his own people, now that he was being commissioned to deliver them he expressed doubt concerning his qualifications. The underlying reason was probably fear—he had fled from Seti I, and he did not relish confrontation with Ramses II. God reassured Moses that in the future he and the Hebrews would worship at this mountain. Then Moses asked to know the name of the Deity commissioning him. The God of the fathers had been known mostly as El 'Elyon (God Most High) or El Shaddai (God of the Mountain or Almighty God), but he identified himself to Moses as Yahweh and gave instructions that he was to be called by his new name from then on. As the causative form of the verb "to be," Yahweh means He Who Creates (Brings Into Being). This revelation enabled Moses to understand the God of the Hebrews as the sovereign Lord over nature and the nations of the world.

Even after further assurances, Moses was still reluctant to accept Yahweh's call; therefore, he pleaded for release because he was a stammerer. Yahweh acknowledged the defect but promised to help him express himself. Awed by his assignment, Moses made a final desperate plea, "Oh, my Lord, send, I pray, some other person." Although angry at Moses, Yahweh would not yield. Moses would still be Yahweh's representative, but his golden-tongued brother Aaron would be the spokesman. Apparently Moses was ready to play the role of God to Pharaoh providing Aaron would serve as his prophet. He returned to Jethro and requested permission to visit his people in Egypt, but he did not disclose that he had been commissioned by Yahweh.

Moses and Pharaoh. Ramses II became king as a teenager and reigned for 67 years. He aspired to defeat the Hittites and control all of Syria, but in the fifth year of his reign Ramses walked into a Hittite trap laid for him at Kadesh, on the Orontes River in Syria. By sheer determination he fought his way out, but in the light of his purpose the battle was an utter failure. Yet Ramses, like all the pharaohs, claimed to be divine; therefore, the defeat had to be interpreted as a marvellous victory in which he alone subdued the Hittites. His wounded ego expressed itself in massive building operations throughout Egypt, and before his reign ended the boast of his success literally filled acres of wall space.

Confrontation with Ramses

It was probably only a few years after the Kadesh incident that Moses and Aaron confronted Ramses with their demand, "Thus says the Lord, the God of Israel, 'Let my people go.' " As a god in human form Ramses was not accustomed to taking orders from lesser gods, let alone an unknown like Yahweh. "Who is the Lord," he inquired, "that I should heed his voice and let Israel go? I do not know the Lord, and moreover I will not let Israel go." Thus the stage was set for a long struggle between a distrustful ruler with an outsize ego and a prophet with a new understanding of Yahweh and his power.

Ramses increased the oppression of the Hebrews by the fiendish plan of requiring them to gather the straw binder for the bricks and still produce the same quota each day. Some of the Hebrews rebuffed Moses, and in frustration he asked Yahweh, "Why didst thou ever send me?" Moses' doubt was allayed by Yahweh's promise to take action against Pharaoh. Scholars differ widely concerning the narrative about the plagues. Some claim that three sources have been combined, but more recent scholarship finds only the two traditions. While granting that some of the plagues had a core of historicity, older critics tended to discount the present accounts as fantastic stories with pious decorations. A recent school of research suggests that, notwithstanding some later additions, all the plagues probably had a historical core.

The basic cause, according to one interpretation, was an unusually high flooding of the Nile. The White Nile originates in the lake region of east central Africa, known today as Uganda. The flow is fairly even throughout the year because of consistent equatorial rains. The Blue Nile, on the other hand, originates in the headwaters of the Ethiopian highlands, and it varies from a small stream to a raging torrent. At the time Moses was bargaining with Ramses, excessively heavy summer rains in Ethiopia

washed powdery, carmine-red soil from the slopes of the hills. Around the Lake Tana region the blood-red torrent picked up bright red algae (known as flagellates) and their bacteria. Since there were no dams at that time, the Nile flowed blood-red all the way to the Mediterranean. It probably reached the delta region in August. Thus, this rare natural event, it is held, set in motion a series of conditions that continued until the following March.

During these months Moses used the plagues of the frogs, gnats, mosquitoes, cattle murrain, boils, hail, locusts, and thick darkness to increase the pressure on Ramses. At first the King was adamant. The Hebrews were not the only disgruntled slaves, and, if he agreed to let them go, then other groups would want the same privilege. To protect his building program, he had to suppress the slave rebellion at its outset. Yet he could not discount the effect of the plagues, and grudgingly he began to acknowledge Yahweh's power. As an expedient attempt to restore order, he offered to let the Hebrews sacrifice in Goshen. When this failed, he suggested that they make offerings to Yahweh at the edge of the Egyptian border. Moses, however, insisted on a three-day journey into the wilderness. Pharaoh countered by allowing the Hebrew men to make the journey, but this, too, was rejected. As his final offer Pharaoh agreed to let the people go. He would keep the livestock, however, as the guarantee of their return. Moses spurned the condition, and in anger Pharaoh drove him out. After nine rounds with Pharaoh it appeared that the deliverance of the Hebrews was no nearer, but, in contrast to his earlier periods of doubt and frustration, Moses showed no despair. Apparently he had an inner assurance that Pharaoh would not have the last word.

From Goshen to Sinai. Chapters 11–14 of Exodus comprise an exceedingly complex section, and at times the traditions have contradictory statements. The drama is more blurred than usual, and scholars vary tremendously in their interpretation of the material. One tradition notes that Pharaoh was shaken when death took his son and that he ordered the Hebrews to leave. Another source indicates that Moses used the period of mourning for the first-born son as the occasion for fleeing secretly from the country. In either case, it is clear that Pharaoh finally had his forces pursue the Hebrews. Although tradition interpreted the Hebrew text to claim that about 2,000,000 people left Egypt, interpretation by critical methods reduces the number to 15,000 or so.

Yahweh's victory at the Reed Sea

The Egyptian army cornered them at the Sea of Reeds (papyrus), which barred their exit to the east. Later Jewish tradition understood the body of water to be the Red Sea, and this erroneous interpretation persists today, even in some of the most recent English translations of the Bible. Scholars disagree as to the precise location of the Reed Sea, but, since papyrus grows only in freshwater, it was most probably a shallow lake in the far northeastern corner of Egypt.

Hemmed in by the Egyptians, the people vented their complaints on Moses. According to one tradition, Moses shared their uneasiness, and he called to Yahweh for help. Another account claims that Moses confidently challenged them to be calm and watch for Yahweh's deliverance. A strong east wind blew all night, creating a dry corridor through the lake and permitting the Hebrews to cross. The pursuing Egyptians were destroyed when the waters returned. The timing of this natural event gave the final answer to Pharaoh's arrogant question, "Who is Yahweh?" Safely on the other side, Moses and his sister Miriam led the people in a victory song of praise to Yahweh (Ex. 15:1–21). The style of the poetry is similar to that of 14th-century Canaanite literature, and there is every reason to believe that the poem virtually preserves the original form of the song, with its refrain, "Sing to the Lord, for he has triumphed gloriously; the horse and his rider he has thrown into the sea."

The route of the Hebrews is contested by scholars, but the most likely possibility is the southern route to Jabal Mūsā, the traditional location of Mt. Sinai (Horeb), in the granite range at the southern tip of the Sinai Peninsula. The journey there traversed some very desolate country, and Moses had to contend with bitter complaints about the lack of water and food. Finally, however, he brought the people to "the mountain of God," where Yahweh had appeared to him in the burning bush.

The Covenant at Sinai. During the 14th century BCE the Hittites of Asia Minor made a number of treaties with neighbouring rulers who came under their control. The agreement was not between equals, but between the Hittite king (the suzerain) and a subordinate ruler (the vassal). In the prologue the Hittite ruler described himself as "the great king," the one granting the treaty. Then followed a historical survey of relationships between the Hittite suzerain and his vassal. Special attention to the kindnesses shown the underling by the overlord was intended to remind the vassal of his obligation to abide by the treaty stipulations. The basic requirement was an oath of loyalty. Since Egypt was involved with the Hittites in the international politics of the time, Moses probably learned about the Hittite treaty form during his years in the Egyptian court.

The revelation at Sinai: the Ten Commandments

The appearance of Yahweh in a terrific storm at Mt. Sinai, narrated in chapters 19 and 20 of Exodus, was a revelatory experience for Moses, just as the burning bush had been. Somehow he realized that the Hittite treaty was an accurate analogy of the relationship between Yahweh and the Hebrews. Yahweh had a claim upon them because he had delivered them. The only proper response to his love and care would be a pledge of obedience to his will. Scholars have tended to date the Ten Commandments, or Decalogue (contained in the revelation at Sinai), after the conquest of Canaan, but there is absolutely nothing in these guidelines to indicate their origin in an agricultural context. More likely they were the stipulations in the covenant ceremony at Mt. Sinai.

Because Yahweh was proclaimed the only true God, one of the first commands was appropriately a ban against all other gods. Authorities have debated whether or not this understanding was interpreted as monotheism. Most certainly it was not the philosophical monotheism of later periods, but it was a practical monotheism in that any gods recognized by other nations were under Yahweh's control. Inasmuch as he had brought them into being and authorized their presence in his council, he was Lord over all gods and nations.

Another early command has been taken to mean a ban on making images of other gods, but originally the prohibition applied to representations of Yahweh himself. Worship in the ancient world was unthinkable without some idol or image; therefore, the uniqueness of Moses' restriction is all the more evident. Yahweh is the unimageable Deity who cannot be represented in material forms. Since Yahweh had revealed the meaning of his name to Moses, it was fitting that the Decalogue should also prohibit any magical or unethical use of his name. Undoubtedly the ideas underlying the other commands came from the religious culture of his day, but they were raised to a significantly higher level because of the holy, righteous character of Yahweh. Moses realized that, if the Covenant people were to have a stable, just society, they would have to emulate their God. Concern for his creatures would mean respect for them as persons. Murder, adultery, theft, lying, and covetousness would never be legitimate because they lead to chaos and breakdown of the community. Moreover, inasmuch as Yahweh had been concerned to protect the powerless Hebrews in Egypt, they in turn would have to guarantee justice for the orphans, widows, resident aliens, and any other disadvantaged persons under their jurisdiction.

Interpretations and elaborations

On confirmation of the Covenant, Moses and the people faced the task of living by the stipulations. This called for interpretations of the commands, and so Moses began issuing ordinances for specific situations. Many of these he drew from the case law of his day, but insight as to their selection and application probably came in the "tent of meeting" (a simple sanctuary tent pitched outside the camp), where Yahweh spoke to Moses "face to face, as a man speaks to his friend." Breaches of the Covenant necessitated means of atonement, which in turn meant provision of a priesthood to function at sacrifices and in worship. In short, the rudiments of the whole Hebrew

cult, according to tradition, originated at Sinai. At Jethro's suggestion Moses instituted a system of judges and hearings to regulate the civil aspects of the community. It was at Sinai, perhaps, where the people were organized into 12 tribes.

One of Moses' most remarkable characteristics was his concern for the Hebrews, in spite of their stubborn, rebellious ways. When they reverted to worshipping a golden calf, Yahweh was ready to disown them and begin anew with Moses and his descendants. Moses rejected the offer, however, and later, when pleading for the forgiveness of the people, he even asked to have his own name blotted out of Yahweh's book of remembrance if the Lord would not forgive them.

From Sinai to Transjordan. After leaving Mt. Sinai, Moses faced increasing resistance and frustration, according to the narrative in the book of Numbers. Apparently his virility did not diminish during these years because he took a Cushite woman as his second wife. But Miriam, with the support of Aaron, opposed the marriage. At Kadesh-barnea the pessimistic majority report of the spies who had been sent out to reconnoitre thwarted Moses' desire to march north and conquer the land of Canaan. When he urged the people to reconsider their action they almost stoned him. But here again, according to tradition, Moses interceded for the people with Yahweh, who threatened to destroy them and raise up another and greater nation. In one instance, however, tradition recalled that Moses' anger overrode his compassion. At Meribah, probably in the area of Kadesh-barnea, Moses addressed the complaining people as rebels and struck a rock twice in anger, whereupon water flowed forth for the thirsty people. He had been angry before in defense of Yahweh's name, honour, and cause, but this time his anger stemmed from utter frustration with his contentious people. Although tradition interpreted this lapse as the reason why Yahweh would not permit Moses to enter Canaan, the remarkable fact is that Moses was able to bear up under such continuous pressure.

In Transjordan the new states of Edom and Moab, vassals of the Midianites, rejected Moses' request for passage. He wisely circled east of them and moved north to conquer Sihon, king of the Amorites, and Og, king of Bashan. Moses permitted some of the tribes to settle in Transjordan, a decision that evoked opposition from the Moabites and their Midianite overlords. They hired the Syrian diviner Balaam to put a curse on the Hebrews, but instead he pronounced a blessing. Some scholars interpret this as proof that Balaam was a convert to Yahwism. If this was indeed the case, he must have reverted later on, because the biblical tradition implies that Balaam incited his former employers to weaken the Hebrews by religious seduction. Moses responded to the enmity of the Midianites with a successful holy war against them not long before his death.

Final conflict against the Midianites

As his last official act Moses renewed the Sinai Covenant with those who had survived the wilderness wanderings. From his camp in the Jordan Valley, Moses climbed to a vantage point on Mt. Pisgah. There he viewed the land of promise. The Hebrews never saw him again, and the circumstances of his death and burial remain shrouded in mystery. Tradition claimed that Yahweh buried him in the valley opposite Beth-peor, the shrine of the people's apostasy.

MOSES THE MAN

Although time undoubtedly enhanced the portrait of Moses, a basic picture emerges from the sources. Five times the narratives claim that Moses kept written records (Ex. 17:14; 24:4; 34:27–28; Num. 33:2; and Deut. 31:9, 24–26). Even with a generous interpretation of the extent of these writings, they do not amount to more than a fifth of the total Pentateuch; therefore, the traditional claim of Mosaic authorship of the whole Pentateuch is untenable. Moses formulated the Decalogue, mediated the Covenant, and began the process of rendering and codifying supplemental interpretations of the Covenant stipulations. Undoubtedly he kept some records, and they served as the core of the growing corpus of law and tradition. In a general sense, therefore, the first five books of the Hebrew Bible can be described as Mosaic. Without him there would have been no Israel and no collection known as Torah.

Moses was a gifted, well-trained person, but his true greatness was probably due to his personal experience of and relationship with Yahweh. This former stammering murderer understood his preservation and destiny as coming from the grace of a merciful Lord who had given him another chance. Moses had an understanding spirit and a forgiving heart because he knew how much Yahweh had forgiven him. He was truly humble because he recognized that his gifts and strength came from Yahweh.

The multiple roles of Moses

Because of the uniqueness of his situation, Moses had to function in a number of roles. As Yahweh's agent in the deliverance of the Hebrews, he was their prophet and leader. As mediator of the Covenant, he was the founder of the community. As interpreter of the Covenant, he was an organizer and legislator. As intercessor for the people, he was their priest. Moses had a special combination of gifts and graces that made it impossible to replace him. Although his successor, Joshua, and the priest Eleazar, the son of Aaron, tried to do so, together they did not measure up to him. Later prophets were great men who spoke out of the spirit that Moses had, but they were not called to function in so many roles. As tradition claimed, he was indeed the greatest of the prophets, and, as history shows, few of mankind's great personalities outrank him in influence.

(D.M.Be.)

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(D.M.Be./Ed.)

Moss Animals: Phylum Bryozoa

Bryozoa, also called Polyzoa or Ectoprocta, comprises a phylum in which there are probably more than 4,000 extant species. The bryozoans are a widely distributed, aquatic, invertebrate group of animals whose members form colonies composed of numerous units called zooids (hence the term Polyzoa, which means "many animals"). Until the mid-18th century, bryozoans, like corals, were regarded as plants; hence their name, which means "moss animals." Seventy-five years later, the bryozoans were distinguished from the cnidarians, and the characteristic structure of the zooid was first described.

Bryozoans are separated into three classes: Phylactolaemata (freshwater dwelling); Stenolaemata (marine); and Gymnolaemata (mostly marine). The order Cheilostomata (class Gymnolaemata), containing 600 genera, is the most successful bryozoan group.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, section 313, and the *Index*.

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GENERAL FEATURES

Distribution and abundance. Bryozoan colonies are found in both fresh and salt waters, most commonly as growths or crusts on other objects. Freshwater bryozoans live among vegetation in clear, quiet, or slowly flowing water. Marine species range from the shore to the ocean depths but are most plentiful in the shallow waters of the continental shelf. They cover seaweeds, form crusts on stones and shells, hang from boulders, or rise from the seabed. Bryozoans readily colonize submerged surfaces, including the hulls of ships and the insides of water pipes. A few types of bryozoans form nonattached populations on sandy seabeds.

The zooid walls, which constitute the most permanent portion of the colony, generally are calcareous (*i.e.*, impregnated with calcium carbonate), giving bryozoans a fossil record that dates from the Ordovician onward (*i.e.*, from about 500,000,000 years ago).

Size range and diversity of structure. Bryozoan colonies vary in size. In the gymnolaemate genus *Monobryozoon*, which lives between marine sand particles, a colony consists of little more than a single feeding zooid less than one millimetre (0.04 inch) in height. Colonies of the coralline genus of European seas *Pentapora*, however, can reach one metre (3.3 feet) or more in circumference; a warm-water gymnolaemate genus, *Zoobotryon*, which hangs from harbour pilings, and the freshwater phylactolaemate *Pectinatella* each produce masses that may be one-half metre across. Colonies that form crusts generally cover only a few square centimetres; erect colonies may rise only two to five centimetres (0.8–2 inches).

The texture of the colonies is variable. Some colonies, especially those in fresh water and on seashores, are gelatinous or membranous; others are tufted, with flat fronds (leaflike structures) or whorls of slender branches, whose horny texture results from light deposits of lime in zooid walls. Still other colonies are hard and have calcified skeletons. Such colonies may form rough-surfaced patches or may rise in slender branching twigs (such as those that form a network in the beautiful lace corals; *e.g.*, *Sertella*).

Colonies

The colonies, diverse and complex in structure, are composed of individual modules, or zooids, and each zooid effectively is a complete animal. A bryozoan colony usually has many zooids, which may be of one type or of types that differ both functionally and structurally. Neighbouring zooids are united and may communicate by tiny pores present in the zooids' walls. Zooids capable of feeding have a ring of slender tentacles at one end on which are found cilia (hairlike projections) that propel tiny particles of food toward the zooid mouth. The mouth opens into a digestive tract that is divided into several regions and terminates at an anus, which is outside (but near) the tentacles (hence the name Ectoprocta, meaning "outside anus"). If zooids are disturbed, they withdraw their tentacles inside the body cavity. Only if the zooids have transparent walls, such as in the gymnolaemates *Bowerbankia* and *Membranipora*, is the digestive tract visible. The internal living parts of each zooid—*i.e.*, the nervous and muscular systems, the tentacles, and the digestive tract—are called the polypide.

NATURAL HISTORY

Reproduction and life cycle. Many animals, bryozoans included, have a life cycle that incorporates phases of asexual and sexual reproduction (Figure 1). Asexual reproduction, in which gametes (sex cells) do not participate, produces genetically identical progeny (clones), which separate in larger animals (*e.g.*, sea anemones). In bryozoans, the progeny, called zooids, are produced by an asexual process called budding and almost invariably remain in intimate contact as a colony. As the colony continues to grow by budding, the zooids become sexually mature, producing eggs and spermatozoa. Sexual reproduction, by the production and subsequent fusion of gametes, generates the genetic variability necessary for a species to survive in a habitat that varies from place to place and from time to time. Fertilized eggs develop into larvae.

Some bryozoans also propagate colonies asexually. The cheilostome *Discoporella* has small, nonattached, saucer-like colonies. Groups of zooids at the colony rim detach

From (colony) E. Marcus, "Bryozoarios Marinhos Brasileiros," *Boletins da Faculdade de Philosophia, Sciencias e Letras* (1938), Universidade de Sao Paulo; (others) J.H. Barrois, *Recherches sur l'embryologie des bryozoaires*, pl. X (1877), Six-Horemans, Lille

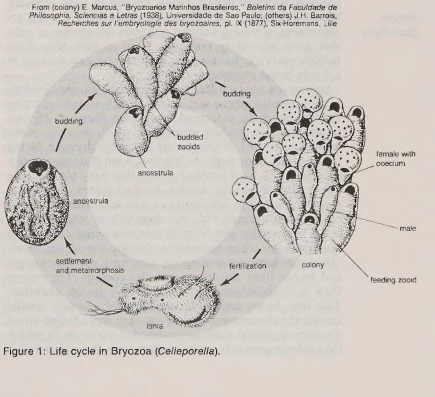


Figure 1: Life cycle in Bryozoa (*Celleporella*).

at special fracture zones and grow into new colonies. The statoblasts (dormant buds) of freshwater bryozoans are another asexual means of reproduction. Asexual reproduction, whether leading to a clone, a colony, or a clone of colonies, is a means of perpetuating and spreading a successful genetic constitution (genotype).

Primary zooid

Budding. The colony formed by asexual budding originates from either a primary zooid (or ancestrula) or a statoblast. The ancestrula is formed by the metamorphosis of a sexually produced larva (Figure 1). New zooids bud from the ancestrula to produce colonies of definite shape and growth habit. In the phylactolaemates, the primitive zooids are cylindrical in form, and the budding pattern results in a branched colony. In more highly evolved phylactolaemates, colonies are compact, and discrete zooids can be recognized only with difficulty. New polypides, which originate by ingrowth of the superficial cell layer, or epithelium, remain suspended within a common colonial coelom, or body cavity.

Among living members of the primitive (and mainly fossil) marine stenolaemates, the long and slender zooids have calcified tubular skeletons. A larva metamorphoses into a hemispherical primary disk (or proancestrula). A cylindrical extension grows from the proancestrula, and the matrix of the colony then is built up by repeated divisions of the zooidal walls. Internal walls of the colony are called septa. The growth and budding zones of the colony are found at its outer edges. Cells from the surface epithelium push inward to produce the polypide, and the septa create a chamber around it. The walled portion of a zooid is called the cystid.

In the gymnolaemates, in which the zooids frequently are flattened, budding occurs as transverse septa form and cut off parts of the primary zooid (or any other parent zooid). As each bud enlarges to become a zooid, a polypide forms inside. In the order Cheilostomata, budding usually produces rows of identical zooids that radiate from the primary zooid. The rows divide periodically to keep pace with the increasing circumference of the colony. Successive zooids in a row are separated by transverse septa, but adjoining rows are separated by double walls. Interzooidal pores are present both in the walls and in the septa.

Reproduction. Mature gymnolaemate and phylactolaemate zooids are generally hermaphroditic (*i.e.,* both male and female reproductive organs in the same zooid); small gonads are attached in clusters to the membrane that lines the body wall or the polypide. In a few species the individual zooids are of one sex only. In these circumstances, female zooids are usually larger (*e.g.,* the cheilostome *Reptadeonella*), male zooids may be simpler (*e.g.,* the cheilostome *Hippoporidra*), or female and male reproductive zooids each may be distinguishable from ordinary feeding zooids (*e.g.,* the cheilostome *Celleporella*). Among living stenolaemates most zooids contain only testes (male gonads). The few female zooids enlarge to form spacious brood chambers, which are called gonozooids. During development, a young embryo squeezes off groups of cells that form secondary embryos; these in turn may form tertiary embryos. In this way, many larvae can develop in a single brood chamber.

Brood chambers

Among the phylactolaemates, the fertilized egg develops in an internal embryo sac; a larva, which already contains the first polypide, is formed there, then liberated. Phylactolaemates also produce statoblasts, which develop on the funiculus, a cord of tissue that links the stomach to the lining of the body wall. As it grows, each statoblast is surrounded by a hard protective case that may also include an air-filled float and slender, hooked spines. Statoblasts usually develop in late summer and are liberated as the colony disintegrates with the approach of winter. Statoblasts survive dry and freezing conditions and can initiate a new colony when favourable climatic conditions recur.

In gymnolaemates one oocyte at a time usually enlarges and bursts from the ovary into the coelom. The oocyte then is fertilized and transferred to a brood chamber. This may be an undifferentiated part of a zooid; usually among the cheilostomes, however, each reproducing zooid develops a special globular or hooded ooecium in which the embryo grows. In most cheilostomes the egg at transfer has sufficient yolk to nourish its developing embryo, but in the cheilostomes *Bugula* and *Celleporella* the egg, which is small at transfer, establishes a pseudoplacenta with tissues of the mother zooid and receives nourishment as the embryo develops. The ciliated larvae, spherical and often about ¼ millimetre in diameter, are liberated when fully developed and may swim first toward the light and thus away from the parent colony; later, however, the larvae avoid light as they seek a place in which to settle. Metamorphosis of larvae to adults occurs within a few hours after larvae are liberated.

In certain genera (*e.g., Membranipora*) of the class Gymnolaemata, each zooid produces many tiny eggs, which are fertilized by sperm from another zooid as they are shed directly into the sea. The fertilized eggs develop into triangular, bivalved larvae, known as cyphonautes, which for several weeks live among, and feed on, plankton. Larvae from brood chambers and cyphonautes settle in a similar way; *i.e.,* both locate a suitable surface and explore it with sensory cilia. Attachment is achieved by flattening a sticky holdfast, which pulls the larva down on top of it. As metamorphosis proceeds, larval organization degenerates, and the first polypide develops inside a primary zooid.

Ecology. *Freshwater bryozoans.* Freshwater bryozoans live mainly on leaves, stems, and tree roots in shallow water. Before drinking water was filtered, they regularly polluted water supply pipes. Though not uncommon, freshwater bryozoans are inconspicuous in pools, lakes, or gently flowing rivers, especially in slightly alkaline water.

Bryozoans along shores

Marine bryozoans. The most familiar marine bryozoans are those that inhabit shores, though they occur in greater numbers below tidemarks. Dredge hauls of stones and shells yield colonies in abundance. Colonies also occur on the ocean bed, even at great depths, but the frequently muddy bottom of the oceanic abyss is an unfavourable habitat. A few species tolerate hypersaline or brackish waters. The predominantly marine Gymnolaemata have a few freshwater representatives; *e.g., Paludicella.*

Shallow, sheltered channels that have currents but are protected from severe waves are typical bryozoan habitats. Open coastlines support fewer species, but noncalcareous species occur abundantly on intertidal algae in temperate waters. A familiar genus is the lacy gymnolaemate *Membranipora*, which is found throughout the world and is well adapted to living on kelp weeds at, and just below, the low-water mark. Although the zooid walls of *Membranipora* colonies are calcified, they contain flexible joints, which allow the colony to bend as the alga sways in the waves. *Membranipora,* which may cover large areas with a million or more zooids, always grows predominantly toward the youngest part of an algal frond. Overhangs, which form when soft rock erodes along a shoreline, as well as the shaded pilings of jetties and piers are other favoured bryozoan habitats. Since they do not require light and can grow in dark places, bryozoans can avoid competition from algae that could smother them. Sea slugs and sea spiders appear to be the principal predators of bryozoans.

Food and feeding. Bryozoans feed on minute planktonic particles that are captured by the tentacles (from eight to about 30), which, in marine species, spread as a funnel with the mouth at its vertex (Figure 2). The beating of long lateral cilia draws water into the top of the funnel and propels it out between the tentacles. Particles are projected toward the mouth, and those that would leave the funnel between the tentacles appear to be flicked back into it by a reversal of the ciliary beat. Shorter cilia on the inner face of the tentacles carry food particles toward the mouth without the involvement of mucus; from there they are sucked into the pharynx. Diatom shell valves are separated or broken in the gizzard, when present. Digestion and absorption occur in the stomach, and indigestible remains are compacted by rotation and expelled as fecal pellets. Freshwater bryozoans have more tentacles, which are disposed in a crescent shape, the ends of which project behind the mouth.

FORM AND FUNCTION

Zooids. Although zooid appearance and structure vary considerably from class to class, all conform to a basic

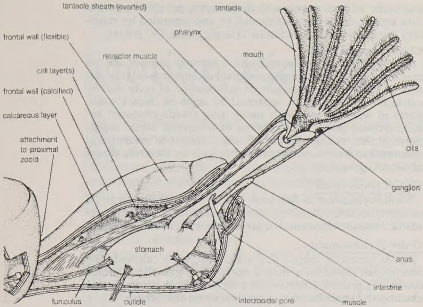


Figure 2: Characteristics of the bryozoan zooid with the lophophore protruded.

From *Treatise on Invertebrate Paleontology*, part G, Bryozoa revised, vol. 1, fig. 4, p. 8; courtesy of The Geological Society of America and University of Kansas

plan (Figure 2). Zooids are rarely longer than one millimetre; the most primitive are cylindrical, suggesting that the bryozoan ancestor was probably wormlike. The skeleton is external, ranging from a thin, cuticular cover to a thick, calcified layer. The tentacles, collectively termed the lophophore, are raised above the zooid on a slender extension of the body wall (the tentacle sheath, or introvert). When not spread for feeding, the tentacles are withdrawn into the coelom in a movement that involves the inrolling of the tentacle sheath as the mouth and tentacles are pulled down within by the action of paired retractor muscles. Eversion of the tentacle sheath and tentacles is effected by raising the hydrostatic pressure of the body fluid. Phylactolaemates have a muscular and contractile body wall for this purpose; in gymnolaemates the wall is nonmuscular but in whole or in part flexible, so that it can be pulled inward by the body musculature associated with it (parietal muscles). In most extant bryozoans the zooids are not cylindrical but flat, with rigid side walls. The upward-facing or frontal wall either remains flexible or has concealed below its calcified surface a membranous cavity, the ascus (sac), which can be inflated with seawater, thereby compressing the body fluid. At the free end of a cylindrical zooid or near the distal end of a flat zooid is an opening known as the orifice, through which the tentacle sheath and tentacles emerge; in cheilostome gymnolaemates the orifice has a closable lid, the operculum. Stenolaemate zooids are different, and the walls have the form of a slender calcareous tube, no part of which can be inflected to evert the tentacles; instead, body fluid is forced from one part of the zooid to another by muscles.

Digestive system

The digestive canal forms a deep loop; the pharynx descends to the stomach, the anterior part of which forms a gizzard in some genera, such as the gymnolaemate *Bowerbankia;* the rectum rises from the stomach, and the anus is situated just outside the lophophore. Respiratory, circulatory, and excretory systems are absent in bryozoans. The reproductive organs (ovary, testes) are sited on the lining of the body wall or on the funiculus, a cord of tissue that links the stomach to the lining of the body wall and distributes nutrients throughout the colony. The polypide degenerates periodically during the lifetime of a zooid, and a compact mass, called a brown body, frequently remains in its place. A new polypide soon differentiates from living cells of the cystid.

Zooid polymorphism exists among the cheilostome colonies, and the operculum seems to have been significant in the evolution of the specialized zooids of this order. The avicularium type of zooid has a small body and a rudimentary polypide; the operculum, however, is proportionally larger, has strong adductor (closing) muscles, and has become, in effect, a jaw. Avicularia are found among normal zooids but usually are smaller and attached to normal zooids, as in the gymnolaemate *Schizoporella.* In the gymnolaemate *Bugula* the avicularia are movable on short stalks and closely resemble miniature birds' heads—hence the name avicularium. Another specialized form of zooid is the vibraculum, in which the operculum has become a whiplike seta (*i.e.,* hairlike projection). The functions of avicularia and vibracula are not clearly known, but both types of zooids may help to keep the colony free from particles and epizoites (*i.e.,* organisms that attach to the surface of the colony but do not parasitize it).

Colonies. Despite their ill-defined shape, colonies, at least in extant bryozoans, are not just aggregations of zooids but whole organisms having an integrated physiology and behaviour that appear to be coordinated to some extent. The agency for integration is the system of interzooidal pores (Figure 2) and the cells that traverse them. Most conspicuous are those of the funiculus, which in gymnolaemates becomes a colonial network capable of distributing nutrients to nonfeeding areas, such as the growing edge. The nervous system of bryozoans consists of a small ganglion (brain) positioned between the mouth and the anus that supplies nerves to the zooidal organs. In some bryozoans there is also a colonial network that unites the zooids through the interzooidal pores. A stimulus that causes the lophophore to withdraw in a zooid of the gymnolaemate *Membranipora* almost instantaneously evokes the same response nearby, and nerve impulses can at that time be recorded. Nevertheless, to a large extent the colony is not individualistic; for example, it usually has no definite shape, can grow in any direction, and can be partially destroyed without harm to the rest. It may live a few months or a couple of years, or it may be theoretically immortal, its life of continual budding terminated only by some catastrophe.

EVOLUTION AND PALEONTOLOGY

The Bryozoa have a long history. From the Lower Ordovician (500,000,000 to 430,000,000 years ago) onward, most limestone formations, especially those with shale alternations, are rich in bryozoan fossils. The skeletons of calcified bryozoans are easily preserved. Stenolaemates are abundant fossils; after their appearance in the Upper Jurassic (140,000,000 years ago), cheilostome fossils also are abundant. The soft-bodied phylactolaemates, on the other hand, have left no fossil record, and fossilized ctenostomes are rare but long antedate the cheilostomes.

Oldest bryozoan fossil

The most ancient bryozoans are stenolaemates from the Lower Ordovician of the United States and Russia (Arenig series, about 488,000,000 years old); both cystoporate and trepostome stenolaemates have been found. The ceramoporoids, a group belonging to the order Cystoporata, flourished during the Ordovician and evidently were the progenitors of a more advanced group, the fistuliporoids, which were successful until the end of the Permian (280,000,000 to 225,000,000 years ago).

Dominant among the early Paleozoic (570,000,000 to 225,000,000 years ago) stenolaemates, however, was the order Trepostomata, which evolved rapidly during the Ordovician and attained its peak during the upper part of the same system. The long, slender zooids of trepostomes grew together to form large, solid colonies. As a zooid grew longer and longer, diaphragms (or transverse partitions) were deposited. The trepostomes declined in importance after the Ordovician, perhaps as a result of competition from the cryptostomes, and were extinct by the close of the Permian (225,000,000 years ago).

Cryptostomes evolved rapidly during the Ordovician. They were similar to the trepostomes but evolved freely erect, leaflike, branching or lacy colonies in the ptilodictyoids, or branching in rhabdomesoids, and were the dominant bryozoans from the start of the Devonian until the Permian (395,000,000 to 225,000,000 years ago). For reasons not yet clear, the cryptostomes dwindled and became extinct soon after the end of the Paleozoic Era (225,000,000 years ago).

The Cyclostomata arose in the Paleozoic, flourished during the Jurassic (190,000,000 to 136,000,000 years ago) and Lower Cretaceous, and still survive.

The ctenostomes (class Gymnolaemata) have left a sparse fossil record. During the Late Jurassic Period they appar-

ently gave rise to the complex and successful cheilostomes. The early cheilostomes had encrusting flat zooids similar to some of their contemporary ctenostomes, but with side walls that were calcified. This type of organization, termed anascan (meaning without an ascus), permitted inflexion of the front wall to evert the lophophore but seemed to offer little protection. The Ascophora (ascus bearers) evolved in the Late Cretaceous by calcifying the membranous front but preserving its hydrostatic function by a flexible infolding (ascus) below the wall. The parietal muscles attach to the ascus and pull its lower surface into the coelom to evert the lophophore, while the ascus itself fills with seawater.

CLASSIFICATION

Distinguishing taxonomic features. Although both colony type and zooid morphology are used to classify bryozoans, zooidal characters are more reliable. The cylindrical zooids are of rather uniform appearance in the stenolaemates, making classification difficult. Wall structure and the morphology of the embryo chambers are important taxonomic characters. In cheilostomes the skeletal features of the zooids, particularly the presence, extent, and structure of the frontal wall—together with shape of the orifice, type of ooecia, and zooid polymorphism—provide the most important distinguishing taxonomic criteria. Among ctenostomes and phylactolaemates, whose zooids lack skeletal features, colony form is more important. Statoblasts are of taxonomic value. Internal characters have been used less, but the presence or absence of a gizzard, number of tentacles, and colour of developing embryos are of taxonomic significance.

Annotated classification.

PHYLUM BRYOZOA

Sedentary, aquatic invertebrates; form colonies of zooids by budding; each zooid with circular or crescentic lophophore surrounding a mouth from which slender, ciliated tentacles arise; anterior part of body forms an introvert within which the lophophore can be withdrawn; alimentary canal deeply looped; anus opens near mouth but outside lophophore; excretory organs and a blood vascular system absent; each zooid secretes a rigid or gelatinous wall to support colony; over 4,000 extant species.

Class Phylactolaemata

Zooids basically cylindrical, with a crescentic lophophore and an epistome (hollow flap overhanging mouth); body wall noncalcareous, muscular, used for everting the lophophore; coelom continuous between zooids; new zooids arise by replication of polypides; special dormant buds (statoblasts) are produced; zooids monomorphic; exclusively freshwater; cosmopolitan; apparently primitive, but with no certain fossil record; about 12 genera.

Class Stenolaemata

Fossil except for some Cyclostomata; zooids cylindrical; body wall calcified, without muscle fibres; not used for everting the lophophore; zooids separated by septa; new zooids produced by division of septa; limited polymorphism; marine; Ordovician to present; about 550 genera.

Order Cyclostomata

Orifice of zooid circular; lophophore circular; no epistome; zooids interconnected by open pores; sexual reproduction involves polyembryony, usually in special reproductive zooids; all seas; Ordovician to present; about 250 genera.

Order Cystoporata

Zooid skeletons long and tubular, interconnected by pores and containing diaphragms (transverse partitions); cystopores (not pores but supporting structures between the zooid skeletons) present; Ordovician to Permian; about 80 genera.

Order Trepostomata

Colonies generally massive, composed of long tubular zooid skeletons with lamellate calcification; without interzooidal pores; orifices polygonal; sometimes with numerous diaphragms, zooid walls thin proximally, thicker distally; Ordovician to Permian; about 100 genera.

Order Cryptostomata

Colonies mostly with foliaceous or reticulate fronds or with branching stems; zooid skeletons tubular, shorter than in trepostomes; without pores; with diaphragms; proximal portions thin walled, distal portions funnellike and separated by extensive calcification; Ordovician to Triassic; about 130 genera.

Class Gymnolaemata

Zooids cylindrical or squat, with a circular lophophore; no epistome; body wall sometimes calcified; nonmuscular; eversion of lophophore dependent on deformation of body wall by extrinsic muscles; zooids separated by septa or duplex walls; pores in walls plugged with tissue; new zooids produced behind growing points by formation of transverse septa; zooids polymorphic; mainly marine; all seas; Jurassic to present, but presumed to have been established at least by the Ordovician; about 650 genera.

Order Ctenostomata

Zooids cylindrical to flat; walls not calcified; orifice terminal or nearly so, often closed by a pleated collar; no ooecia or avicularia; Jurassic to present, but presumed older; about 40 genera.

Order Cheilostomata

Zooids generally shaped like a flat box, walls calcified; orifice frontal, closed by a hinged operculum; specialized zooids commonly present; embryos often developing in ooecia (brood chambers); Upper Jurassic to present; about 600 genera.

Critical appraisal. Classification of bryozoans began in 1837 when the freshwater and marine Bryozoa were separated into the classes now known as Phylactolaemata and Gymnolaemata. Later a third class, the Stenolaemata, was separated from the Gymnolaemata. The cyclostomes and the fossil trepostomes were placed in the new class, which was acceptable to many paleontologists. In recent years, the cryptostomes have also been placed in the Stenolaemata. The most satisfactory system, therefore, separates the bryozoans into three classes, distinct since the beginning of the fossil record.

Most of the bryozoan orders were named many years ago. Cheilostomata, Ctenostomata, and Cyclostomata were named in 1852; Trepostomata was named in 1882; and Cryptostomata was named in 1883. In 1964 a Soviet bryozoologist introduced a new order, Cystoporata, which includes the Paleozoic ceramoporoids and fistuliporoids. Some authorities regard the phylum Entoprocta to be related to Bryozoa (it is sometimes classified as a subphylum of Bryozoa), but the evidence is conflicting and opinion divided.

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(J.S.R.)

Motion Pictures

A remarkably effective medium in conveying drama and especially in the evocation of emotion, motion pictures consist of the projection of luminous moving images onto a screen. The art of motion pictures is exceedingly complex, requiring contributions from nearly all of the other arts as well as countless technical skills. Nonetheless, probably no other art has proliferated as much in the 20th century nor can any other equal it in popularity or influence.

The motion picture is the newest of the generally recognized "fine arts." It is the product of photographic and technological developments that culminated by 1900 in practical devices for the recording of a moving image and its projection onto a flat surface. During its early development, the motion picture was discounted by many critics for its supposed subservience to commercial interests, for the immediacy of its appeal to the uninstructed, for its seemingly mechanical technique, and for its apparent lack of an identifiable artist as its primary creator. After the middle of the 20th century, however, increasing attention was devoted to it as a form of artistic endeavour that is as legitimate as the theatre, literature, dance, music, or the visual arts. (R.St.)

This article traces the historical development of the motion picture, the art of film, and film technology. Other articles in which specialized aspects of the subject are treated include SOUND; PHOTOGRAPHY; and OPTICS, PRINCIPLES OF.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, sections 623 and 735, and the *Index*.

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History

EARLY YEARS: 1830–1910

Persistence of vision and the phi phenomenon

Origins. The illusion of motion pictures is based on the optical phenomena known as persistence of vision and the phi phenomenon. The first of these causes the brain to retain images cast upon the retina of the eye for a fraction of a second beyond their disappearance from the field of sight, while the latter creates apparent movement between images when they succeed one another rapidly. Together, these phenomena permit the succession of still frames on a motion-picture film strip to represent continuous movement when projected at the proper speed (traditionally 16 frames per second for silent films and 24 frames per second for sound films). Before the invention of photography, a variety of optical toys exploited this effect by mounting successive phase drawings of things in motion on the face of a twirling disk (the phenakistoscope, *c.* 1832) or inside of a rotating drum (the zoetrope, *c.* 1834). Then, in 1839, Louis-Jacques-Mandé Daguerre, a French painter, perfected the positive photographic process known as daguerreotypy, and that same year the English scientist William Henry Fox Talbot successfully demonstrated a negative photographic process that theoretically allowed unlimited positive prints to be produced from each negative. As photography was innovated and refined over the next few decades, it became possible to replace the phase drawings in the early optical toys and devices with individually posed phase photographs, a practice that was widely and popularly carried out.

There would be no true motion pictures, however, until live action could be photographed spontaneously and simultaneously as it occurred. This required not only a reduction in exposure time from the hour or so necessary for the pioneer photographic processes to the one-hundredth (and, ultimately, one-thousandth) of a second achieved in 1870 but also the development of the technology of series photography by the British-American photographer Eadweard Muybridge between 1872 and 1877. During that time, Muybridge was employed by Governor Leland Stanford of California, a zealous racehorse breeder, to prove that at some point in its gallop a running horse lifts all four hooves off the ground at once. Conventions of 19th-century illustration suggested otherwise, and the

Series photography

movement itself occurred too rapidly for perception by the naked eye; so Muybridge experimented with multiple cameras to take successive photographs of horses in motion. Finally, in 1877, he set up a battery of 12 cameras along a Sacramento racecourse with wires stretched across the track to operate their shutters. As a horse strode down the track, its hooves tripped each shutter individually to expose a successive photograph of the gallop, confirming Stanford's belief. When Muybridge later mounted these images on a rotating disk and projected them on a screen through a magic lantern, they produced a "moving picture" of the horse at full gallop as it had actually occurred in life.

The French physiologist Étienne-Jules Marey took the first series photographs with a single instrument in 1882; once again, the impetus was the analysis of motion too rapid for perception by the human eye. Marey invented the chronophotographic gun, a camera shaped like a rifle that recorded 12 successive photographs per second, in order to study the movement of birds in flight. These images were imprinted on a rotating glass plate (later, paper roll film), and Marey subsequently attempted to project them. Like Muybridge, however, Marey was interested in deconstructing movement rather than synthesizing it, and he did not carry his experiments much beyond the realm of high-speed, or instantaneous, series photography. Muybridge and Marey, in fact, conducted their work in the spirit of scientific inquiry; they both extended and elaborated existing technologies in order to probe and analyze events that occurred beyond the threshold of human perception. Those who came after would return their discoveries to the realm of normal human vision and exploit them for profit.

In 1887 in Newark, N.J., an Episcopalian minister named Hannibal Goodwin first used celluloid roll film as a base for photographic emulsions, and within the year his idea had been appropriated by the industrialist George Eastman, who in 1888 began to mass-produce celluloid roll film for still photography at his plant in Rochester, N.Y. This event was crucial to the development of cinematography: series photography such as Marey's chronophotography could employ glass plates or paper strip film because it recorded events of short duration in a relatively small number of images, but cinematography would inevitably find its subjects in longer, more complicated events, requiring thousands of images and therefore just the kind of flexible but durable recording medium represented by celluloid. It remained for someone to combine the principles embodied in the apparatuses of Muybridge and Marey with celluloid strip film to arrive at a viable motion-picture camera—an innovation achieved by William Kennedy Laurie Dickson in the West Orange, N.J., laboratories of the Edison Company in 1888.

Edison and the Lumière brothers. Thomas Alva Edison invented the phonograph in 1877, and it had quickly become the most popular home entertainment device of the century. It was to provide a visual accompaniment to the phonograph that Edison commissioned Dickson, a young laboratory assistant, to invent a motion-picture camera in 1887. Dickson built upon the work of Muybridge and Marey, a fact that he readily acknowledged, but he was the first to combine the two final essentials of motion-picture camera and projection technology. These were a device, adapted from the escapement mechanism of a clock, to ensure the intermittent but regular motion of the film strip through the camera and a regularly perforated celluloid film strip to ensure precise synchronization between the film strip and the shutter. Dickson's camera was patented as the Kinetograph in 1893, and it initially imprinted up to 50 feet of celluloid film at the rate of about 40 frames per second.

The Kinetograph

Dickson was not the only person who had been tackling the problem of recording and reproducing moving images. Inventors throughout the world had been trying for years to devise working motion-picture machines. In fact, several European inventors, including the Frenchborn Louis Le Prince and the Englishman William Friese-Greene, applied for patents on various cameras, projectors, and camera-projector combinations contemporaneously or even before Edison and his associates did. These machines were unsuccessful for a number of reasons, however, and little evidence survives of their actual practicality or workability.

Because Edison had originally conceived of motion pictures as an adjunct to his phonograph, he did not commission the invention of a projector to accompany the Kinetograph. Rather, he had Dickson design a type of peep-show viewing device called the Kinetoscope in which a continuous 47-foot film loop ran on spools between an incandescent lamp and a shutter for individual viewing. Starting in 1894, Kinetoscopes were marketed commercially through the firm of Raff and Gammon for $250 to $300 apiece, and the Edison Company established its own Kinetograph studio (a single-room building called the "Black Maria" that rotated on tracks to follow the sun) in West Orange, N.J., to supply films for the Kinetoscopes that Raff and Gammon were installing in penny arcades, hotel lobbies, amusement parks, and other such semipublic places. In April of that year the first Kinetoscope parlour was opened in a converted storefront in New York City. The parlour charged 25 cents for admission to a bank of five machines.

The syndicate of Maguire and Baucus acquired the foreign rights to the Kinetoscope in 1894 and began to market the machines. Edison had declined to file for international patents on either his camera or his viewing device, and as a result the machines were widely and legally copied throughout Europe, where they were modified and improved far beyond the American originals. In fact, it was a Kinetoscope exhibition in Paris that inspired the Lumière brothers, Auguste and Louis, to invent the first commercially viable projector. Their *cinématographe*, which functioned as a camera and printer as well as a projector, ran at the economical speed of 16 frames per second. It was given its first commercial demonstration on Dec. 28, 1895.

Unlike the Kinetograph, which was battery-driven and weighed more than 1,000 pounds, the *cinématographe* was hand-cranked, lightweight (less than 20 pounds), and relatively portable. This naturally affected the kinds of films that were made with each machine: Edison films initially featured material such as circus or vaudeville acts that could be brought into a small studio and played out before an inert camera, while early Lumière films were mainly documentary views, or "actualities," shot outdoors on location. In both cases, however, the films themselves were composed of a single, unedited shot emphasizing lifelike movement; they contained little or no narrative content. (After a few years design changes in the machines made it possible for Edison and the Lumières to shoot the same

The *cinématographe*

By courtesy of the British Film Institute, London



An early series of photographs by Eadweard Muybridge (1887).

kinds of subjects.) In general, Lumière technology became the European standard during the early primitive era, and because the Lumières sent their cameramen all over the world in search of exotic subjects, the *cinématographe* became the founding instrument of such far-flung cinemas as the Russian, the Australian, and the Japanese. (It also, of course, is the source for the word cinema.)

In the United States, the Kinetoscope installation business had reached saturation point by the summer of 1895, although it was still quite profitable for Edison as a supplier of films. Raff and Gammon persuaded Edison to buy the rights to a state-of-the-art projector, developed by Thomas Armat of Washington, D.C., which incorporated a superior intermittent movement mechanism and a loop-forming device (known as the Latham loop, after its earliest promoters, Grey and Otway Latham) to reduce film breakage, and in early 1896 Edison began to manufacture and market this machine as his own invention. Given its first public demonstration on April 23, 1896, at Koster and Bial's Music Hall in New York City, the Edison Vitascope brought projection to the United States and established the format for American film exhibition for the next several years. It also encouraged the activities of such successful Edison rivals as the American Mutoscope and Biograph Company, which was formed in 1896 to exploit the Mutoscope peep-show device and the American Biograph camera and projector patented by W.K.L. Dickson in 1896. During this time, which has been characterized as the "novelty period," emphasis fell on the projection device itself, and films achieved their main popularity as self-contained vaudeville attractions. Vaudeville houses, among which there was intense competition at the turn of the century, headlined the name of the machines rather than the films (The Vitascope—Edison's Latest Marvel, The Amazing Cinématographe). The projectors came supplied from the producer, or manufacturer, with an operator and a program of shorts. These films, whether they were Edison-style theatrical variety shorts or Lumière-style actualities, were perceived by their original audiences not as motion pictures in the modern sense of the term but as "animated photographs" or "living pictures," emphasizing their continuity with more familiar media of the time.

The novelty period

During the novelty period, the film industry was autonomous and unitary, with production companies leasing a complete film service of projector, operator, and shorts to the vaudeville market as a single, self-contained act. Starting around 1897, however, manufacturers began to sell both projectors and films to itinerant exhibitors who traveled with their programs from one temporary location (vaudeville theatres, fairgrounds, circus tents, lyceums) to another as the novelty of their films wore off at a given site. This new mode of screening by circuit marked the first separation of exhibition from production and gave the exhibitors a large measure of control over early film form, since they were responsible for arranging the one-shot films purchased from the producers into audience-pleasing programs. The putting together of these programs—which often involved narration, sound effects, and music—was in effect a primitive form of editing, so that it is possible to regard the itinerant projectionists working between 1896 and 1904 as the earliest directors of motion pictures. Several of them, notably Edwin S. Porter, were, in fact, hired as directors by production companies after the industry had stabilized in the first decade of the 20th century.

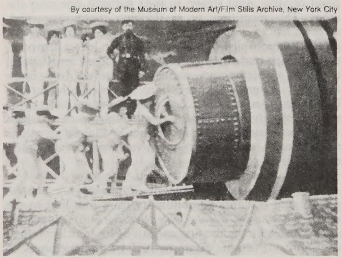
By encouraging the practice of peripatetic exhibition, the U.S. producers' policy of outright sales inhibited the development of permanent film theatres in the United States until nearly a decade after their appearance in Europe, where England and France had taken an early lead in both production and exhibition. Britain's first projector, the theatrograph (later, the animatograph), had been demonstrated in 1896 by the scientific instrument maker Robert W. Paul. In 1899 Paul formed his own production company for the manufacture of actualities and trick films, and until 1905 Paul's Animatograph Works, Ltd., was England's largest producer, turning out an average of 50 films per year. Between 1896 and 1898, two Brighton photographers, George Albert Smith and James Williamson, constructed their own motion-picture cameras and began producing trick films featuring superimpositions (*The Corsican Brothers,* 1897) and interpolated close-ups (*Grandma's Reading Glass,* 1900; *The Big Swallow,* 1901). Smith subsequently developed the first commercially successful photographic colour process (Kinemacolor, *c.* 1906–08, with Charles Urban), while Williamson experimented with parallel editing as early as 1900 (*Attack on a Chinese Mission Station*) and became a pioneer of the chase film (*Stop Thief!,* 1901; *Fire!,* 1901). Both Smith and Williamson had built studios at Brighton by 1902 and, with their associates, came to be known as members of the "Brighton school," although they did not represent a coherent movement. Another important early British filmmaker was Cecil Hepworth, whose *Rescued by Rover* (1905) is regarded by many historians as the most skillfully edited narrative produced before the Biograph shorts of D.W. Griffith.

Méliès and Porter. The shift in consciousness away from films as animated photographs to films as stories, or narratives, began to take place around the turn of the century and is most evident in the work of the French filmmaker Georges Méliès. Méliès was a professional magician who had become interested in the illusionist possibilities of the *cinématographe:* when the Lumières refused to sell him one, he bought an animatograph projector from Paul in 1896 and reversed its mechanical principles to design his own camera. The following year he organized the Star Film company and constructed a small glass-enclosed studio on the grounds of his house at Montreuil, where he produced, directed, photographed, and acted in more than 500 films between 1896 and 1913.

Méliès' "trick" films

Initially, Méliès used stop-motion photography (the camera and action are stopped while something is added to or removed from the scene, then filming and action are continued) to make one-shot "trick" films in which objects disappeared and reappeared, or transformed themselves into other objects entirely. These films were widely imitated by producers in England and the United States. Soon, however, Méliès began to experiment with brief multi-scene films, such as *L'Affaire Dreyfus* (*The Dreyfus Affair,* his first, 1899), which followed the logic of linear temporality to establish causal sequences and tell simple stories. By 1902 he had produced the influential 30-scene narrative *Le Voyage dans la lune (A Trip to the Moon).* Adapted from a novel by Jules Verne, it was nearly one reel in length (about 825 feet, or 14 minutes).

By courtesy of the Museum of Modern Art/Film Stills Archive, New York City



Le Voyage dans la lune (1902), directed by Georges Méliès.

The first film to achieve international distribution (mainly through piracy), *Le Voyage dans la lune* was an enormous popular success. It helped to make Star Film one of the world's largest producers (an American branch was opened in 1903) and to establish the fiction film as the cinema's mainstream product. In both respects Méliès dethroned the Lumières' cinema of actuality. Despite his innovations, Méliès' productions remained essentially filmed stage plays. He conceived them quite literally as successions of living pictures or, as he termed them, "artificially arranged scenes." From his earliest trick films through his last successful fantasy, *La Conquête du pole* ("The Conquest of the Pole," 1912), Méliès treated the frame of

the film as the proscenium arch of a theatre stage, never once moving his camera or changing its position within a scene. He ultimately lost his audience in the late 1910s to filmmakers with more sophisticated narrative techniques.

The origination of many such techniques is closely associated with the work of Edwin S. Porter, a free-lance projectionist and engineer who joined the Edison Company in 1900 as production head of its new skylight studio on East 21st Street in New York City. For the next few years, he served as director-cameraman for much of Edison's output, starting with simple one-shot films (*Kansas Saloon Smashers,* 1901) but progressing rapidly to trick films (*The Finish of Bridget McKeen,* 1901) and short multi-scene narratives based on political cartoons and contemporary events (*Sampson-Schley Controversy,* 1901; *Execution of Czolgosz, with Panorama of Auburn Prison,* 1901). Porter also filmed the extraordinary *Pan-American Exposition by Night* (1901), which used time-lapse photography to produce a circular panorama of the exposition's electrical illumination, and the 10-scene *Jack and the Beanstalk* (1902), a narrative that simulates the sequencing of lantern slides to achieve a logical, if elliptical, spatial continuity.

Continuity editing

It was probably Porter's experience as a projectionist at the Eden Musee theatre in 1898 that ultimately led him in the early 1900s to the practice of continuity editing. The process of selecting one-shot films and arranging them into a 15-minute program for screen presentation was very much like that of constructing a single film out of a series of separate shots. Porter, by his own admission, was also influenced by other filmmakers—especially Méliès, whose *Le Voyage dans la lune* he came to know well in the process of duplicating it for illegal distribution by Edison in October 1902. Years later, Porter claimed that the Méliès film had given him the notion of "telling a story in continuity form," which resulted in *The Life of an American Fireman* (about 400 feet, or six minutes, produced in late 1902 and released in January 1903). This film, which was also influenced by James Williamson's *Fire!,* combined archival footage with staged scenes to create a nine-shot narrative of a dramatic rescue from a burning building. It was for years the subject of controversy because in a later version the last two scenes were intercut, or crosscut, into a 14-shot parallel sequence. It is now generally believed that in the earliest version of the film these scenes, which repeat the same rescue operation from an interior and exterior point of view, were shown in their entirety, one after the other. This repetition, or overlapping continuity, which owes much to magic lantern shows, clearly defines the spatial relationships between scenes but leaves temporal relationships underdeveloped and, to modern sensibilities, confused. Contemporary audiences, however, were conditioned by lantern slide projections and even comic strips; they understood a sequence of motion-picture shots to be a series of individual moving photographs, each of which was self-contained within its frame. Spatial relationships were clear in such earlier narrative forms because their only medium was space.

Motion pictures, however, exist in time as well as space, and the major problem for early filmmakers was the establishment of temporal continuity from one shot to the next. Porter's *The Great Train Robbery* (1903) is widely acknowledged to be the first narrative film to achieve such continuity of action. Comprised of 14 separate shots of noncontinuous, nonoverlapping action, the film contains an early example of parallel editing, two credible back, or rear, projections (the projection from the rear of previously filmed action or scenery onto a translucent screen to provide the background for new action filmed in front of the screen), two camera pans, and several shots composed diagonally and staged in depth—a major departure from the frontally composed, theatrical staging of Méliès.

The Great Train Robbery

The industry's first spectacular box-office success, *The Great Train Robbery* is credited with establishing the realistic narrative, as opposed to Méliès-style fantasy, as the commercial cinema's dominant form. The film's popularity encouraged investors and led to the establishment of the first permanent film theatres, or nickelodeons, across the country. Running about 12 minutes, it also helped to



The Great Train Robbery (1903), directed by Edwin S. Porter.
By courtesy of the Museum of Modern Art/Film Stills Archive, New York City

boost standard film length toward one reel, or 1,000 feet (about 16 minutes at the average silent speed). Despite the film's success, Porter continued to practice overlapping action in such conventional narratives as *Uncle Tom's Cabin* (1903) and the social-justice dramas *The Ex-Convict* (1904) and *The Kleptomaniac* (1905). He experimented with model animation in *Dream of a Rarebit Fiend* (1906) and *The Teddy Bears* (1907) but lost interest in the creative aspects of filmmaking as the process became increasingly industrialized. He left Edison in 1909 to pursue a career as a producer and equipment manufacturer. Porter, like Méliès, could not adapt to the linear narrative modes and assembly-line production systems that were developing.

Industrialization of European cinema

Early growth of the film industry. Méliès' decline was assisted by the industrialization of the French and, for a time, the entire European cinema by the Pathé Frères company, founded in 1896 by the former phonograph importer Charles Pathé. Financed by some of France's largest corporations, Pathé acquired the Lumière patents in 1902 and commissioned the design of an improved studio camera that soon dominated the market on both sides of the Atlantic (it has been estimated that, before 1918, 60 percent of all films were shot with a Pathé). Pathé also manufactured his own film stock and in 1902 established a vast production facility at Vincennes where films were turned out on an assembly-line basis under the managing direction of Ferdinand Zecca. The following year, Pathé began to open foreign sales agencies, which would soon become full-blown production companies—Hispano Film (1906), Pathé-Rouss, Moscow (1907), Film d'Arte Italiano (1909), Pathé-Britannia, London (1909), and Pathé-America (1910). He acquired permanent exhibition sites, building the world's first luxury cinema (the Omnia-Pathé) in Paris in 1906. In 1911 Pathé became Méliès' distributor and helped to drive Star Film out of business.

Pathé's only serious rival on the Continent at this time was Gaumont Pictures, founded by the engineer-inventor Léon Gaumont in 1895. Though never more than a quarter the size of Pathé, Gaumont followed the same pattern of expansion, manufacturing its own equipment and mass-producing films under a supervising director (through 1906, Alice Guy, the cinema's first woman director; afterward, Louis Feuillade). Like Pathé, Gaumont opened foreign offices and acquired theatre chains. From 1905 to 1914 its studios at La Villette, Fr., were the largest in the world. Pathé and Gaumont dominated pre-World War I motion-picture production, exhibition, and sales in Europe, and they effectively brought to an end the artisanal mode of filmmaking practiced by Méliès and his British contemporaries.

The formation of film exchanges

In the United States a similar pattern was emerging through the formation of film exchanges and the consolidation of an industry-wide monopoly based on the pooling of patent rights. Around 1897 producers had adopted the practice of selling prints outright, which had the effect of promoting itinerant exhibition and discriminating against the owners of permanent sites. In 1903, in response to the needs of theatre owners, Harry J. and Herbert Miles

opened a film exchange in San Francisco. The exchange functioned as a broker between producers and exhibitors, buying prints from the former and leasing them to the latter for 25 percent of the purchase price (in subsequent practice, rental fees were calculated on individual production costs and box-office receipts). The exchange system of distribution quickly caught on because it profited nearly everyone: the new middlemen made fortunes by collecting multiple revenues on the same prints; exhibitors were able to reduce their overheads and vary their programs without financial risk; and, ultimately, producers experienced a tremendous surge in demand for their product as exhibition and distribution boomed nationwide. (Between November 1906 and March 1907, for example, producers increased their weekly output from 10,000 to 28,000 feet and still could not meet demand.)

The most immediate effect of the rapid rise of the distribution sector was the nickelodeon boom, the exponential growth of permanent film theatres in the United States from a mere handful in 1904 to between 8,000 and 10,000 by 1908. Named for the Nickelodeon (ersatz Greek for "nickel theatre"), which opened in Pittsburgh in 1905, these theatres were makeshift facilities lodged in converted storefronts. They showed approximately an hour's worth of films for an admission price of five to 10 cents. Originally identified with working-class audiences, nickelodeons appealed increasingly to the middle class as the decade wore on, and they became associated with the rising popularity of the story film. Their spread also forced the standardization of film length at one reel, or 1,000 feet, to facilitate high-efficiency production and the trading of products within the industry.

By 1908 there were about 20 motion-picture production companies operating in the United States. They were constantly at war with one another over business practices and patent rights, and they had begun to fear that their fragmentation would cause them to lose control of the industry to the two new sectors of distribution and exhibition. The most powerful among them—Edison, Biograph, Vitagraph, Essanay, Kalem, Selig Polyscope, Lubin, the American branches of the French Star Film and Pathé Frères, and Kleine Optical, the largest domestic distributor of foreign films—therefore entered into a collusive trade agreement to ensure their continued dominance. On Sept. 9, 1908, these companies formed the Motion Picture Patents Company (MPPC), pooling the 16 most significant U.S. patents for motion-picture technology and entering into an exclusive contract with the Eastman Kodak Company for the supply of raw film stock.

The Motion Picture Patents Company

The MPPC, also known as the "Trust," sought to control every segment of the industry and therefore set up a system to issue licenses and assess royalties therefrom. The use of its patents was granted only to licensed equipment manufacturers; film stock could be sold only to licensed producers; licensed producers and importers were required to fix rental prices at a minimum level and to set quotas for foreign footage to reduce competition; Patents Company films could be sold only to licensed distributors, who could lease them only to licensed exhibitors; and only licensed exhibitors had the right to use Patents Company projectors and rent company films. To further ensure their control, in 1910—the same year in which motion-picture attendance in the United States rose to 26,000,000 persons a week—the MPPC formed the General Film Company, which integrated the licensed distributors into a single corporate entity. Although it was clearly monopolistic in practice and intent, the MPPC helped to stabilize the American film industry during a period of unprecedented growth and change by standardizing exhibition practice, increasing the efficiency of distribution, and regularizing pricing in all three sectors. Its collusive nature, however, provoked a reaction that ultimately destroyed it.

In a sense, the MPPC's iron-clad efforts to eliminate competition merely fostered it. Almost from the outset there was widespread resistance to the Patents Company on the part of independent distributors (numbering 10 or more in early 1909) and exhibitors (estimated at 2,000 to 2,500); and in January 1909 they formed their own trade association, the Independent Film Protective Association—reorganized that fall as the National Independent Moving Picture Alliance—to provide financial and legal support against the Trust. A more effective and powerful anti-Trust organization was the Motion Picture Distributing and Sales Company, which began operation in May 1910 (three weeks after the inception of General Film) and which eventually came to serve 47 exchanges in 27 cities. For nearly two years, independents were able to present a united front through the Sales Company, which finally split into two rival camps in the spring of 1912 (the Mutual Film Corporation and the Universal Film Manufacturing Company).

By imitating Patents Company practices of joining forces and licensing, the early independents were able to compete effectively against the Trust in its first three years of operation, netting about 40 percent of all American film business. In fact, their product, the one-reel short, and their mode of operation were initially fundamentally the same as the MPPC's. The independents later revolutionized the industry, however, by adopting the multiple-reel film as their basic product, a move that caused the MPPC to embrace the one-reeler with a vengeance, hastening its own demise.

THE SILENT FEATURE: 1910–27

Introduction of the feature film

Pre-World War I U.S. cinema. Multiple-reel films had appeared in the United States as early as 1907, when Adolph Zukor distributed Pathé's three-reel *Passion Play;* but when Vitagraph produced the five-reel *The Life of Moses* in 1909, the Patents Company forced it to be released in serial fashion at the rate of one reel a week. The multiple-reel film—which came to be called a "feature," in the vaudevillian sense of a headline attraction—achieved general acceptance with the smashing success of Louis Mercanton's three-and-one-half-reel *Les Amours de la Reine Elizabeth* (*Queen Elizabeth,* 1912), which starred Sarah Bernhardt and was imported by Adolph Zukor (who founded the independent Famous Players production company with its profits). In 1912 Enrico Guazzoni's nine-reel Italian super-spectacle *Quo Vadis?* was road-shown in legitimate theatres across the nation at a top admission price of one dollar, and the feature craze was on.

At first, there were difficulties in distributing features, because the exchanges associated with both the Patents Company and the independents were geared toward cheaply made one-reel shorts. Owing to their more elaborate production values, features had relatively higher negative costs. This was a disadvantage to distributors, who charged a uniform price per foot. By 1914, however, several national feature-distribution alliances that correlated pricing with a film's negative cost and box-office receipts were organized. These new exchanges demonstrated the economic advantage of multiple-reel films over shorts. Exhibitors quickly learned that features could command higher admission prices and longer runs; single title packages were also cheaper and easier to advertise than programs of multiple titles. As for manufacturing, producers found that the higher expenditure for features was readily amortized by high volume sales to distributors, who in turn were eager to share in the higher admission returns from the theatres. The whole industry soon reorganized itself around the economics of the multiple-reel film, and the effects of this restructuring did much to give motion pictures their characteristic modern form.

Feature films, for example, made motion pictures respectable for the middle class by providing a format that was analogous to that of the legitimate theatre and was suitable for the adaptation of middle-class novels and plays. This new audience had more demanding standards than the older lower-class one, and producers readily increased their budgets to provide high technical quality and elaborate productions. The new viewers also had a more refined sense of comfort, which exhibitors quickly accommodated by replacing their storefronts with large, elegantly appointed new theatres in the major urban centres (one of the first was Mitchell L. Marks's 3,300-seat Strand, which opened in the Broadway district of Manhattan in 1914). Known as "dream palaces" because of the fantastic luxuriance of their interiors, these houses had to show features

End of the nickelodeon era

rather than a program of shorts to attract large audiences at premium prices. By 1916 there were more than 21,000 movie palaces in the United States. Their advent marked the end of the nickelodeon era and foretold the rise of the Hollywood studio system, which dominated urban exhibition from the 1920s to the 1950s. Before the new studio-based monopoly could be established, however, the patents-based monopoly of the MPPC had to expire, and this it did as a result of its own basic assumptions in about 1914.

As conceived by Edison, the basic operating principle of the Trust was to control the industry through patents pooling and licensing, an idea logical enough in theory but difficult to practice in the context of a dynamically changing marketplace. Specifically, the Trust's failure to anticipate the independents' widespread and aggressive resistance to its policies cost it a fortune in patent-infringement litigation. Furthermore, the Trust badly underestimated the importance of the feature film, permitting the independents to claim this popular new product as entirely their own. Another issue that the MPPC misjudged was the power of the marketing strategy known as the "star system." Borrowed from the theatre industry, this system involves the creation and management of publicity about key performers, or stars, to stimulate demand for their films. Trust company producers used this kind of publicity after 1910, when Carl Laemmle of Independent Motion Pictures (IMP) promoted Florence Lawrence into national stardom through a series of media stunts in St. Louis, Mo., but they never exploited the technique as forcefully or as imaginatively as the independents. Finally, and most decisively, in August 1912 the U.S. Justice Department brought suit against the MPPC for "restraint of trade" in violation of the Sherman Antitrust Act. Delayed by countersuits and by World War I, the government's case was finally won and the MPPC formally dissolved in 1918, although it had been functionally inoperative since 1914.

The rise and fall of the Patents Company was concurrent with the industry's move to southern California. As a result of the nickelodeon boom, exhibitors had begun to require as many as 20 to 30 new films per week, and it became necessary to put production on a systematic year-round schedule. Because most films were still shot outdoors in available light, such schedules could not be maintained in the vicinity of New York City or Chicago, where the industry had originally located itself in order to take advantage of trained theatrical labour pools. As early as 1907, production companies, such as Selig Polyscope, began to dispatch production units to warmer climates during winter. It was soon clear that what producers required was a new industrial centre—one with warm weather, a temperate climate, a variety of scenery, and other qualities (such as access to acting talent) essential to their highly unconventional form of manufacturing.

Hollywood

Various companies experimented with location shooting in Jacksonville, Fla., in San Antonio, Texas, in Santa Fe, N.M., and even in Cuba, but the ultimate site of the American film industry was a Los Angeles suburb (originally a small industrial town) called Hollywood. It is generally thought that Hollywood's distance from the MPPC's headquarters in New York City made it attractive to the independents, but Patents Company members such as Selig, Kalem, Biograph, and Essanay had also established facilities there by 1911 in response to a number of the region's attractions. These included the temperate climate required for year-round production (the U.S. Weather Bureau estimated that an average of 320 days per year were sunny and/or clear); a wide range of topography within a 50-mile radius of Hollywood, including mountains, valleys, forests, lakes, islands, seacoast, and desert; the status of Los Angeles as a professional theatrical centre; the existence of a low tax base; and the presence of cheap and plentiful labour and land. This latter factor enabled the newly arrived production companies to buy up tens of thousands of acres of prime real estate on which to locate their studios, standing sets, and backlots.

By 1915 approximately 15,000 workers were employed by the motion-picture industry in Hollywood, and more than 60 percent of American production was centred there. In that same year, the trade journal *Variety* reported that capital investment in American motion pictures—the business of artisanal craftsmen and fairground operators only a decade before—had exceeded $500,000,000. The most powerful companies in the new film capital were the independents, who were flush with cash from their conversion to feature production. These included the Famous Players-Lasky Corporation (later Paramount Pictures, *c.* 1927), which was formed by a merger of Adolph Zukor's Famous Players Company, Jesse L. Lasky's Feature Play Company, and the Paramount distribution exchange in 1916; Universal Pictures, founded by Carl Laemmle in 1912 by merging IMP with Powers, Rex, Nestor, Champion, and Bison; Goldwyn Picture Corporation, founded in 1916 by Samuel Goldfish (later Goldwyn) and Edgar Selwyn; Metro Picture Corporation and Louis B. Mayer Pictures, founded by Louis B. Mayer in 1915 and 1917, respectively; and the Fox Film Corporation (later 20th Century-Fox, 1935), founded by William Fox in 1915. After World War I, these companies were joined by Loew's, Inc. (parent corporation of MGM, by merger of Metro, Goldwyn, and Mayer companies cited above, 1924), a national exhibition chain organized by Marcus Loew and Nicholas Schenck in 1919; First National Pictures, Inc., a circuit of independent exhibitors who established their own production facilities at Burbank, Calif., in 1922; Warner Bros. Pictures, Inc., founded by Harry, Albert, Samuel, and Jack Warner in 1923; and Columbia Pictures, Inc., incorporated in 1924 by Harry and Jack Cohn.

These organizations became the backbone of the Hollywood studio system, and the men who controlled them shared several important traits. They were all independent exhibitors and distributors who had outwitted the Trust and earned their success by manipulating finances in the post-nickelodeon feature boom, merging production companies, organizing national distribution networks, and ultimately acquiring vast theatre chains. They saw their business as basically a retailing operation modeled on the practice of chain stores such as Woolworth's and Sears. Not incidentally, these men were all first- or second-generation Jewish immigrants from eastern Europe, most of them with little formal education, while the audience they served was 90 percent Protestant and Catholic. This circumstance would become an issue during the 1920s, when the movies became a mass medium that was part of the life of every American citizen and when Hollywood became the chief purveyor of American culture to the world.

Pre-World War I European cinema. Before World War I European cinema was dominated by France and Italy. At Pathé Frères, director-general Ferdinand Zecca perfected the *course comique*, a uniquely Gallic version of the chase film, which inspired Mack Sennett's Keystone Kops, while the immensely popular Max Linder created a comic persona that would deeply influence the work of Charlie Chaplin. The episodic crime film was pioneered by Victorin Jasset in the "Nick Carter" series, produced for the small Éclair Company, but it remained for Gaumont's Louis Feuillade to bring the genre to aesthetic perfection in the extremely successful serials *Fantômas* (1913–14), *Les Vampires* (1915–16), and *Judex* (1916).

French *film d'art* movement

Another influential phenomenon to appear from prewar France was the *film d'art* movement. It began with *L'Assassinat du duc de Guise* (1908), directed by Charles Le Bargy and André Calmettes of the Comédie Française for the Société Film d'Art, which was formed for the express purpose of transferring prestigious stage plays starring famous performers to the screen. *L'Assassinat's* success inspired other companies to make similar films, which came to be known as *films d'art*. These films were long on intellectual pedigree and short on narrative sophistication. The directors simply filmed theatrical productions in toto, without adaptation. Their brief popularity nevertheless created a context for the lengthy treatment of serious material in motion pictures and was directly instrumental in the rise of the feature.

Italian super-spectacles

No country, however, was more responsible for the popularity of the feature than Italy. The Italian cinema's lavishly produced costume spectacles brought it international prominence in the years before the war. The prototypes of

the genre, by virtue of their epic material and lengths, were the Cines company's six-reel *Gli ultimi giorni di Pompei* (*The Last Days of Pompei*), directed by Luigi Maggi in 1908, and its 10-reel remake, directed by Ernesto Pasquali in 1913; but it was Cines' nine-reel *Quo vadis?* (1912), with its huge three-dimensional sets of ancient Rome and 5,000 extras, that established the standard for the superspectacle and briefly conquered the world market for Italian motion pictures. Its successor, the Italia company's 12-reel *Cabiria* (1914), was even more extravagant in its historical reconstruction of the Second Punic War, from the burning of the Roman fleet at Syracuse to Hannibal crossing the Alps and the sack of Carthage. The Italian superspectacle stimulated public demand for features and influenced such important directors as Cecil B. deMille, Ernst Lubitsch, and especially D.W. Griffith.

Griffith. There has been a tendency in modern film scholarship to view motion-picture narrative form as being governed by the operations of an overall production system. Although narrative film was and continues to be strongly influenced by a combination of economic, technological, and social factors, it also owes a great deal to the individual artists who viewed film as a medium of personal expression. Chief among these innovators was D.W. (David Wark) Griffith. It is true that Griffith's self-cultivated reputation as a Romantic artist—"the father of film technique," "the man who invented Hollywood," "the Shakespeare of the screen," and the like—is somewhat overblown. It is also true that by 1908 film narrative had already been systematically organized to accommodate the material conditions of production. Griffith's work nevertheless transformed that system from its primitive to its classical mode. He was the first filmmaker to realize that the motion-picture medium, properly vested with technical vitality and seriousness of theme, could exercise enormous persuasive power over an audience, or even a nation, without recourse to print or human speech.

Griffith began his film career in late 1907 as an actor. He was cast as the lead in the Edison Company's *Rescued from an Eagle's Nest* (1907) and also appeared in many Biograph films. He had already attempted to make a living as a stage actor and a playwright without much success, and his real goal in approaching the film companies seems to have been to sell them scripts. In June 1908 Biograph gave him an opportunity to replace its ailing director, George "Old Man" McCutcheon, on the chase film *The Adventures of Dollie.* With the advice of the company's two cameramen, G.W. "Billy" Bitzer (who would become Griffith's personal cinematographer for much of his career) and Arthur Marvin (who actually shot the film), Griffith turned in a fresh and exciting film. His work earned him a full-time director's contract at Biograph, where, over the next five years, he directed more than 450 one- and two-reel films.

In the Biograph films, Griffith experimented with all of the narrative techniques he would later use in the epics *The Birth of a Nation* (1915) and *Intolerance* (1916)—techniques that helped to formulate and stabilize Hollywood's classical narrative style. A few of these techniques were already in use when Griffith started; he simply refined them. Others were innovations Griffith devised to solve practical problems in the course of production. Still others resulted from his conscious analogy between film and literary narrative, chiefly Victorian novels and plays. In all cases, however, Griffith brought to the practice of filmmaking a seriousness of purpose and an intensity of vision, which, combined with his intuitive mastery of film technique, made him the first great artist of the cinema.

Griffith's innovations in editing

Griffith's first experiments were in the field of editing and involved varying the standard distance between the audience and the screen. In *Greaser's Gauntlet,* made one month after *Dollie,* he first used a "cut-in" from a long shot to a full shot to heighten the emotional intensity of a scene. In an elaboration of this practice, he was soon taking shots from multiple camera set-ups—long shots, full shots, medium shots, close shots, and, ultimately, close-ups—and combining their separate perspectives into single dramatic scenes. By October 1908, Griffith was practicing parallel editing between the dual narratives of *After Many Years,* and the following year he extended the technique to the representation of three simultaneous actions in *Lonely Villa,* cutting rapidly back and forth from a band of robbers breaking into a suburban villa, to a woman and her children barricaded within, to the husband rushing from town to the rescue. This type of crosscutting or intercutting came to be known as the "Griffith last-minute rescue" and was employed as a basic structural principle in both *The Birth of a Nation* and *Intolerance.* It not only employed the rapid alternation of shots but also called for the shots themselves to be held for shorter and shorter durations as the parallel lines of action converged; in its ability to create the illusion of simultaneous actions, the intercut chase sequence prefigured Soviet theories of montage by at least a decade, and it remains a basic component of narrative film form to this day.

Griffith's use of camera movement and placement

Another area of experiment for Griffith involved camera movement and placement, most of which had been purely functional before him. When Biograph started sending his production unit to southern California in 1910, Griffith began to practice panoramic panning shots not only to provide visual information but also to engage his audience in the total environment of his films. Later, he would prominently employ the tracking, or traveling, shot, in which the camera—and therefore the audience—participates in the dramatic action by moving with it. In California, Griffith discovered that camera angle could be used to comment upon the content of a shot or to heighten its dramatic emphasis in a way that the conventionally mandated head-on medium shot could not; and, at a time when convention dictated the flat and uniform illumination of every element in a scene, he pioneered the use of expressive lighting to create mood and atmosphere. Like so many of the other devices he brought into general use, these had all been employed by earlier directors, but Griffith was the first to practice them with the care of an artist and to rationalize them within the overall structure of his films.

Griffith's one-reelers grew increasingly complex between 1911 and 1912, and he began to realize that only a longer and more expansive format could contain his vision. At first he made such two-reel films as *Enoch Arden* (1911), *Man's Genesis* (1912), *The Massacre* (1912), and *The Mothering Heart* (1913), but these went virtually unnoticed by a public enthralled with such recent features from Europe as *Queen Elizabeth* and *Quo Vadis?.* Finally, Griffith determined to make an epic himself, based on the story of Judith and Holofernes from the Apocrypha. The result was the four-reel *Judith of Bethulia* (1913), filmed secretly on a 12-square-mile set in Chatsworth Park, Calif. In addition to its structurally complicated narrative, *Judith* contained massive sets and battle scenes unlike anything yet attempted in American film. It cost twice the amount Biograph had allocated for its budget. Company officials, stunned at Griffith's audacity and extravagance, tried to relieve the director of his creative responsibilities by promoting him to studio production chief. Griffith quit instead, publishing a full-page advertisement in *The New York Dramatic Mirror* (Dec. 3, 1913), in which he took credit for all of the Biograph films he had made from *The Adventures of Dollie* through *Judith,* as well as for the narrative innovations they contained. He then accepted an offer from Harry E. Aitken, the president of the recently formed Mutual Film Corporation, to head the feature production company Reliance-Majestic; he took Bitzer and most of his Biograph stock company with him.

Griffith's departure from Biograph

As part of his new contract, Griffith was allowed to make two independent features per year, and for his first project he chose to adapt *The Clansman,* a novel about the Civil War and Reconstruction by the Southern clergyman Thomas Dixon, Jr. (As a Kentuckian whose father had served as a Confederate officer, Griffith was deeply sympathetic to the material, which was highly sensational in its depiction of Reconstruction as a period in which mulatto carpetbaggers and their black henchmen had destroyed the social fabric of the South and given birth to a heroic Ku Klux Klan.) Shooting on the film began in secrecy in late 1914. Although a script existed, Griffith kept most of the continuity in his head—a remarkable feat considering

that the completed film contained 1,544 separate shots at a time when the most elaborate of foreign spectacles boasted fewer than 100. When the film opened in March 1915, retitled *The Birth of a Nation,* it was immediately pronounced "epoch-making" and recognized as a remarkable artistic achievement. The complexity of its narrative and the epic sweep of its subject were unprecedented, but so too were its controversial manipulations of audience response, especially its blatant appeals to racism. Despite its brilliantly conceived battle sequences, its tender domestic scenes, and its dignified historical reconstructions, the film also contained shocking images of miscegenation and racial violence that provoked fear and disgust. As the film's popularity swept the nation, denunciations followed, and many who had originally praised it, such as President Woodrow Wilson, were forced to recant. Ultimately, after screenings of *The Birth of a Nation* had caused riots in several cities, it was banned in eight northern and midwestern states. (First Amendment protection was not extended to motion pictures in the United States until the late 1950s.) Such measures, however, did not prevent *The Birth of a Nation* from becoming the single most popular film in history to date; it achieved national distribution in the year of its release and was seen by nearly 3,000,000 people.

The Birth of a Nation

Although it is difficult to believe that the film's racism was unconscious, as some have claimed, it is easy to imagine that Griffith had not anticipated the power of his own images. He seems to have been genuinely stunned by the hostile public reaction to his masterpiece, and he fought back by publishing a pamphlet entitled *The Rise and Fall of Free Speech in America* (1915), which vilified the practice of censorship and especially intolerance. At the height of his notoriety and fame, Griffith decided to produce a spectacular cinematic polemic against this flaw in human character as it had endangered civilization throughout history. The result was the massive epic *Intolerance* (1916), which interweaves stories of martyrdom from four separate historical periods. The film was conceived on a scale so monumental as to dwarf all predecessors. Crosscutting freely between a contemporary tale of courtroom injustice, the fall of ancient Babylon to Cyrus the Great in 539 BC, the St. Bartholomew's Day Massacre in 16th-century France, and the Crucifixion of Christ, Griffith created an editing structure so abstract that contemporary audiences could not understand it. Even the extravagant sets and exciting battle sequences could not save *Intolerance* at the box-office. To reduce his losses, Griffith withdrew the film from distribution after 22 weeks; he subsequently cut into the negative and released the modern and the Babylonian stories as two separate features, *The Mother and the Law* and *The Fall of Babylon,* in 1919. (Although ignored by Americans, *Intolerance* was both popular and vastly influential in the Soviet Union, where filmmakers minutely analyzed Griffith's editing style and techniques.)

Intolerance

It would be fair to say that Griffith's career as an innovator of film form ended with *Intolerance,* but his career as a film artist certainly did not. He went on to direct another 26 features between 1916 and 1931, chief among them the World War I anti-German propaganda epic (financed, in part, by the British government) *Hearts of the World* (1918), the subtle and lyrical *Broken Blossoms* (1919), and the rousing melodrama *Way Down East* (1920). The financial success of the latter made it possible for Griffith to establish his own studio at Mamaroneck, N.Y., where he produced the epics *Orphans of the Storm* (1921) and *America* (1924), which focused on the French and American revolutions, respectively; both lost money. Griffith's next feature was the independent semidocumentary *Isn't Life Wonderful?* (1925), which was shot on location in Germany and is thought to have influenced both the "street" films of the German director G.W. Pabst and the post-World War II Italian Neorealist movement.

Griffith's last films, with the exception of *The Struggle* (1931), were all made for other producers. Not one could be called a success, although his first sound film, *Abraham Lincoln* (1930), was recognized as an effective essay in the new medium. The critical and financial failure of *The Struggle,* however, a version of Zola's *L'Assommoir* (*The Drunkard*), forced Griffith to retire.

It might be said of Griffith that, like Méliès and Porter, he outlived his genius, but that is not true. Griffith was fundamentally a 19th-century man who became one of the 20th-century's greatest artists. Transcending personal defects of vision, judgment, and taste, he developed the narrative language of film. He lost touch with his contemporaries because his subjects came to seem old-fashioned, but he remains peculiarly, uniquely in touch with the present because the techniques and structure he contributed to the motion-picture medium are still in use.

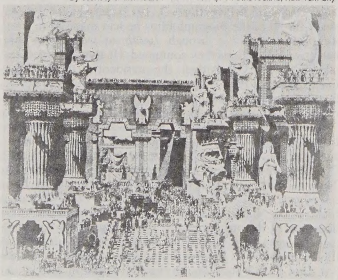
Post-World War I European cinema. Prior to World War I, the American cinema had lagged behind the film industries of Europe, particularly those of France and Italy, in such matters as feature production and the establishment of permanent theatres. During the war, however, European film production virtually ceased, in part because the same chemicals used in the production of celluloid were necessary for the manufacture of gun powder. The American cinema, meanwhile, experienced a period of unprecedented prosperity and growth. By the end of the war it exercised nearly total control of the international market: when the Treaty of Versailles was signed in 1919, 90 percent of all films screened in Europe, Africa, and Asia were American, and the figure for South America was (and remained through the 1950s) close to 100 percent. The main exception was Germany, which had been cut off from American films from 1914 until the end of the war.

Germany. Before World War I, the German motion-picture audience was largely uneducated and unemployed or from the working class. Most of the films exhibited were imported from other countries, particularly Denmark. The few German films produced were usually cheaply and crudely made. This impoverished state of the domestic industry became a matter of concern among military leaders during the war, when a flood of effective anti-German propaganda films began to pour into Germany from the Allied countries. Therefore, on Dec. 18, 1917, the German general Erich Ludendorff ordered the merger of the main German production, distribution, and exhibition companies into the government-subsidized conglomerate Universum Film Aktiengesellschaft. UFA's mission was to upgrade the quality of German films. The organization proved to be highly effective, and when the war ended in Germany's defeat in November 1918, the German film industry was prepared for the first time to compete in the international marketplace. Transferred to private control, UFA became the single largest studio in Europe and produced most of the films associated with the "golden age" of German cinema during the Weimar Republic (1919–33).

UFA

UFA's first peacetime productions were elaborate costume dramas (*Kostümfilme*) in the vein of the prewar Italian superspectacles, and the master of this form was Ernst Lubitsch, who directed such lavish and successful historical pageants as *Madame Dubarry* (released in the United

By courtesy of the Museum of Modern Art/Film Stills Archive, New York City

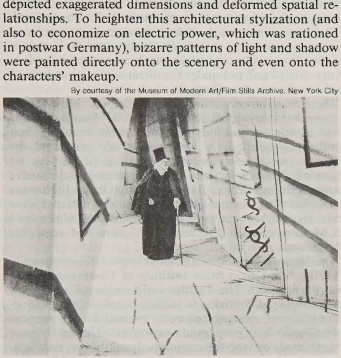


The temple of Babylon sequence from *Intolerance* (1916), directed by D.W. Griffith.

States as *Passion,* 1919), *Anna Boleyn* (*Deception,* 1920), and *Das Weib des Pharao* (*The Loves of Pharaoh,* 1921) before emigrating to the United States in 1922. These films earned the German cinema a foothold in the world market, but it was an Expressionist work, *Das Kabinett des Dr. Caligari* (*The Cabinet of Dr. Caligari,* 1919), that brought the industry its first great artistic acclaim. Based on a scenario by the Czech poet Hans Janowitz and the Austrian writer Carl Mayer, the film recounts a series of brutal murders that are committed in the north German town of Holstenwall by a somnambulist at the bidding of a demented mountebank, who believes himself to be the incarnation of a homicidal 18th-century hypnotist named Dr. Caligari. Erich Pommer, *Caligari*'s producer at Decla-Bioskop (an independent production company that was to merge with UFA in 1921), added a scene to the original scenario so that the story appears to be narrated by a madman confined to an asylum of which the mountebank is director and head psychiatrist. To represent the narrator's tortured mental state, the director, Robert Wiene, hired three prominent Expressionist artists—Hermann Warm, Walter Röhrig, and Walter Reimann—to design sets that depicted exaggerated dimensions and deformed spatial relationships. To heighten this architectural stylization (and also to economize on electric power, which was rationed in postwar Germany), bizarre patterns of light and shadow were painted directly onto the scenery and even onto the characters' makeup.

German Expressionism

By courtesy of the Museum of Modern Art/Film Stills Archive, New York City



Werner Krauss in *The Cabinet of Dr. Caligari,* directed by Robert Wiene (1919).

In its effort to embody disturbed psychological states through decor, *Caligari* influenced enormously the UFA films that followed it and gave rise to the movement known as German Expressionism. The films of this movement were completely studio-made and often used distorted sets and lighting effects to create a highly subjective mood. They were primarily films of fantasy and terror that employed horrific plots to express the theme of the soul in search of itself. Most were photographed by one of the two great cinematographers of the Weimar period, Karl Freund and Fritz Arno Wagner. Representative works include F.W. Murnau's *Der Januskopf* (*Janus-Faced,* 1920), adapted from Robert Louis Stevenson's *Dr. Jekyll and Mr. Hyde;* Paul Wegener and Carl Boese's *Der Golem* (*The Golem,* 1920), adapted from a Jewish legend in which a gigantic clay statue becomes a raging monster; Arthur Robison's *Schatten* (*Warning Shadows,* 1922); Wiene's *Raskolnikow* (1923), based on Dostoyevsky's *Crime and Punishment;* Paul Leni's *Das Wachsfigurenkabinett* (*Waxworks,* 1924); and Henrik Galeen's *Der Student von Prag* (*The Student of Prague,* 1926), which combines the Faust legend with a doppelgänger, or double, motif. In addition to winning international prestige for German films, Expressionism produced two directors who would become major figures in world cinema, Fritz Lang and F.W. (Friedrich Wilhelm) Murnau.

Lang had already directed several successful serials, including *Die Spinnen* (*The Spiders,* 1919–20), when he collaborated with his future wife, the scriptwriter Thea von Harbou, to produce *Der müde Tod* ("The Weary Death"; English title: *Destiny,* 1921) for Decla-Bioscop. This episodic Romantic allegory of doomed lovers, set in several different historical periods, earned Lang acclaim for his dynamic compositions of architectural line and space. Lang's use of striking, stylized images is also demonstrated in the other films of his Expressionist period, notably the crime melodrama *Dr. Mabuse, der Spieler* (*Dr. Mabuse, the Gambler,* 1922), the Wagnerian diptych *Siegfried* (1922–24) and *Kriemhilds Rache* (*Kriemhild's Revenge,* 1922–23), and the stunningly futuristic *Metropolis* (1926), perhaps the greatest science-fiction film ever made. After directing the early sound masterpiece *M* (1931), based on child murders in Dusseldorf, Lang became increasingly estranged from German political life. He emigrated in 1933 to escape the Nazis and began a second career in the Hollywood studios the following year.

Murnau made several minor Expressionist films before directing one of the movement's classics, an (unauthorized) adaptation of Bram Stoker's novel *Dracula* entitled *Nosferatu—eine Symphonie des Grauens* ("Nosferatu, a Symphony of Horror," 1922), but it was *Der letzte Mann* ("The Last Man"; English title: *The Last Laugh,* 1924), a film in the genre of *Kammerspiel* ("intimate theatre"), that made him world famous. Scripted by Carl Mayer and produced by Erich Pommer for UFA, *Der letzte Mann* told the story of a hotel doorman who is humiliated by the loss of his job and—more important, apparently, in postwar German society—of his splendid paramilitary uniform. Murnau and Freund, his cameraman, gave this simple tale a complex narrative structure through their innovative use of camera movement and subjective point-of-view shots. In one famous example, Freund strapped a lightweight camera to his chest and stumbled drunkenly around the set of a bedroom to record the inebriated porter's point of view. In the absence of modern cranes and dollies, at various points in the filming Murnau and Freund placed the camera on moving bicycles, fire engine ladders, and overhead cables in order to achieve smooth, sustained movement. The total effect was a tapestry of subjectively involving movement and intense identification with the narrative.

Use of subjective camera movement in *The Last Laugh*

Der letzte Mann was universally hailed as a masterpiece and probably had more influence on Hollywood style than any other single foreign film in history. Its "unchained camera" technique (Mayer's phrase) spawned many imitations in Germany and elsewhere, the most significant being E.A. (Ewald André) Dupont's circus-tent melodrama *Variété* (1925). The film also brought Murnau a long-term Hollywood contract, which he began to fulfill in 1927 after completing two last super-productions, *Tartüff* (1925) and *Faust* (1926), for UFA.

In 1924 the German mark was stabilized by the so-called Dawes Plan, which financed the long-term payment of Germany's war reparations debt and curtailed all exports. This created an artificial prosperity in the economy at large, which lasted only until the stock market crash of 1929, but it was devastating to the film industry, the bulk of whose revenues came from foreign markets. Hollywood then seized the opportunity to cripple its only serious European rival, saturating Germany with American films and buying its independent theatre chains. As a result of these forays and its own internal mismanagement, UFA stood on the brink of bankruptcy by the end of 1925. It was saved by a $4,000,000 loan offered by two major American studios, Famous Players-Lasky (later Paramount) and Metro-Goldwyn-Mayer, in exchange for collaborative rights to UFA studios, theatres, and creative personnel. This arrangement resulted in the founding of the Parufamet (Paramount-UFA-Metro) Distribution Company in early 1926 and the almost immediate emigration of UFA film artists and technicians to Hollywood, where they worked for a variety of studios. This first Germanic migration was temporary. Many of the filmmakers returned to UFA disgusted at the assembly-line character of the American studio system, but many—such as Lubitsch, Freund, Murnau, and Kertész—stayed on to launch full-fledged Hollywood careers, and many more would come back during the 1930s to escape Adolf Hitler.

In the meantime, the new sensibility that had entered German intellectual life turned away from the morbid psychological themes of Expressionism toward an acceptance of "life as it is lived." Called *die neue Sachlichkeit* ("the new objectivity"), this spirit stemmed from the economic dislocations that beset German society in the wake of the war, particularly the impoverishment of the middle classes through raging inflation. In cinema, *die neue Sachlichkeit* translated into the grim social realism of the "street" films of the late 1920s, including G.W. Pabst's *Die freudlose Gasse* (*The Joyless Street,* 1925), Bruno Rhan's *Dirnentragödie* (*Tragedy of the Streets,* 1927), Joe May's *Asphalt* (1929), and Piel Jutzi's *Berlin-Alexanderplatz* (1931). Named for their prototype, Karl Grune's *Die Strasse* (*The Street,* 1923), these films focused on the disillusionment, cynicism, and ultimate resignation of ordinary German people whose lives were crippled during the postwar inflation.

The master of the form was G.W. (Georg Wilhelm) Pabst, whose work established conventions of continuity editing that would become essential to the sound film. In such important realist films as *Die freudlose Gasse*, *Die Liebe der Jeanne Ney* (*The Love of Jeanne Ney,* 1927), *Die Büchse der Pandora* (*Pandora's Box,* 1929), and *Tagebuch einer Verlorenen* (*Diary of a Lost One,* 1929), Pabst created complex continuity sequences using techniques that became key features of the Hollywood "invisible" editing style, such as cutting on action, cutting from a shot of a character's glance to one of what the character sees (motivated point-of-view shots), and cutting to a reverse angle shot (one in which the camera angle has changed 180 degrees; *e.g.,* in a scene in which a man and a woman face one another in conversation, the man is seen from the woman's point of view, then the woman is shown from the man's point of view). Pabst later became an important figure of the early sound period, contributing in his pacifist films *Westfront 1918* (1930) and *Kameradschaft* ("Comradeship," 1931) two significant works. A few years later, however, Pabst found himself making films for the Nazis, a condition that afflicted the entire German film industry after 1933.

Pabst's editing techniques

By March 1927, UFA was once again facing financial collapse, and it turned this time to the Prussian financier Alfred Hugenberg, a director of both the powerful Krupp industrial empire and the right-wing German National Party, who was sympathetic to the Nazis. Hugenberg bought out the American interests in UFA, acquiring a majority of the company's stock and directing the remainder into the hands of his political allies. As chairman of the UFA board, he quietly instituted a nationalistic production policy that gave increasing prominence to the Nazis and their cause and that enabled the Nazis to subvert the German film industry when Hitler came to power in 1933. German cinema then fell under the authority of Joseph Goebbels and his Ministry of Public Enlightenment and Propaganda. For the next 12 years every film made in the Third Reich had to be personally approved for release by Goebbels. Jews were officially banned from the industry, causing a vast wave of German film artists to emigrate to Hollywood. Los Angeles became known as "the new Weimar," and the German cinema was emptied of the talent and brilliance that had created its golden age.

German cinema under the Third Reich

The Soviet Union. Before the Bolshevik Revolution of October 1917, Russia for all practical purposes had no native film industry. In the industrialized nations of the West, motion pictures had first been accepted as a form of cheap recreation and leisure for the working class. From that base, they had reached out successfully to the middle class and gained wide popularity among all classes by about 1914. In prerevolutionary Russia, however, the working class was composed largely of serfs too poor to support a native industry, and the small movie business that did develop was dominated by foreign interests and foreign films—mainly French, German, and Danish.

The first native Russian company was not founded until 1908, and by the time of the Revolution, there were perhaps 20 more; but even these were small, importing all of their technical equipment and film stock from Germany and France. When Russia entered World War I in August 1914, foreign films could no longer be imported, and the tsarist government established the Skobelev Committee to stimulate domestic production and produce propaganda in support of the regime. The committee had little immediate effect, but when the Tsar fell in March 1917 the provisional Kerensky government reorganized it to produce antitsarist propaganda. When the Bolsheviks inherited the group eight months later, they transformed it into the Cinema Committee of the People's Commissariat of Education.

A minority party with approximately 200,000 members, the Bolsheviks had assumed the leadership of 160,000,000 people who were scattered across the largest continuous landmass in the world, spoke more than 100 separate languages, and were mostly illiterate. Vladimir Ilich Lenin and other Bolshevik leaders looked on the motion-picture medium as a means of unifying the huge, disparate nation. Lenin was the first political leader of the 20th century to recognize both the importance of film as propaganda and its power to communicate quickly and effectively. He understood that audiences did not require literacy to comprehend a film's meaning and that more people could be reached through mass-distributed motion pictures than through any other medium of the time. Lenin declared: "The cinema is for us the most important of the arts," and his government gave top priority to the rapid development of the Soviet film industry, which was nationalized in August 1919 and put under the direct authority of Lenin's wife, Nadezhda Krupskaya.

There was, however, little to build upon. Most of the prerevolutionary producers had fled to Europe, taking their equipment and film stock with them, wrecking their studios as they left. A foreign blockade prevented the importation of new equipment or stock (there were no domestic facilities for manufacturing them), and massive power shortages restricted the use of what limited resources remained. The Cinema Committee was not deterred however; its first act was to found a professional film school in Moscow to train directors, technicians, and actors for the cinema.

The Vsesoyuznyi Gosudarstvenyi Institut Kinematografii (VGIK; "All-Union State Institute of Cinematography") was the first such school in the world and is still among the most respected. Initially, it trained people in the production of *agitki,* existing newsreels reedited for the purpose of agitation and propaganda (agitprop). The *agitki* were transported on specially equipped agit-trains and agit-steamers to the provinces, where they were exhibited to generate support for the Revolution. (The state-controlled Cuban cinema used the same tactic after the revolution of 1959.) In fact, during the abysmal years of the Civil War (1918–20), nearly all Soviet films were *agitki* of some sort. Most of the great directors of the Soviet silent cinema were trained in that form, although, having very little technical equipment and no negative film stock, they were often required to make "films without celluloid."

Soviet *agitki*

Students at the VGIK were instructed to write, direct, and act out scenarios as if they were before cameras. Then—on paper—they assembled various "shots" into completed "films." The great teacher Lev Kuleshov obtained a print of Griffith's *Intolerance* and screened it for students in his "Kuleshov workshop" until they had memorized its shot structures and could rearrange its multilayered editing sequences on paper in hundreds of different combinations.

Kuleshov further experimented with editing by intercutting the same shot of a famous actor's expressionless face with several different shots of highly expressive content—a steaming bowl of soup, a dead woman in a coffin, and a little girl playing with a teddy bear. The invariable response of film school audiences when shown these sequences was that the actor's face assumed the emotion appropriate to the intercut object—hunger for the soup, sorrow for the dead woman, paternal affection for the little girl. Kuleshov reasoned from this phenomenon, known today as the "Kuleshov effect," that the shot in film always has two values: that which it carries in itself as a photographic image of reality, and that which it acquires when placed into juxtaposition with another shot. He reasoned further that the second value is more important to cinematic

The Kuleshov effect

signification than the first and that, therefore, time and space in the cinema must be subordinate to the process of editing, or montage (coined by the Soviets from the French verb *monter*, "to assemble"). Kuleshov ultimately conceived of montage as an expressive process whereby dissimilar images could be linked together to create nonliteral or symbolic meaning.

Although Kuleshov made several important films, including *By the Law* (1926), it was as a teacher and theorist that he most deeply influenced an entire generation of Soviet directors. Two of his most brilliant students were Sergey Eisenstein and Vsevolod Illarionovich Pudovkin.

Sergey Eisenstein

Eisenstein was, with Griffith, one of the great pioneering geniuses of the modern cinema, and like his predecessor he produced a handful of enduring masterworks. Griffith, however, had elaborated the structure of narrative editing intuitively, whereas Eisenstein was an intellectual who formulated a modernist theory of editing based on the psychology of perception and Marxist dialectic. Trained as a civil engineer, in 1920 he joined the Moscow Proletkult Theatre, where he fell under the influence of the stage director Vsevolod Meyerhold and directed a number of plays in the revolutionary style of Futurism. In the winter of 1922–23 Eisenstein studied under Kuleshov and was inspired to write his first theoretical manifesto, "The Montage of Attractions." Published in the radical journal *Lef*, the article advocated assaulting an audience with calculated emotional shocks for the purpose of agitation.

Eisenstein was invited to direct the Proletkult-sponsored film *Strike* in 1924, but, like Griffith, he knew little of the practical aspects of production. He therefore enlisted the aid of Eduard Tisse, a brilliant cinematographer at the state-owned Goskino studios, beginning a lifelong artistic collaboration. *Strike* is a semidocumentary representation of the brutal suppression of a strike by tsarist factory owners and police. In addition to being Eisenstein's first film, it was also the first revolutionary mass-film of the new Soviet state. Conceived as an extended montage of shock stimuli, the film concludes with the now famous sequence in which the massacre of the strikers and their families is intercut with shots of cattle being slaughtered in an abattoir.

Strike was an immediate success, and Eisenstein was next commissioned to direct a film celebrating the 20th anniversary of the failed 1905 revolution against tsarism. Originally intended to provide a panorama of the entire event, the project eventually came to focus on a single representative episode—the mutiny of the battleship *Potemkin* and the massacre of the citizens of the port of Odessa by tsarist troops. *Battleship Potemkin* (1925) emerged as one of the most important and influential films ever made, especially in Eisenstein's use of montage, which had improved far beyond the formulaic, if effective, juxtapositions of *Strike*.

Although agitational to the core, *Potemkin* is a work of extraordinary pictorial beauty and great elegance of form. It is symmetrically broken into five movements or acts, according to the structure of Greek tragedy. In the first of these, "Men and Maggots," the flagrant mistreatment of the sailors at the hands of their officers is demonstrated, while the second, "Drama on the Quarterdeck," presents the actual mutiny and the ship's arrival in Odessa. "Appeal from the Dead" establishes the solidarity of the citizens of Odessa with the mutineers, but it is the fourth sequence, "The Odessa Steps," which depicts the massacre of the citizens, that thrust Eisenstein and his film into the historical eminence that both occupy today. Its power is such that the film's conclusion, "Meeting the Squadron," in which the *Potemkin* in a show of brotherhood is allowed to pass through the squadron unharmed, is anticlimactic.

Eisenstein's theory of montage

Unquestionably the most famous sequence of its kind in film history, "The Odessa Steps" incarnates the theory of dialectical montage that Eisenstein later expounded in his collected writings, *The Film Sense* (1942) and *Film Form* (1949). Eisenstein believed that meaning in motion pictures is generated by the collision of opposing shots. Building on Kuleshov's ideas, Eisenstein reasoned that montage operates according to the Marxist view of history as a perpetual conflict in which a force (thesis) and a counterforce (antithesis) collide to produce a totally new and greater phenomenon (synthesis). He compared this dialectical process in film editing to "the series of explosions of an internal combustion engine, driving forward its automobile or tractor." The force of the Odessa steps sequence arises when the viewer's mind combines individual, independent shots and forms a new, distinct conceptual impression that far outweighs the shots' narrative significance. Through Eisenstein's accelerated manipulations of filmic time and space, the slaughter on the stone steps—where hundreds of citizens find themselves trapped between descending tsarist militia above and Cossacks below—acquires a powerful symbolic meaning. With the addition of a stirring revolutionary score by the German Marxist composer Edmund Meisel, the agitational appeal of *Potemkin* became nearly irresistible, and, when exported in early 1926, it made Eisenstein world famous.

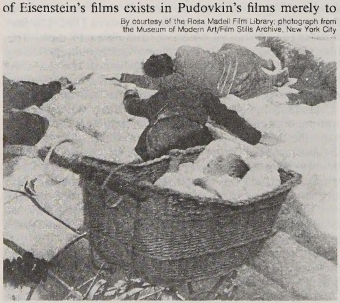
Eisenstein's next project, *October* (1928), was commissioned by the Central Committee to commemorate the 10th anniversary of the Bolshevik Revolution. Accordingly, vast resources, including the Soviet Army and Navy, were placed at the director's disposal. Eisenstein based the shooting script on voluminous documentary material from the era and on John Reed's book *Ten Days That Shook the World*. When the film was completed in November 1927, it was just under four hours long. While Eisenstein was making *October*, however, Joseph Stalin had taken control of the Politburo from Leon Trotsky, and the director was forced to cut the print by one-third to eliminate references to the exiled Trotsky.

Eisenstein had consciously used *October* as a laboratory for experimenting with "intellectual" or "ideological" montage, an abstract type of editing in which the relationships established between shots are conceptual rather than visual or emotional. When the film was finally released, however, Stalinist critics attacked this alleged "formalist excess" (aestheticism or elitism). The same charge was leveled even more bitterly against Eisenstein's next film, *Old and New* (1929), which Stalinist bureaucrats completely disavowed. Stalin hated Eisenstein because he was an intellectual and a Jew, but the director's international stature was such that he could not be publicly purged. Instead, Stalin used the Soviet state-subsidy apparatus to foil Eisenstein's projects and attack his principles at every turn, a situation that resulted in the director's failure to complete another film until *Alexander Nevsky* was commissioned in 1938.

Eisenstein's nearest rival in the Soviet silent cinema was his fellow student Pudovkin. Like Eisenstein, Pudovkin developed a new theory of montage but one based on cognitive linkage rather than dialectical collision. He maintained that "the film is not shot, but built, built up from the separate strips of celluloid that are its raw material." Pudovkin, like Griffith, most often used montage for narrative rather than symbolic purpose. His films are more personal than Eisenstein's; the epic drama that is the focus of Eisenstein's films exists in Pudovkin's films merely to

Pudovkin's use of montage

By courtesy of the Rosa Madell Film Library; photograph from the Museum of Modern Art/Film Stills Archive, New York City



The descent of the baby carriage during the "Odessa Steps" sequence from *Battleship Potemkin*, Sergey Eisenstein (1925).

provide a backdrop for the interplay of human emotions.

Pudovkin's major work is *Mother* (1926), a tale of strike-breaking and terrorism in which a woman loses first her husband and then her son to the opposing sides of the 1905 Revolution. The film was internationally acclaimed for the revolutionary intensity of its montage, as well as for its emotion and lyricism. Pudovkin's later films include *The End of St. Petersburg* (1927), which, like Eisenstein's *October,* was commissioned to celebrate the 10th anniversary of the Bolshevik Revolution, and *The Heir to Genghis Khan* (1928; English title: *Storm over Asia*), which is set in Central Asia during the 1920 Civil War. Both mingle human drama with the epic and the symbolic as they tell a story of a politically naive person who is galvanized into action by tsarist tyranny. Although Pudovkin was never persecuted as severely by the Stalinists as Eisenstein, he too was publicly charged with formalism for his experimental sound film *A Simple Case* (1932) and was forced to release the film without its sound track. Pudovkin made several more sound films but remains best known for his silent work.

Two other seminal figures of the Soviet silent era were Aleksandr Dovzhenko and Dziga Vertov (original name Denis Kaufman). Dovzhenko, the son of Ukrainian peasants, had been a political cartoonist and painter before becoming a director at the state-controlled Odessa studios in 1926. After several minor works, he made *Zvenigora* (1928), a collection of boldly stylized tales about a hunt for an ancient Scythian treasure set during four different stages of Ukrainian history; *Arsenal* (1929), an epic film poem about the effects of revolution and civil war upon the Ukraine; and *Earth* (1930), which is considered to be his masterpiece. *Earth* tells the story of the conflict between a family of wealthy land-owning peasants (kulaks) and the young peasants of a collective farm in a small Ukrainian village, but the film is less a narrative than a lyric hymn to the cyclic recurrence of birth, life, love, and death in nature and in humankind. Although the film is acclaimed today, when it was released Stalinist critics denounced it as counterrevolutionary. Soon after, Dovzhenko entered a period of political eclipse, during which, however, he continued to make films.

Dziga Vertov's theory of the *kino-glaz*

Dziga Vertov (a pseudonym meaning "spinning top") was an artist of quite different talents. He began his career as an *agitki* photographer and newsreel editor and is now acknowledged as the father of *cinéma-vérité* (a self-consciously realistic documentary movement of the 1960s and '70s) for his development and practice of the theory of the *kino-glaz* ("cinema-eye"). Vertov articulated this doctrine in the early 1920s in a number of radical manifestos in which he denounced conventional narrative cinema as impotent and demanded that it be replaced with a cinema of actuality based on the "organization of camera-recorded documentary material." Between 1922 and 1925, he put his idea into practice in a series of 23 carefully crafted newsreel-documentaries entitled *Kino-Pravda* ("film truth") and *Goskinokalender.* Vertov's most famous film is *Man with a Movie Camera* (1929), a feature-length portrait of Moscow from dawn to dusk. The film plays upon the "city symphony" genre inaugurated by Walter Ruttman's *Berlin, the Symphony of a Great City* (1927), but Vertov repeatedly draws attention to the filmmaking process to create an autocritique of cinema itself.

Unlike most of his contemporaries, Vertov welcomed the coming of sound, envisioning it as a "radio-ear" to accompany the "cinema-eye." His first sound film, *Symphony of the Donbas* (1931), was an extraordinary contribution to the new medium, as was *Three Songs About Lenin* (1934), yet Vertov could not escape the charge of formalist error any more than his peers. Although he did make the feature film *Lullaby* in 1937, for the most part the Stalinist establishment reduced him to the status of a newsreel photographer after 1934.

Many other Soviet filmmakers played important roles in the great decade of experiment that followed the Revolution, among them Grigory Kozintsev and Leonid Trauberg (*The Overcoat,* 1926; *The New Babylon,* 1929), Boris Barnet (*The House on Trubnaya Square,* 1928), Yakov Protazanov (*Aelita,* 1924), Olga Preobrazhenskaya (*Women of Ryazan,* 1927), Abram Room (*Bed and Sofa,* 1927), and the documentarian Esther Shub (*The Fall of the Romanov Dynasty,* 1927). The period came to an abrupt end in 1929, when Stalin removed the state film trust (then called Sovkino) from the jurisdiction of the Commissariat of Education and placed it under the direct authority of the Supreme Council of the National Economy. Reorganized as Soyuzkino, the trust was turned over to the reactionary bureaucrat Boris Shumyatsky, a proponent of the narrowly ideological doctrine known as socialist realism. This policy, which came to dominate the Soviet arts, dictated that individual creativity be subordinated to the political aims of the party and the state. In practice, it militated against the symbolic, the experimental, and the avant-garde in favour of a literal-minded "people's art" that glorified representative Soviet heroes and idealized Soviet experience. The restraints imposed made it impossible for the great filmmakers of the postrevolutionary era to produce creative or innovative work, and the Soviet cinema went into decline.

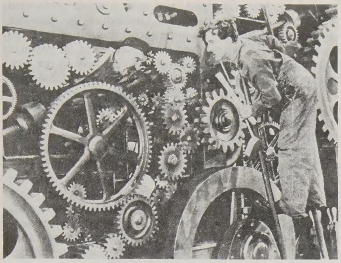
Soviet socialist realism

Post-World War I U.S. cinema. During the 1920s in the United States, motion-picture production, distribution, and exhibition became a major national industry and movies perhaps the major national obsession. The salaries of stars reached monumental proportions, filmmaking practices and narrative formulas were standardized to accommodate mass production, and Wall Street began to invest heavily in every branch of the business. The growing industry was organized according to the studio system that, in many respects, the producer Thomas Harper Ince had developed at Inceville, his studio in the Santa Ynez Canyon near Hollywood, between 1914 and 1918. Ince functioned as the central authority over multiple production units, each headed by a director who was required to shoot an assigned film according to a detailed continuity script. Every project was carefully budgeted and tightly scheduled, and Ince himself supervised the final cut. This central producer system was the prototype for the studio system of the 1920s, and, with some modification, it prevailed as the dominant mode of Hollywood production for the next 40 years.

Virtually all of the major film genres evolved and were codified during the 1920s, but none was more characteristic of the period than the slapstick comedy. This form was originated by Mack Sennett, who, at his Keystone Studios, produced countless one- and two-reel shorts and features (*Tillie's Punctured Romance,* 1914; *The Surf Girl,* 1916; *Teddy at the Throttle,* 1917) whose narrative logic was subordinated to fantastic, purely visual humour. An anarchic mixture of circus, vaudeville, burlesque, pantomime, and the chase, Sennett's Keystone comedies created a world of inspired madness and mayhem, and they employed the talents of such future stars as Charlie Chaplin, Harry Langdon, Roscoe "Fatty" Arbuckle, Mabel Normand, and Harold Lloyd. When these performers achieved fame, many of them left Keystone, often to form their own production companies, a practice still (if briefly) possible in the early 1920s.

Charlie Chaplin

Chaplin, for example, who had developed the persona of the "little tramp" at Keystone, went on to direct and star in a series of shorts produced by Essanay in 1915 (*The Tramp, A Night in the Show*) and Mutual between 1916 and 1917 (*One A.M., The Rink, Easy Street*). In 1917 he was offered an eight-film contract with First National that enabled him to establish his own studio. He directed his first feature there, the semiautobiographical *The Kid* (1921), but most of his First National films were two-reelers. In 1919 Chaplin, Griffith, Mary Pickford, and Douglas Fairbanks, the four most popular and powerful film artists of the time, jointly formed the United Artists Corporation in order to produce and distribute—and thereby retain artistic and financial control over—their own films. Chaplin directed three silent features for United Artists: *A Woman of Paris* (1923), his great comic epic *The Gold Rush* (1925), and *The Circus* (1928), which was released after the introduction of sound into motion pictures. He later made several sound films, but the two most successful—his first two, *City Lights* (1931) and *Modern Times* (1936)—were essentially silent films with musical scores.



Charlie Chaplin in *Modern Times* (1936).
© Roy Export Company Establishment; photograph, the Museum of Modern Art/Film Stills Archive, New York City

Buster Keaton

Buster Keaton possessed a very different kind of comic talent than Chaplin; but both men were wonderfully subtle actors with a keen sense of the tragic often contained within the comic, and both were major directors of their period. Keaton, like Chaplin, was born into a theatrical family and began performing in vaudeville skits at a young age. Intrigued by the new film medium, he left the stage and worked for two years as a supporting comedian for Arbuckle's production company. In 1919 Keaton formed his own production company, where, over the next four years, he made 20 shorts (*One Week,* 1920; *The Boat,* 1921; *Cops,* 1922; *The Balloonatic,* 1923) that represent, with Chaplin's Mutual films, the acme of American slapstick comedy. A Keaton trademark was the "trajectory gag," in which perfect timing of acting, directing, and editing propels his film character through a geometric progression of complicated sight gags that seem impossibly dangerous but are still dramatically logical. Such routines inform all of Keaton's major features—*Our Hospitality* (1923), *Sherlock Jr.* (1924), *The Navigator* (1924), *Seven Chances* (1925), and his masterpieces *The General* (1927) and *Steamboat Bill, Jr.* (1928). Keaton's greatest films, all made before his company was absorbed by MGM, have a reflexive quality that indicates his fascination with film as a medium. Although some of his MGM films were financially successful, the factory-like studio system stifled Keaton's creativity, and he was reduced to playing bit parts after the early 1930s.

Important but lesser silent comics were Lloyd, the team of Stan Laurel and Oliver Hardy, Langdon, and Arbuckle. Working at the Hal Roach Studios, Lloyd cultivated the persona of an earnest, sweet-tempered boy-next-door. He specialized in a variant of Keystone mayhem known as the "comedy of thrills," in which—as in Lloyd's most famous features, *Safety Last* (1923) and *The Freshman* (1925)—an innocent protagonist finds himself placed in physical danger. Laurel and Hardy also worked for Roach. They made 27 silent two-reelers, including *Putting Pants on Philip* (1927) and *Liberty* (1929), and became even more popular in the 1930s in such sound films as *Another Fine Mess* (1930) and *Sons of the Desert* (1933). Their comic characters were basically grown-up children whose relationship was sometimes disturbingly sadomasochistic. Langdon also traded on a childlike, even babylike, image in such popular features as *The Strong Man* (1926) and *Long Pants* (1927), both directed by Frank Capra. Arbuckle, however, in his few years of stardom, unfortunately created the character of a leering, sensual adult. Arbuckle's talent was limited, but his persona affected the course of American film history in a quite unexpected way.

By the early 1920s some 40,000,000 Americans—half of them minors—were attending the movies each week. The rapid spread of the medium and its easy accessibility had already caused mild public concern, especially since films had begun to feature increasingly risqué plots and situations. Concern increased as Hollywood became identified in the popular mind with the materialism, cynicism, and sexual license of the Jazz Age. Then, in September 1921 the popular Arbuckle was charged with the rape and manslaughter of a young starlet, and the concern turned into anger and rage. Arbuckle was eventually exonerated, but other Hollywood scandals surfaced—the murder of director William Desmond Taylor, the death from drug addiction of matinee idol Wallace Reid—and the tabloid press screamed for blood.

The Hays Office

In an attempt to stave off probable mass boycotts and government censorship, in March 1922 the studio heads formed a self-regulatory trade organization, the Motion Picture Producers and Distributors of America (MPPDA), and hired the U.S. postmaster general, Will H. Hays, to head it. In practice, the Hays Office, as the MPPDA was known, functioned as an advisory body and engaged in little actual censorship. It promulgated an unenforceable "Purity Code," which was facetiously called the "Don'ts and Be Carefuls," and it endorsed a policy of "compensating values," whereby all manner of screen vileness could be depicted so long as it was shown to be punished by the film's end. Throughout the 1920s, the Hays Office primarily (and successfully) served to mollify pressure groups and to manage public relations.

The leading practitioner of the compensating values formula was the flamboyant director Cecil B. deMille. He first became famous after World War I for a series of sophisticated comedies of manners that were aimed at Hollywood's new middle-class audience (*Old Wives for New,* 1918; *Forbidden Fruit,* 1921). When the Hays Office was established deMille turned to the sex- and violence-drenched religious spectacles that made him an international figure, notably *The Ten Commandments* (1923; remade 1956). DeMille's chief rival in the production of stylish sex comedies was the German émigré Ernst Lubitsch. An early master of the UFA *Kostümfilm,* Lubitsch excelled at sexual innuendo and understatement in such urbane essays as *The Marriage Circle* (1924). Also popular during the 1920s were the swashbuckling exploits of Douglas Fairbanks, whose lavish adventure spectacles, including *Robin Hood* (1922) and *The Thief of Bagdad* (1924), thrilled a generation, and the narrative documentaries of Robert Flaherty, whose *Nanook of the North* (1922) and *Moana* (1926) were unexpectedly successful with the public and with critics.

The most enigmatic and unconventional figure working in Hollywood at the time, however, was without a doubt the remarkable Viennese émigré Erich von Stroheim. Stroheim, who also acted, learned directing as an assistant to Griffith on *Intolerance* and *Hearts of the World.* His first three films—*Blind Husbands* (1918), *The Devil's Passkey* (1919), and *Foolish Wives* (1922)—constitute an obsessive trilogy of adultery; each features a sexual triangle in which an American wife is seduced by a Prussian army officer. Even though all three films were enormously popular, the great sums Stroheim was spending on the extravagant production design and costuming of his next project brought him into conflict with his Universal producers, and he was replaced.

Stroheim then signed a contract with Goldwyn Pictures and began work on a long-cherished project—an adaptation of Frank Norris' grim, naturalistic novel *McTeague.* Shot entirely on location in the streets and rooming houses of San Francisco, in Death Valley, and in the California hills, the film was conceived as a sentence-by-sentence translation of its source. Stroheim's original version ran approximately 10 hours. Realizing that the film was too long to be exhibited, he cut almost half of the footage. The film was still deemed too long, so Stroheim, with the help of director Rex Ingram, edited it down into a four-hour version that could be shown in two parts. By that time, however, Goldwyn Pictures had merged with Metro Pictures and Louis B. Mayer Pictures to become MGM. MGM took the negative from Stroheim and cut out another two hours, destroying the excised footage in the process. Released as *Greed* (1924), the film had enormous gaps in continuity, but it was still recognized as a work of genius in its rich psychological characterization and in its creation of a naturalistic analogue for the novel.

Stroheim made one more film for MGM, a darkly satiric

adaptation of the Franz Lehár operetta *The Merry Widow* (1925). He then went to Celebrity Pictures, where he directed *The Wedding March* (1928), a two-part spectacle of imperial Vienna, but his work was taken from him and recut into a single film when Celebrity was absorbed by Paramount. Stroheim's last directorial duties were on the botched *Queen Kelly* (1929) and *Walking Down Broadway* (1932), although he was removed from both films for various reasons. He made his living thereafter by writing screenplays and acting.

Decline of independent filmmaking

Although many of Stroheim's troubles with Hollywood were personal, he was also a casualty of the American film industry's transformation during the 1920s from a speculative entrepreneurial enterprise into a vertically and horizontally integrated oligopoly that had no tolerance for creative difference. His situation was not unique; many singular artists, including Griffith, Sennett, Chaplin, and Keaton, found it difficult to survive as filmmakers under the rigidly standardized studio system that had been established by the end of the decade. The industry's conversion to sound at that time reinforced its big-business tendencies and further discouraged independent filmmakers. The studios, which had borrowed huge sums of money on the very brink of the Great Depression in order to finance the conversion, were determined to reduce production costs and increase efficiency. They therefore became less and less willing to tolerate artistic innovation or eccentricity.

THE PRE-WORLD WAR II SOUND ERA

Introduction of sound. The idea of combining motion pictures and sound had been around since the invention of the cinema itself: Edison had commissioned the Kinetograph to provide visual images for his phonograph, and Dickson had actually synchronized the two machines in a device briefly marketed in the 1890s as the "Kinetophone." Léon Gaumont's Chronophone in France and Cecil Hepworth's Vivaphone system in England employed a similar technology, and each was used to produce hundreds of synchronized shorts between 1902 and 1912. In Germany, producer-director Oskar Messter began to release all of his films with recorded musical scores as early as 1908. By the time the feature had become the dominant film form in the West, producers regularly commissioned orchestral scores to accompany prestigious productions, and virtually all films were accompanied by cue sheets suggesting appropriate musical selections for performance during exhibition.

Actual recorded sound required amplification for sustained periods of use, however, which became possible only after Lee De Forest's perfection in 1907 of the Audion tube, a three-element, or triode, vacuum tube that magnified sound and drove it through speakers so that it could be heard by a large audience. In 1919 De Forest developed an optical sound-on-film process patented as Phonofilm, and between 1923 and 1927 he made more than 1,000 synchronized sound shorts for release to specially wired theatres. The public was widely interested in these films, but the major Hollywood producers, to whom De Forest vainly tried to sell his system, were not: they viewed "talking pictures" as an expensive novelty with little potential return.

By that time, Western Electric, the manufacturing subsidiary of American Telephone & Telegraph Company, had perfected a sophisticated sound-on-disc system called Vitaphone, which their representatives attempted to market to Hollywood in 1925. Like De Forest, they were rebuffed by the major studios, but Warner Bros., then a minor studio in the midst of aggressive expansion, bought both the system and the right to sublease it to other producers. Warner Bros. had no more faith in talking pictures than did the major studios but thought that the novelty could be exploited for short-term profits. The studio planned to use Vitaphone to provide synchronized orchestral accompaniment for all Warner films, thereby enhancing their marketability to second- and third-run exhibitors who could not afford to hire live orchestral accompaniment. After mounting a $3,000,000 promotion, Warners gave the system its debut on Aug. 6, 1926, in *Don Juan,* a lavish costume drama starring John Barrymore, directed by Alan Crosland, and with a score performed by the New York Philharmonic Orchestra. The response was enthusiastic; Warners announced that all of its films for 1927 would be released with synchronized musical accompaniment and then turned immediately to the production of its second Vitaphone feature. *The Jazz Singer* (1927), also directed by Crosland, included popular songs and incidental dialogue in addition to the orchestral score; its phenomenal success virtually ensured the industry's conversion to sound.

Success of Warners' first sound films

Sensing that Warners' gamble on sound might pay off, MGM, First National, Paramount, and others had asked the MPPDA to investigate competing sound systems in early 1927. There were several sound-on-film systems that were technologically superior to Vitaphone, but the rights to most of them were owned by William Fox, president of Fox Film Corporation. Fox, like the Warners, had seen sound as a way of cornering the market among smaller exhibitors. In the summer of 1926 he therefore acquired the rights to the Case-Sponable sound-on-film system (the similarity of which to De Forest's Phonofilm was the subject of subsequent patent litigation) and formed the Fox-Case Corporation to make shorts under the trade name Fox Movietone. Six months later he secretly bought the American rights to the German Tri-Ergon process, whose flywheel mechanism was essential to the continuous reproduction of optical sound. To cover himself completely Fox negotiated a reciprocal pact between Fox-Case and Vitaphone in which each licensed the other to use its sound systems, equipment, and personnel. The sound-on-film system eventually prevailed over sound-on-disc because it enabled image and sound to be recorded simultaneously in the same (photographic) medium, ensuring their precise and automatic synchronization.

Despite Warners' obvious success with its sound films, film industry leaders were not eager to lease sound equipment from a direct competitor. They banded together, and Warner Bros. was forced to give up its rights to the Vitaphone system in exchange for a share in any new royalties earned. The major film companies then wasted no time. By May 1928 virtually every studio in Hollywood, major and minor, was licensed by Western Electric's newly created marketing subsidiary, Electrical Research Products, Incorporated (ERPI), to use Western Electric equipment with the Movietone sound-on-film recording system. ERPI's monopoly did not please the Radio Corporation of America (RCA), which had tried to market a sound-on-film system that had been developed in the laboratories of its parent company, General Electric, and had been patented in 1925 as RCA Photophone. In October 1928, RCA therefore acquired the Keith-Albee-Orpheum vaudeville circuit and merged it with Joseph P. Kennedy's Film Booking Offices of America (FBO) to form RKO Radio Pictures for the express purpose of producing sound films using the Photophone system (which ultimately became the industry standard).

The wholesale conversion to sound of all three sectors of the American film industry took place in less than 15 months between late 1927 and 1929, and the profits of the major companies increased during that period by as much as 600 percent. Although the transition was fast, orderly, and profitable, it was also enormously expensive. The industrial system as it had evolved for the previous three decades needed to be completely overhauled; studios and theatres had to be totally reequipped and creative personnel retrained or fired. In order to fund the conversion, the film companies were forced to borrow in excess of $350,000,000, which placed them under the indirect control of the two major New York-based financial groups, the Morgan group and the Rockefeller group.

Furthermore, although cooperation among the film companies through such agencies as the the MPPDA, the Academy of Motion Picture Arts and Sciences, and the Society of Motion Picture Engineers (SMPE) ensured a smooth transition in corporate terms, inside the newly wired theatres and studio sound stages there was confusion and disruption. The three competing systems—Vitaphone, Movietone, and Photophone—were all initially incompatible, and their technologies were under such constant

modification that equipment was sometimes obsolete before it was uncrated. Whatever system producers chose, exhibitors during the early transitional period were forced to maintain both sound-on-disc and sound-on-film reproduction equipment. Even as late as 1931, studios were still releasing films in both formats to accommodate theatres owned by sound-on-disc interests.

Production problems caused by conversion to sound

It was in the area of production, however, that the greatest problems arose. The statement that "the movies ceased to move when they began to talk" accurately described the films made during the earliest years of the transition, largely because of technical limitations. Early microphones, for example, had a very limited range. In addition, they were large, clumsy, and difficult to move, so that they were usually concealed in a single, stationary location on the set. The actors, who had to speak directly into the microphones to register on the sound track, were therefore forced to remain practically motionless while speaking dialogue. The microphones caused further problems because they were omnidirectional within their range and picked up every sound made near them on the set, especially the noisy whir of running cameras (which were motorized in 1929 to run at an even speed of 24 frames per second to ensure undistorted sound synchronization; silent cameras had been mainly hand-cranked at rates averaging 16 to 18 frames per second). To prevent the recording of camera noise, cameras and their operators were initially enclosed in soundproof glass-paneled booths that were only six feet long per side. The booths, which were facetiously called "ice-boxes" because they were uncomfortably hot and stuffy, literally imprisoned the camera. The filmmakers' inability to tilt or dolly the camera (although they could pan it by as much as 30 degrees on its tripod), combined with the actors' immobility, helps to account for the static nature of so many early sound films.

The impact of sound recording on editing was even more regressive because sound and image had to be recorded simultaneously to be synchronous. In sound-on-disc films, scenes were initially made to play for 10 minutes at a time in order to record dialogue continuously on 16-inch discs; such scenes were impossible to edit until the technology of rerecording was perfected in the early 1930s. Sound-on-film systems also militated against editing at first because optical sound tracks run approximately 20 frames in advance of their corresponding image tracks, making it extremely difficult to cut a composite print without eliminating portions of the relevant sound. As a result, no matter which system of sound recording was used, most of the editing in early sound films was purely functional. In general, cuts could only be made—and the camera moved—when no sound was being recorded on the set.

Most of these technical problems were resolved by 1933, although equilibrium was not fully restored to the production process until after the mid-1930s. Sound-on-disc filming, for example, was abandoned in 1930, and by 1931 all the studios had removed their cameras from the ice-boxes and converted to the use of lightweight, soundproof camera housings known as "blimps." Within several years, smaller, quieter, self-insulating cameras were produced, eliminating the need for external soundproofing altogether. It even became possible to move the camera again by using a wide range of boom cranes, camera supports, and steerable dollies. Microphones, too, became increasingly mobile as a variety of booms were developed for them from 1930 onward. These long radial arms suspended the microphone above the set, allowing it to follow the movements of actors and rendering the stationary microphones of the early years obsolete. Microphones also became more directional throughout the decade, and track noise suppression techniques came into use as early as 1931.

Postsynchronization

The technological development that most liberated the sound film, however, was the practice known variously as postsynchronization, rerecording, or dubbing, in which image and sound are printed on separate pieces of film so that they can be manipulated independently. Postsynchronization enabled filmmakers to edit images freely again. Because the overwhelming emphasis of the period from 1928 to 1931 had been on obtaining high-quality sound in production, however, the idea that the sound track could be modified after it was recorded took a while to catch on. Many motion-picture artists and technicians felt that sound should be reproduced in films exactly as it had originally been produced on the set; they believed that anything less than an absolute pairing of sound and image would confuse audiences.

For several years, both practice and ideology dictated that sound and image be recorded simultaneously, so that everything heard on the sound track would be seen on the screen, and vice versa. A vocal minority of film artists nevertheless viewed this practice of synchronous, "naturalistic," sound-recording as a threat to the cinema. In their 1928 manifesto "Sound and Image," the Soviet directors Eisenstein, Pudovkin, and Grigory Aleksandrov denounced synchronous sound in favour of asynchronous, contrapuntal sound—sound that would counterpoint the images it accompanied to become another dynamic element in the montage process. Like the practical editing problem, the theoretical debate over the appropriate use of sound was eventually resolved by the practice of postsynchronization.

Postsynchronization seems to have first been used by the American director King Vidor in the all-black musical *Hallelujah* (1929) for a sequence in which the hero is chased through Arkansas swamplands. Vidor shot the action on location without sound, using a freely moving camera. Later, in the studio, he added to the film a separately recorded sound track containing both naturalistic and impressionistic effects. In the following year Lewis Milestone's *All Quiet on the Western Front* and Pabst's *Westfront 1918* both used postsynchronization for their battle scenes. Lubitsch used dubbing in his first American sound films, the dynamic musicals *The Love Parade* (1929) and *Monte Carlo* (1930), as did the French director René Clair in *Sous les toits de Paris* (1930). In all of these early instances, sound was recorded and rerecorded on a single track, although some American directors, including Milestone and the Russian-born Armenian Rouben Mamoulian (*Applause,* 1929; *City Streets,* 1931), had experimented with multiple microphone setups and overlapping dialogue as early as 1929. Generally, through 1932, either dialogue or music dominated the sound track unless they had been simultaneously recorded on the set. In 1933, however, technology was introduced that allowed filmmakers to mix separately recorded tracks for background music, sound effects, and synchronized dialogue at the dubbing stage. By the late 1930s, postsynchronization and multiple-channel mixing had become standard industry procedure.

Other changes wrought by sound were more purely human. Directors, for example, could no longer literally direct their performers while the cameras were rolling and sound was being recorded. Actors and actresses were suddenly required to have pleasant voices and to act without the assistance of mood music or the director's shouted instructions through long dialogue takes. Many found that they could not learn lines; others tried and were defeated by heavy foreign accents (*e.g.,* Emil Jannings, Pola Negri, Vilma Banky, and Lya de Putti) or voices that did not match their screen image (*e.g.,* Colleen Moore, Corinne Griffith, Norma Talmadge, and John Gilbert). Numerous silent stars were supplanted during the transitional period by stage actors or film actors with stage experience. "Canned theatre," or literal transcriptions of stage hits, became a dominant Hollywood form between 1929 and 1931, which brought many Broadway players and directors into the film industry on a more or less permanent basis. In addition, to fulfill the unprecedented need for dialogue scripts, the studios imported hundreds of editors, critics, playwrights, and novelists, many of whom would make lasting contributions to the verbal sophistication of the American sound film.

Sound's effect on film genres

As sound demanded new filmmaking techniques and talents, it also created new genres and renovated old ones. The realism it permitted inspired the emergence of tough, socially pertinent films with urban settings. Crime epics such as Mervyn LeRoy's *Little Caesar* (1930), William Wellman's *Public Enemy* (1931), and Howard Hawks's *Scarface* (1932) used sound to exploit urban slang and the

audible pyrotechnics of the recently invented Thompson submachine gun. Subgenres of the gangster film appeared in the prison film (*The Big House,* 1930; Hawks's *The Criminal Code,* 1931; LeRoy's *I Am a Fugitive from a Chain Gang,* 1932) and the newspaper picture (Milestone's *The Front Page;* LeRoy's *Five Star Final,* 1931; John Cromwell's *Scandal Sheet,* 1931; Frank Capra's *Platinum Blonde,* 1931), both of which relied on authentic-sounding vernacular speech.

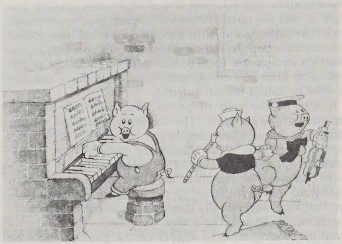
The public's fascination with speech also accounted for the new popularity of historical biographies, or "biopics." These films were modeled on the UFA's silent *Kostümfilm,* but dialogue enhanced their verisimilitude. Several actors with impressive speaking voices were often associated with the genre, notably George Arliss (*Disraeli,* 1929; *The House of Rothschild,* 1934) and Paul Muni (*The Life of Emile Zola,* 1937; *Juarez,* 1939) in the United States and Charles Laughton (Alexander Korda's *The Private Life of Henry VIII,* 1933, and *Rembrandt,* 1936) in England.

In the realm of comedy, pure slapstick could not and did not survive, predicated as it was on purely visual humour. It was replaced by equally vital—but ultimately less surreal and abstract—sound comedies: the anarchic dialogue comedies of the Marx Brothers (*The Cocoanuts,* 1929; *Animal Crackers,* 1930; *Monkey Business,* 1931; *Horse Feathers,* 1932; *Duck Soup,* 1933) and W.C. Fields (*The Golf Specialist,* 1930; *The Dentist,* 1932; *Million Dollar Legs,* 1932) and the fast-paced wisecracking "screwball" comedies of directors like Frank Capra (*Lady for a Day,* 1933; *It Happened One Night,* 1934; *Mr. Deeds Goes to Town,* 1936), Howard Hawks (*Twentieth Century,* 1934; *Bringing Up Baby,* 1938), Gregory La Cava (*My Man Godfrey,* 1936), Mitchell Leisen (*Easy Living,* 1937), and Leo McCarey (*The Awful Truth,* 1937).

The horror-fantasy genre, traditionally rooted in German Expressionism, was greatly enhanced by sound, which not only permitted the addition of eerie sound effects but also restored the dimension of literary dialogue present in so many of the original sources. Appropriately, Universal Pictures' three great horror classics—Tod Browning's *Dracula* (1931), James Whale's *Frankenstein* (1931), and Karl Freund's *The Mummy* (1932)—were all early sound films.

One significant genre whose emergence was obviously contingent upon sound was the musical. Versions of Broadway musicals were among the first sound films made (including, of course, the catalyst for the conversion, Warner Bros.' *The Jazz Singer*), and by the early 1930s the movie musical had developed in formal sophistication to become perhaps the major American genre of the decade. Among the formidable artists who helped to achieve this sophistication were Lubitsch at Paramount (*The Love Parade,* 1929; *Monte Carlo,* 1930; *The Smiling Lieutenant,* 1931), dance director Busby Berkeley at Warners (*42nd Street,* 1933: *Gold Diggers of 1933,* 1933; *Footlight Parade,* 1933; *Dames,* 1934), and dancer-star Fred Astaire, who choreographed and directed his own integrated dance sequences at RKO (*The Gay Divorcee,* 1934; *Roberta,* 1935; *Top Hat,* 1935; *Swing Time,* 1936).

Walt Disney pioneered a genre that might be called the animated musical with *The Skeleton Dance* (1929), the first entry in his "Silly Symphony" series. Unburdened by the awkward logistics of live-action shooting, Disney was free to combine sound and image asynchronously or with perfect frame-by-frame synchronization in such classic cartoons as *Steamboat Willie* (1928—Mickey Mouse's debut) and *The Three Little Pigs* (1933). To enhance their fantasy-like appeal, both the musical and the animated film made early use of the photographic colour systems introduced by the Technicolor Corporation during the conversion to sound (two-colour imbibition, 1928; three-colour, three-strip imbibition, 1932), and the two genres quickly became associated with colour in the public mind.



Walt Disney pioneered the use of sound and colour in motion pictures with such cartoon shorts as *The Three Little Pigs* (1933).

The Three Little Pigs, © 1933, The Walt Disney Company; photograph from the Museum of Modern Art/Film Stills Archive, New York City

Early colour effects

Introduction of colour. Photographic colour entered the cinema at approximately the same time as sound, although, as with sound, various colour effects had been used in films since the invention of the medium. Méliès, for example, employed 21 women at his Montreuil studio to hand-colour his films frame by frame, but hand-colouring was not cost-effective unless films were very short. In the mid-1900s, as films began to approach one reel in length and more prints of each film were sold, mechanized stenciling processes were introduced. In Pathé's Pathécolor system, for example, a stencil was cut for each colour desired (up to six) and aligned with the print; colour was then applied through the stencil frame by frame at high speeds. With the advent of the feature and the conversion of the industry to mass production during the 1910s, frame-by-frame stenciling was replaced by mechanized tinting and toning. Tinting coloured all the light areas of a picture and was achieved by immersing a black-and-white print in dye or by using coloured film base for printing. The toning process involved chemically treating film emulsion to colour the dark areas of the print. Each process produced monochrome images, the colour of which was usually chosen to correspond to the mood or setting of the scene. Occasionally, the two processes were combined to produce elaborate two-colour effects. By the early 1920s, nearly all American features included at least one coloured sequence; but after 1927, when it was discovered that tinting or toning film stock interfered with the transmission of optical sound, both practices were temporarily abandoned, leaving the market open to new systems of colour photography.

Photographic colour can be produced in motion pictures using either an additive process or a subtractive one (see below *Technology: Introduction of colour*). The first systems to be developed and used were all additive ones, such as Charles Urban's Kinemacolor (*c.* 1906) and Gaumont's Chronochrome (*c.* 1912). They achieved varying degrees of popularity, but none was entirely successful, largely because all additive systems involve the use of both special cameras and projectors, which ultimately makes them too complicated and costly for widespread industrial use.

One of the first successful subtractive processes was a two-colour one introduced by Herbert Kalmus' Technicolor Corporation in 1922. It used a special camera and a complex procedure to produce two separate positive prints that were then cemented together into a single print. The final print needed careful handling but could be projected using ordinary equipment. This "cemented positive" process was used successfully in such features as *Toll of the Sea* (1922) and Douglas Fairbanks' *The Black Pirate* (1926). In 1928 Technicolor introduced an improved process in which two gelatin positives were used as relief matrices to "print" colour onto a single strip of film. This printing process, known as imbibition or dye-transfer, made it possible to mass-produce sturdy, high-quality prints. Its introduction resulted in a significant rise in Technicolor production between 1929 and 1932. Colour reproduction in the two-colour Technicolor process was good, but because only two of the three primary colours were used, it was still not completely lifelike. Its popularity began to decline sharply in 1932, and Technicolor replaced it with a three-colour system that employed the same basic principles but included all three primary colours.

Drawbacks of Technicolor's three-colour system

For the next 25 years almost every colour film made was produced using Technicolor's three-colour system. Although the quality of the system was excellent, there were drawbacks. The bulk of the camera made location shooting difficult. Furthermore, Technicolor's virtual monopoly gave it indirect control of the production companies, which were required to rent—at high rates—equipment, crew, consultants, and laboratory services from Technicolor every time they used the system. In the midst of the Depression, therefore, conversion to colour was slow and never really complete. After three-colour Technicolor was used successfully in Disney's cartoon short *The Three Little Pigs* (1933), the live-action short *La Cucaracha* (1934), and Rouben Mamoulian's live-action feature *Becky Sharp* (1935), however, it gradually worked its way into mainstream feature production (*The Garden of Allah,* 1936; *Snow White and the Seven Dwarfs,* 1937; *The Adventures of Robin Hood,* 1938; *The Wizard of Oz,* 1939; *Gone with the Wind,* 1939), although it remained strongly associated with fantasy and spectacle.

The Hollywood studio system. If the coming of sound changed the aesthetic dynamics of the filmmaking process, it altered the economic structure of the industry even more, precipitating some of the largest mergers in motion-picture history. Throughout the 1920s, Paramount, MGM, First National, and other studios had conducted ambitious campaigns of vertical integration by ruthlessly acquiring first-run theatre chains. It was primarily in response to these aggressive maneuvers that Warners and Fox sought to dominate smaller exhibitors by providing prerecorded musical accompaniment to their films. The unexpected success of their strategy forced the industry-wide conversion to sound and transformed Warners and Fox into major corporations. By 1929, Warners had acquired the Stanley theatre circuit, which controlled nearly all of the first-run houses in the mid-Atlantic states, and the production and distribution facilities of its former rival First National to become one of the largest studios in Hollywood. Fox went even further, building the multimillion-dollar Movietone City in Westwood, Calif., in 1928 and acquiring controlling shares of both Loew's, Inc., the parent corporation of MGM, and Gaumont British, England's largest producer-distributor-exhibitor. Its holdings were surpassed only by those of Paramount, which controlled an international distribution network and the vast Publix theatre chain. In an effort to become even more powerful, Paramount in 1929 acquired one-half of the newly formed Columbia Broadcasting System and proposed a merger with Warner Bros. It was then that the U.S. Department of Justice intervened, forbidding Paramount's merger with Warners and divorcing Fox from Loew's.

Without government interference, "Paramount-Vitaphone" and "Fox-Loew's" might have divided the entertainment industries of the entire English-speaking world between them. As it was, by 1930, 95 percent of all American production was concentrated in the hands of only eight studios—five vertically integrated major companies, which controlled production, distribution, and exhibition, and three horizontally integrated minor ones that controlled production and distribution. Distribution was conducted at both a national and an international level: since about 1925, foreign rentals had accounted for half of all American feature revenues, and they would continue to do so for the next two decades. Exhibition was controlled through the major studios' ownership of 2,600 first-run theatres, which represented 16 percent of the national total but generated three-fourths of the revenue. Film production throughout the 1930s and '40s consumed only 5 percent of total corporate assets, while distribution accounted for another 1 percent. The remaining 94 percent of the studios' investment went to the exhibition sector. In short, as film historian Douglas Gomery pointed out, the five major studios of the time can best be characterized as "diversified theater chains, producing features, shorts, cartoons, and newsreels to fill their houses."

The major studios

Each studio produced a distinctive style of entertainment, depending on its corporate economy and the personnel it had under contract. Metro-Goldwyn-Mayer, the largest and most powerful of the major studios, was also the most "American" and was given to the celebration of middle-class values in a visual style characterized by bright, even, high-key lighting and opulent production design. Paramount, with its legions of UFA-trained directors, art directors, and cameramen, was thought to be the most "European" of the studios. It produced the most sophisticated and visually baroque films of the era. Conditioned by its recent experience as a struggling minor studio, Warner Bros. was the most cost-conscious of the major companies. Its directors worked on a quota system, and a flat, low-key lighting style was decreed by the studio to conceal the cheapness of its sets. Warners' films were often targeted for working-class audiences. 20th Century-Fox was formed in 1935 by the merger of Fox Film Corporation and Joseph M. Schenck's 20th Century Pictures after William Fox was bankrupted through his financial manipulations. The studio acquired a reputation for its tight budget and production control, but its films were noted for their glossy attractiveness and state-of-the-art special effects. RKO Radio was the smallest of the major companies and never achieved complete financial stability during the studio era; it became prominent, however, as the producer of *King Kong* (1933), the Astaire-Rogers dance cycle, and Orson Welles's *Citizen Kane* (1941) and also as the distributor of Disney's features.

The minor studios were Carl Laemmle's Universal Pictures, which became justly famous for its horror films; Harry Cohn's Columbia Pictures, whose main assets were director Frank Capra and screenwriter Robert Riskin; and United Artists, which functioned as a distributor for independent American features and for Alexander Korda's London Film Productions. In terms of total assets, the five major studios were about four times as big as the three minor ones, with MGM, Paramount, Warners, and 20th Century-Fox all about the same size and RKO approximately 25 percent smaller than its peers. At the very bottom of the film industry hierarchy were a score of poorly capitalized studios, such as Republic, Monogram, and Grand National, that produced cheap, formulaic, hour-long "B-films" for the second half of double bills. The double feature, an attraction introduced in the early 1930s to counter the Depression-era box-office slump, was the standard form of exhibition for about 15 years. The larger studios were, for the most part, not interested in producing B-films for double bills because unlike the main feature, whose earnings were based on box-office receipts, the second feature rented at a flat rate, which meant that the profit it returned, though guaranteed, was fixed at a small amount. At their peak, the B-film studios produced 40–50 films per year and provided a training ground for such stars as John Wayne. The films were made as quickly as possible, and directors functioned as their own producers, with complete authority over their projects' minuscule budgets.

B-films

The Production Code

An important aspect of the studio system was the Production Code, which was implemented in 1934 in response to pressure from the Legion of Decency and public protest against the graphic violence and sexual suggestiveness of some sound films (the urban gangster films, for example, and the films of Mae West). The Legion had been established in 1933 by the American bishops of the Roman Catholic Church (armed with a mandate from the Vatican) to fight for better and more "moral" motion pictures. In April 1934, with the support of both Protestant and Jewish organizations, the Legion called for a nationwide boycott of movies it considered indecent. The studios, having lost millions of dollars in 1933 as the delayed effects of the Depression caught up with the box office, rushed to appease the protesters by authorizing the MPPDA to create the Production Code Administration. A prominent Catholic layman, Joseph I. Breen, was appointed to head the administration, and under Breen's auspices, Father Daniel A. Lord, a Jesuit priest, and Martin Quigley, a Catholic publisher, coauthored the code whose provisions would dictate the content of American motion pictures, without exception, for the next 20 years.

In a swing away from the excesses of the "new morality" of the Jazz Era, the Production Code was monumentally repressive, forbidding the depiction on screen of almost

everything germane to the experience of normal human adults. It prohibited showing "scenes of passion," and adultery, illicit sex, seduction, and rape could not even be alluded to unless they were absolutely essential to the plot and severely punished by the film's end. The code demanded that the sanctity of marriage be upheld at all times, although sexual relations were not to be suggested between spouses. It forbade the use of profanity, vulgarity, and racial epithets; prostitution, miscegenation, sexual deviance, or drug addiction; nudity, sexually suggestive dancing or costumes, and "lustful kissing"; and excessive drinking, cruelty to animals or children, and the representation of surgical operations, especially childbirth, "in fact or silhouette." In the realm of violence, it was forbidden to display or to discuss contemporary weapons, to show the details of a crime, to show law enforcement officers dying at the hands of criminals, to suggest excessive brutality or slaughter, or to use murder or suicide except when crucial to the plot. Finally, the code required that all criminal activity be shown to be punished; under no circumstances could any crime be represented as justified. Studios were required to submit their scripts to Breen's office for approval before beginning filming, and completed films had to be screened for the office, and altered if necessary, in order to receive a Production Code Seal, without which no film could be distributed in the United States. Noncompliance with the code's restrictions brought a fine of $25,000, but the studios were so anxious to please that the fine was never levied in the 22-year lifetime of the code.

Studio acceptance of the code

The studio heads were willing not merely to accept but also to institutionalize this system of de facto censorship and prior restraint because they believed it was necessary for the continued success of their business. The economic threat of a national boycott during the worst years of the Depression was real, and the film industry, which depends on pleasing a mass audience, could not afford to ignore public opinion. Producers found, moreover, that they could use the code to increase the efficiency of production. By rigidly prescribing and proscribing the kinds of behaviour that could be shown or described on the screen, the code could be used as a scriptwriter's blueprint. A love story, for example, could only move in one direction (toward marriage), adultery and crime could have only one conclusion (disease or horrible death), dialogue in all situations had well-defined parameters, and so forth. The code, in other words, provided a framework for the construction of screenplays and enabled studios to streamline what had always been (and still is) one of the most difficult and yet most essential tasks in the production process—the creation of filmable continuity scripts. Finally, the Depression was a time of open political anti-Semitism in the United States and the men who controlled the American motion-picture industry were all Jewish; it was not a propitious moment for them to antagonize their predominantly non-Jewish audience.

Between 1930 and 1945, the studio system produced more than 7,500 features, every stage of which, from conception through exhibition, was carefully controlled. Among these assembly-line productions are some of the most important American films ever made, the work of gifted directors who managed to transcend the mechanistic nature of the system to produce work of unique personal vision. These directors include Josef von Sternberg, whose exotically stylized films starring Marlene Dietrich (*Shanghai Express*, 1932; *The Scarlet Empress*, 1934) constitute a kind of painting with light; John Ford, whose vision of history as moral truth produced such mythic works as *Stagecoach* (1939), *Young Mr. Lincoln* (1939), *The Grapes of Wrath* (1940), *My Darling Clementine* (1946), and *She Wore a Yellow Ribbon* (1949); Howard Hawks, a master of genres and the architect of a tough, functional "American" style of narrative exemplified in his films *Scarface* (1932), *Twentieth Century*, *Only Angels Have Wings* (1939), and *The Big Sleep* (1946); British émigré Alfred Hitchcock, whose films appealed to the popular audience as suspense melodramas but were in fact abstract visual psychodramas of guilt and spiritual terror (*Rebecca*, 1940; *Suspicion*, 1941; *Shadow of a Doubt*, 1943; *Notorious*, 1946); and Frank Capra, whose cheerful screwball comedies (*It Happened One Night*) and populist fantasies of good will (*Mr. Smith Goes to Washington*, 1939) sometimes gave way to darker warnings against losing faith and integrity (*It's a Wonderful Life*, 1946). Other significant directors with less consistent thematic or visual styles were William Wyler (*Wuthering Heights*, 1939; *The Little Foxes*, 1941), George Cukor (*Camille*, 1936; *The Philadelphia Story*, 1940), Leo McCarey (*The Awful Truth*, 1937; *Going My Way*, 1944), Preston Sturges (*Sullivan's Travels*, 1941; *The Miracle of Morgan's Creek*, 1944), and George Stevens (*Gunga Din*, 1939; *Woman of the Year*, 1942).

The Big Sleep, © 1946 Warner Bros. Pictures, Inc., renewed 1973, United Artists Television, Inc; photograph from the Museum of Modern Art/Film Stills Archive, New York City



Lauren Bacall and Humphrey Bogart in Howard Hawks's *The Big Sleep* (1946), based on the Raymond Chandler novel and adapted for the screen by William Faulkner.

Welles's innovations in *Citizen Kane*

The most extraordinary film to emerge from the studio system, however, was Orson Welles's *Citizen Kane* (1941), whose controversial theme and experimental technique combined to make it a classic. The first of six films Welles had contracted to produce for RKO with his Mercury Theater radio ensemble company, *Citizen Kane* made radically innovative use of sound and deep-focus photography as it examined the life of Charles Foster Kane, a character based on the press baron William Randolph Hearst. The film employs a complicated flashback structure in which Kane's friends and associates give their accounts of the man after his death, paradoxically revealing not greatness or might but pathetic insecurity and emptiness. In creating this portrait of a powerful American who could bend international politics to his will but never fathom human love, Welles stretched the technology of image and sound recording beyond its contemporary limits. Using a newly available Eastman film stock with increased sensitivity to light, plastic-coated wide-angle lenses opened to smaller than normal apertures, and high-intensity arc lamps, cinematographer Gregg Toland achieved a photographic depth of field that approximated the perceptual range of the human eye and enabled Welles to place the film's characters in several different planes of depth within a single scene. These deep-focus sequence shots are complemented throughout the film by the techniques of ambient and directional sound that Welles had learned from radio. Most important of all, the resonance of the film's narrative matches the technical brilliance of its presentation, functioning on several levels at once, the historical, the psychological, and the mythic. Although recognized by many critics as a work of genius, *Citizen Kane* was a financial failure on its release, and Welles directed only three other films under his RKO contract. *Citizen Kane* remains, nevertheless, one of the most influential films ever made and is widely considered to be one of the greatest.

European conversion to sound

International cinema. Having created large new markets for their sound recording technologies in the United States, Western Electric and RCA were anxious to do the same abroad. Their objective coincided with the desire of the major American film studios to extend their control of the international motion-picture industry. Accordingly, the studios began to export sound films in late 1928, and ERPI and RCA began installing their equipment in European theatres at the same time. Exhibitors in the

United Kingdom converted the most rapidly, with 22 percent wired for sound in 1929 and 63 percent by the end of 1932. Continental exhibitors converted more slowly, largely because of a bitter patents war between the German cartel Tobis-Klangfilm, which controlled the European rights to sound-on-film technology, and Western Electric. The dispute was finally resolved at the 1930 German-American Film Conference in Paris, where Tobis, ERPI, and RCA agreed to pool their patents and divide the world market among themselves. The language problem also delayed the conversion to sound on the Continent. Because dubbing was all but impossible in the earliest years of the transition, films had to be shot in several different languages (sometimes featuring a different cast for each version) at the time of production in order to receive wide international distribution. Paramount therefore built a huge studio in the Paris suburb of Joinville in 1930 to mass-produce multilingual films. The other major American studios quickly followed suit, making the region a factory for the round-the-clock production of movies in as many as 15 separate languages. By the end of 1931, however, the technique of dubbing had been sufficiently perfected to replace multilingual production, and Joinville was converted into a dubbing centre for all of Europe.

Great Britain. Because of the lack of a language barrier, the United Kingdom became Hollywood's first major foreign market for sound films. The British motion-picture industry was protected from complete American domination, however, by the Cinematograph Films Act passed by Parliament in 1927. The act required that a certain minimum proportion of the films exhibited in British theatres be of domestic origin. Although most of the films made to fulfill this condition were low-budget, low-standard productions known as "quota quickies," the British cinema produced many important film artists (most of whom were soon lured to Hollywood). One of the first major British talents to emerge after the introduction of sound was Hitchcock, who directed a series of stylish thrillers for British International Pictures and Gaumont British, before he moved to Hollywood in 1939. His first sound film, *Blackmail* (1929), marked the effective beginning of sound production in England. The film was already in production as a silent when the director was ordered to make it as a "part-talkie." It was especially noted for the expressive use of both naturalistic and nonnaturalistic sound, which became a distinguishing feature of Hitchcock's later British triumphs (*The Man Who Knew Too Much,* 1934; *The Thirty-Nine Steps,* 1935; *Sabotage,* 1936), as well as of the films of his American career. Among the significant British filmmakers who remained based in London were the Hungarian-born brothers Alexander, Zoltán, and Vincent Korda, who founded London Films in 1932 and collaborated on some of England's most spectacular pre-World War II productions (*e.g., The Private Life of Henry VIII; Rembrandt; Elephant Boy,* 1937; *The Four Feathers,* 1939), and John Grierson, who produced such outstanding documentaries as Robert Flaherty's *Industrial Britain* (1933) and Basil Wright's *Song of Ceylon* (1935) for the Empire Marketing Board Film Unit and its successor, the General Post Office (GPO) Film Unit.

"Quota quickies"

France. In France during the 1920s, as a result of the post-World War I decline of the Pathé and Gaumont film companies, a large number of small studios had leased their facilities to independent companies, which were often formed to produce a single film. This method of film production had lent itself readily to experimentation, encouraging the development of the avant-garde film movement known as Impressionism (led by Germaine Dulac, Jean Epstein, Marcel L'Herbier, and Fernand Léger) and the innovative films of Abel Gance (*La Roue,* 1923; *Napoléon vu par Abel Gance,* 1927) and Dmitri Kirsanoff (*Ménilmontant,* 1926). Because the French film industry had evolved no marketable technology for sound recording, however, the coming of sound left producers and exhibitors alike vulnerable to the American production companies at Joinville and to the German Tobis-Klangfilm, which had been purchasing large studios in the Paris suburb of Epinay since 1929. In the face of this threat, the French industry attempted to regroup itself around what was left of the Pathé and Gaumont empires, forming two consortia—Pathé-Natan and Gaumont-Franco-Film-Aubert—for the production and distribution of sound films. Although neither group was financially successful, they seem to have created an unprecedented demand for French-language films about French subjects, reinvigorating the country's cinema. Between 1928 and 1938, French film production doubled from 66 to 122 features, and in terms of box-office receipts, the French audience was considered to be second only to the American one. By 1937–38 French cinema had become the most critically acclaimed in the world, leading export markets in every industrial nation in the West.

The rise of French cinema

Many filmmakers contributed to the prominence of French cinema during the 1930s, but the three most important were René Clair, Jean Vigo, and Jean Renoir. Clair was a former avant-gardist whose contributions to the aesthetics of sound, although not so crucial as Hitchcock's, were nevertheless significant. His *Sous les toits de Paris* (1930), frequently hailed as the first artistic triumph of the sound film, was a lively musical comedy that mixed asynchronous sound with a bare minimum of dialogue. Clair used the same technique in *Le Million* (1931), which employed a wide range of dynamic contrapuntal effects. *À nous la liberté* (*Liberty Is Ours,* 1931) was loosely based on the life of Charles Pathé and dealt with more serious themes of industrial alienation, although it still used the musical-comedy form. The film's intelligence, visual stylization, and brilliant use of asynchronous sound made it a classic of the transitional period.

Vigo completed only two features before his early death: *Zéro de conduite* (*Zero for Conduct,* 1933) and *L'Atalante* (1934). Both are lyrical films about individuals in revolt against social reality. Their intensely personal nature is thought to have influenced the style of poetic realism that characterized French cinema from 1934 to 1940 and that is exemplified by Jacques Feyder's *Penston mimosas* (1935), Julien Duvivier's *Pépé le Moko* (1937), and Marcel Carné's *Quai des brumes* (*Port of Shadows,* 1938) and *Le Jour se lève* (*Daybreak,* 1939). Darkly poetic, these films were characterized by a brooding pessimism that reflected the French public's despair over the failure of the Popular Front movement of 1935–37 and the seeming inevitability of war.

Jean Renoir, the son of the Impressionist painter Pierre-Auguste Renoir, made nine films before he directed the grimly realistic *La Chienne* (*The Bitch,* 1931) and *La Nuit du carrefour* (*Night at the Crossroads,* 1932), his first important essays in sound. Renoir subsequently demonstrated a spirit of increasing social concern in such films as *Boudu sauvé des eaux* (*Boudu Saved from Drowning,* 1932), a comic assault on bourgeois values; *Toni* (1934), a realistic story of Italian immigrant workers; *Le Crime de Monsieur Lange* (*The Crime of Monsieur Lange,* 1935), a political parable about the need for collective action against capitalist corruption; and *La Vie est à nous* (*Life Is Ours,* 1936), a propaganda film for the French Communist Party that contains both fictional and documentary footage. The strength of his commitment is most clearly expressed, however, by the eloquent appeal he makes for human understanding in his two pre-World War II masterworks. *La Grande Illusion* (*Grand Illusion,* 1937), set in a World War I prison camp, portrays a civilization on the brink of collapse due to national and class antagonisms; in its assertion of the primacy of human relationships and the utter futility of war (the "grand illusion"), the film stands as one of the greatest antiwar statements ever made. In *La Règle du jeu* (*Rules of the Game,* 1939), set in contemporary France, the breakdown of civilization has already occurred. European society is shown to be an elegant but brittle fabrication in which feeling and substance have been replaced by "manners," a world in which "the terrible thing," to quote the protagonist Octave (played by Renoir), "is that everyone has his reasons." In both films Renoir continued his earlier experiments with directional sound and deep-focus composition. His technical mastery came to influence the American cinema when he emigrated to the United States to escape the Nazis in 1940.

Renoir's social concern

Germany. Because of its ownership of the Tobis-Klang-

Early German sound films

film patents, the German film industry found itself in a position of relative strength in the early years of sound, and it produced several important films during that period, including Sternberg's *Der blaue Engel* (*The Blue Angel,* 1930), Pabst's two antiwar films, *Westfront 1918* (1930) and *Kameradschaft* (1931), and his adaptation of Bertolt Brecht's *Die Dreigroschenoper* (*The Threepenny Opera,* 1931). The most influential of the early German sound films, however, was Lang's *M* (1931), which utilized a dimension of aural imagery to counterpoint its visuals in the manner of Hitchcock's *Blackmail. M* has no musical score but makes expressive use of nonnaturalistic sound, as when the child murderer (played by Peter Lorre) is heard to whistle a recurring theme from Grieg's *Peer Gynt* before committing his crimes offscreen.

German cinema became moribund after Hitler took power in 1933, primarily because Goebbels encouraged filmmakers to produce trivial and escapist entertainment rather than more meaningful or thought-provoking fare. One director who did create films of undeniable artistic quality under Goebbels' regime was Leni Riefenstahl. She made striking use of asynchronous sound and montage in two propaganda epics commissioned by Hitler, *Triumph des Willens* (*Triumph of the Will,* 1935) and *Olympische Spiele 1936* (1938). A similar situation existed in Mussolini's Italy, where Fascist censorship mandated the production of *telefono bianco,* or "white telephone" films (lightweight romantic comedies with glamorous studio sets), and occasional nationalist propaganda, although Mussolini did establish a national film school (the Centro Sperimentale di Cinematografia, 1935) and a huge new studio complex (Cinecittà, 1937) in Rome.

Soviet Union. Although the Soviet engineers P.G. Tager and A.F. Shorin had designed optical sound systems as early as 1927, neither was workable until 1929. Sound was slow in coming to the Soviet Union: most Soviet transitional films were technically inferior to those of the West, and Soviet filmmakers continued to make silent films until the mid-30s. As in Germany and Italy, however, sound reemphasized film's propaganda value, and through the authoritarian government's policy of socialist realism the Soviet cinema became an instrument of mass indoctrination as never before. The filmmakers most affected by the new policy were the great montage artists of the 1920s. Each of them made admirable attempts to experiment with sound—Kuleshov's *The Great Consoler* (1933), Vertov's *Symphony of the Donbas* (1931) and *Three Songs About Lenin* (1934), Eisenstein's *Bezhin Meadow* (1935; terminated by Shumyatsky in mid-production), Pudovkin's *A Simple Case* (1932) and *Deserter* (1933), and Dovzhenko's *Ivan* (1932)—but their work was ultimately suppressed or defamed by the party bureaucracy. Only Eisenstein was powerful enough to reassert his genius: in the nationalistic epic *Alexander Nevsky* (1938), whose contrapuntal sound track is a classic of its kind, and in the operatically stylized *Ivan the Terrible, Parts I and II* (1944–46), a veiled critique of Stalin's autocracy. Most of the films produced at the time were propaganda glorifying national heroes (Sergey and Georgy Vasiliev's *Chapayev,* 1934; Vladimir Petrov's *Peter the First, Parts I and II,* 1937–39), literary adaptations (Mark Donskoy's Gorky trilogy: *The Childhood of Maxim Gorky,* 1938; *My Apprenticeship,* 1939; and *My Universities,* 1940), or escapist, Hollywood-style musicals (Grigory Aleksandrov's *Jazz Comedy,* 1934).

Japanese conversion to sound

Japan. In Japan, as in the Soviet Union, the conversion to sound was a slow process: in 1932 only 45 of 400 features were made with sound, and silent films continued to be produced in large numbers until 1937. The main reason for the slow conversion was that Japanese motion pictures had "talked" since their inception through the mediation of a *benshi,* a commentator who stood to the side of the screen and narrated the action for the audience in the manner of Kabuki theatre. The arrival of recorded sound liberated the Japanese cinema from its dependence on live narrators and was resisted by the *benshi,* many of whom were stars in their own right and possessed considerable box-office appeal. In the end, however, Japan's conversion to sound was complete.

As in the United States, the introduction of sound enabled the major Japanese film companies (Nikkatsu, founded 1912; Shochiku, 1920; and Toho, *c.* 1935) to acquire smaller companies and form vertical monopolies controlling production, distribution, and exhibition. Production procedures were standardized and structured for the mass production of motion pictures, and the studios increased their efficiency by specializing in either *jidaigeki,* period films set before 1868 (the year marking the beginning of the Meiji Restoration, 1868–1912, and the abolition of the feudal shogunate), or *gendai-geki,* films of contemporary life, set any time thereafter. Although, as a matter of geopolitical circumstance, there was hardly any export market for Japanese films prior to World War II, the domestic popularity of sound films enabled the Japanese motion-picture industry to become one of the most prolific in the world, releasing 400 films annually to the nation's 2,500 theatres. Most of these films had no purpose other than entertainment, but in the late 1930s, as the government became increasingly expansionist and militaristic, Japan's major directors turned to works of social criticism called "tendency" films, such as Ozu Yasujirō's *The Only Son* and Mizoguchi Kenji's *Osaka Elegy* and *Sisters of the Gion* (all 1936). In response the government imposed a strict code of censorship that was retained throughout the war.

India. In India, sound created a major industrial boom by reviving a popular 19th-century theatrical form: the folk-music drama based on centuries-old religious myths. Despite the fact that films had to be produced in as many as 10 regional languages, the popularity of these "all-talking, all-singing, all-dancing" mythologicals or historicals played an enormous role in winning acceptance for sound throughout the subcontinent and in encouraging the growth of the Indian film industry. An average of 230 features were released per year throughout the 1930s, almost all for domestic consumption.

THE WAR YEARS AND POST-WORLD WAR II TRENDS

Decline of the Hollywood studios. During the U.S. involvement in World War II, the Hollywood film industry cooperated closely with the government to support its war-aims information campaign. Following the declaration of war on Japan, the government created a Bureau of Motion Picture Affairs to coordinate the production of entertainment features with patriotic, morale-boosting themes and messages about the "American way of life," the nature of the enemy and the allies, civilian responsibility on the home front, and the fighting forces themselves. Initially unsophisticated vehicles for xenophobia and jingoism with titles like *The Devil with Hitler* and *Blondie for Victory* (both 1942), Hollywood's wartime films became increasingly serious as the war dragged on (Lang's *Hangmen Also Die,* Renoir's *This Land Is Mine,* Tay Garnett's *Bataan,* all 1943; Delmer Daves's *Destination Tokyo,* 1944; Hitchcock's *Lifeboat,* 1944; Milestone's *The Purple Heart,* 1944; *A Walk in the Sun,* 1946). In addition to commercial features, several Hollywood directors produced documentaries for government and military agencies. Among the best-known of these films, which were designed to explain the war to both servicemen and civilians, are Frank Capra's seven-part series *Why We Fight* (1942–44), William Wyler's *The Memphis Belle* (1944), John Ford's *The Battle of Midway* (1942), and John Huston's *The Battle of San Pietro* (1944). The last three were shot on location and were made especially effective by their immediacy.

When World War II ended, the American film industry seemed to be in an ideal position. Full-scale mobilization had ended the Depression domestically, and victory had opened vast, unchallenged markets in the war-torn economies of western Europe and Japan. Furthermore, from 1942 through 1945, Hollywood had experienced the most stable and lucrative three years in its history, and in 1946, when two-thirds of the American population went to the movies at least once a week, the studios earned record-breaking profits. The euphoria ended quickly, however, as inflation and labour unrest boosted domestic production costs and as important foreign markets, including Britain and Italy, were temporarily lost to protectionist quotas.

The Paramount decrees

The industry was more severely weakened in 1948, when a federal antitrust suit against the five major and three minor studios ended in the "Paramount decrees," which forced the studios to divest themselves of their theatre chains and mandated competition in the exhibition sector for the first time in 30 years. Finally, the advent of network television broadcasting in the 1940s provided Hollywood with its first real competition for American leisure time by offering consumers "movies in the home."

The American film industry's various problems and the nation's general postwar disillusionment generated several new film types in the late 1940s. Although the studios continued to produce traditional genre films, such as westerns and musicals, their financial difficulties encouraged them to make realistic, small-scale dramas rather than fantastic, lavish epics. Instead of depending on spectacle and special effects to create excitement, the new lower-budget films tried to develop thought-provoking or perverse stories reflecting the psychological and social problems besetting returning war veterans and and others adapting to postwar life. Some of the American cinema's grimmest and most naturalistic films were produced during this period, including those of the so-called social consciousness cycle, which attempted to deal realistically with such endemic problems as racism (Elia Kazan's *Gentleman's Agreement,* 1947; Alfred Werker's *Lost Boundaries,* 1949), alcoholism (Stuart Heisler's *Smash-Up,* 1947), and mental illness (Anatole Litvak's *The Snake Pit,* 1948); the semidocumentary melodrama, which reconstructed true criminal cases and were often shot on location (Kazan's *Boomerang,* 1947; Henry Hathaway's *Kiss of Death,* 1947); and the *film noir,* whose dark, fatalistic interpretations of contemporary American reality are unique in the industry's history (Tay Garnett's *The Postman Always Rings Twice,* 1946; Welles's *The Lady from Shanghai,* 1948; Jacques Tourneur's *Out of the Past,* 1947; Abraham Polonsky's *Force of Evil,* 1948).

Hollywood blacklisting

Film content was next influenced strongly by the fear of Communism that pervaded the United States during the late 1940s and early '50s. Anti-Communist "witch-hunts" began in Hollywood in 1947 when the House Un-American Activities Committee (HUAC) decided to investigate Communist influence in motion pictures. More than 100 witnesses, including many of Hollywood's most talented and popular artists, were called before the committee to answer questions about their own and their associates' alleged Communist affiliations. On Nov. 24, 1947, a group of eight screenwriters and two directors, later known as the Hollywood Ten, were sentenced to serve up to a year in prison for refusing to testify. That evening the members of the Association of Motion Picture Producers, which included the leading studio heads, published what became known as the Waldorf Declaration, in which they fired the members of the Hollywood Ten and expressed their support of HUAC. The studios, afraid to antagonize already shrinking audiences, then initiated an unofficial policy of blacklisting, refusing to employ any person even suspected of having Communist associations. Hundreds of people were fired from the industry, and many creative artists were never able to work in Hollywood again. Throughout the blacklisting era, filmmakers refrained from making any but the most conservative motion pictures; controversial topics or new ideas were carefully avoided. The resulting creative stagnation, combined with financial difficulties, contributed significantly to the demise of the studio system, although, paradoxically, the actions that the studios took between 1952 and 1965, including the practice of blacklisting, can be viewed as an attempt to halt the industry's decline.

The film industry's reaction to television

The film industry believed that the greatest threat to its continued success was posed by the television industry, especially in light of the Paramount decrees. The studios seemed to be losing their control of the nation's theatres at the same time that exhibitors were losing their audiences to television. The studios therefore attempted to diminish television's appeal by exploiting the two obvious advantages that film enjoyed over the new medium—the size of its images and, at a time when all television broadcasting was in black and white, the ability to produce photographic colour. (In the 1952–53 season, the ability to produce multiple-track stereophonic sound joined this list.) In the late 1940s, less than 12 percent of Hollywood features were produced in colour, primarily because of the expense of three-strip Technicolor filming. In 1950, however, a federal consent decree dissolved the Technicolor Corporation's de facto monopoly on the process, and Kodak simultaneously introduced a new multilayered film stock in which emulsions sensitive to the red, green, and blue parts of the spectrum were bonded together on a single roll. Patented as Eastmancolor, this "integral tripack" process offered excellent colour resolution at a low cost because it could be used with conventional cameras. Its availability hastened the industry's conversion to full colour production. By 1954 more than 50 percent of American features were made in colour, and the figure reached 94 percent by 1970.

The aspect ratio (the ratio of width to height) of the projected motion-picture image had been standardized at 1.33 to 1 since 1932, but as television eroded the film industry's domestic audience, the studios increased screen size as a way of attracting audiences back into theatres. For both optical and architectural reasons this change in size usually meant increased width, not increased height. Early experiments with multiple-camera wide-screen (Cinerama, 1952) and stereoscopic 3-D (Natural Vision, 1952) provoked audience interest, but it was an anamorphic process called CinemaScope that prompted the wide-screen revolution. Introduced by 20th Century-Fox in the biblical epic *The Robe* (1953), CinemaScope used an anamorphic lens to squeeze a wide-angle image onto conventional 35-millimetre film stock and a similar lens to restore the image's original width in projection. CinemaScope's aspect ratio was 2.55 to 1, and the system had the great advantage of requiring no special cameras, film stock, or projectors. By the end of 1954, every Hollywood studio but Paramount had leased a version of the process from Fox (Paramount adopted a nonanamorphic process called VistaVision that exposed double-frame images by running film through special cameras and projectors horizontally rather than vertically), and many studios were experimenting with wide-gauge film systems (*e.g.,* Todd-AO, 1955; Panavision-70, 1960) that required special equipment but eliminated the distortion inherent in the anamorphic process.

Like the coming of sound, the conversion to wide-screen formats produced an initial regression as filmmakers learned how to compose and edit their images for the new elongated frame. Sound had promoted the rise of aurally intensive genres such as the musical and the gangster film, and the wide-screen format similarly created a bias in favour of visually spectacular subjects and epic scale. The emergence of the three-to-four hour wide-screen "blockbuster" in such films as *War and Peace, Around the World in Eighty Days,* and *The Ten Commandments* in 1956 coincided with the era's affinity for safe and sanitized material. Given the political paranoia of the times, few subjects could be treated seriously, and the studios concentrated on presenting traditional genre fare—westerns, musicals, comedies, and blockbusters—suitable for wide-screen treatment. Only a director like Hitchcock, whose style was oblique and imagist, could prosper in such a climate. He produced his greatest work during the period, much of it in VistaVision (*Rear Window,* 1954; *The Man Who Knew Too Much,* 1956; *Vertigo,* 1958; *North by Northwest,* 1959; *Psycho,* 1960; *The Birds,* 1963).

In spite of the major film companies' elaborate strategies of defense, they continued to decline throughout the 1950s and '60s. Because they could no longer dominate the exhibition sector, they faced serious competition for the first time from independent and foreign filmmakers. "Runaway" productions (films made away from the studios, frequently abroad, to take advantage of lower costs) became common, and the Production Code was dissolved as a series of federal court decisions between 1952 and 1958 extended First Amendment protection to motion pictures. As their incomes shrank, the major companies' vast studios and backlots became liabilities that ultimately crippled them. The minor companies, however, owned

modest studio facilities and had lost nothing by the Paramount decrees because they controlled no theatres. They were thus able to prosper during this era, eventually becoming major companies themselves in the 1970s.

Italian Neorealist movement

International cinema. *Italy.* World War II physically and economically devastated the film industries of the Soviet Union, Japan, and most of the European nations. Italy's early surrender, however, left its facilities relatively intact, enabling the Italian cinema to lead the post-World War II film renaissance with its development of the Neorealist movement. Although it had roots in both Soviet expressive realism and French poetic realism, Neorealism was decidedly national in focus, taking as its subject the day-to-day reality of a country traumatized by political upheaval and war.

Most of the major figures in the Neorealist movement had studied at Mussolini's Centro Sperimentale, but they vigorously rejected the stagy, artificial style associated with the *telefono bianco* films in favour of a Marxist aesthetic of everyday life. The first identifiable Neorealist film was Luchino Visconti's *Ossessione* (*Obsession,* 1942), a bleak contemporary melodrama shot on location in the countryside around Ferrara. It was suppressed by the Fascist censors, however, so that international audiences were first introduced to the movement through Roberto Rossellini's *Roma, città aperta* (*Open City,* 1945), which was shot on location in the streets of Rome only two months after Italy's surrender. The film featured both professional and nonprofessional actors and focused on ordinary people caught up in contemporary events. Its documentary texture, postrecorded sound track, and improvisational quality became the hallmark of the Neorealist movement. Rossellini followed it with *Paisà* (*Paisan,* 1946) and *Germania, anno zero* (*Germany, Year Zero,* 1947) to complete his "war trilogy." Visconti's second contribution to Neorealism was *La terra trema* (*The Earth Trembles,* 1948), an epic of peasant life that was shot on location in a Sicilian fishing village. In many respects it is more exemplary of the movement than *Ossessione* and is widely regarded as a masterpiece. Neorealism's third major director was Vittorio De Sica, who worked in close collaboration with scriptwriter Cesare Zavattini, the movement's major theorist and spokesman. De Sica's films sometimes tend toward sentimentality but in *Sciuscià* (*Shoeshine,* 1946), *Ladri di biciclette* (*The Bicycle Thief,* 1948), and *Umberto D.* (1952), he produced works central to the movement.

By courtesy of the Museum of Modern Art/Film Stills Archive, New York City



Lamberto Maggiorani and Enzo Staiola as the father and son in Vittorio De Sica's *The Bicycle Thief* (1948).

Influence of Neorealism

Neorealism was the first postwar cinema to reject Hollywood's narrative conventions and studio production techniques, and, as such, it had enormous influence on future movements like British "social realism," Brazilian *Cinema Nôvo,* and the French and Czech New Wave. It also heralded the practices of shooting on location using natural lighting and postsynchronizing sound that later became standard in the film industry. Despite its influence, in the 1950s Neorealism disappeared as a distinct national movement, together with the socioeconomic context that had produced it, as the Marshall Plan began to work its "economic miracle" in Europe. Italian cinema remained prominent nevertheless through the films of several gifted directors who began their careers as Neorealists and went on to produce their major work during the 1960s and '70s.

Federico Fellini had worked as a scriptwriter for Rossellini before directing in the 1950s an impressive series of films whose form was Neorealist but whose content was allegorical (*I vitelloni* [*The Loafers*], 1953; *La strada* [*The Road*], 1954; *Le notti di Cabiria* [*Nights of Cabiria*], 1956). During the 1960s Fellini's work became increasingly surrealistic (*La dolce vita* [*The Sweet Life*], 1960; *Otto e mezzo* [*8½*], 1963; *Giulietta degli spiriti* [*Juliet of the Spirits*], 1965; *Fellini Satyricon,* 1969), and by the 1970s he was perceived to be a flamboyant ironic fantasist—a reputation that sustained him through such serious and successful films as *Fellini Roma* (1972), *Amarcord* (1974), and *E la nave va* (*And the Ship Sails On,* 1983).

Michelangelo Antonioni had also collaborated with Rossellini. Accordingly, his first films were Neorealist documentary shorts (*Gente del Po* [*People of the Po*], 1947), but during the 1950s he turned increasingly to an examination of the Italian bourgeoisie in such films as *Cronaca di un amore* (*Story of a Love Affair,* 1950), *La signora senza camelie* (*Camille Without Camellias,* 1953), and *Le amiche* (*The Girlfriends,* 1955), and in the early 1960s Antonioni produced a trilogy on the malaise of the middle class that made him internationally famous. In *L'avventura* (*The Adventure,* 1959), *La notte* (*The Night,* 1960), and *L'eclisse* (*The Eclipse,* 1962), he used long-take sequence shots equating film time with real time to create a vision of the reverberating emptiness of modern urban life. Antonioni then began to use colour expressionistically in *Deserto rosso* (*Red Desert,* 1964) and *Blow-Up* (1966) to convey alienation and abstraction from human feeling, and all of his later works in some way concerned the breakdown of personal relationships (*Zabriskie Point,* 1970; *Identificazione di una donna* [*Identification of a Woman*], 1982) and of identity itself (*The Passenger,* 1975).

While Fellini and Antonioni were putting Italy in the vanguard of modernist cinema, the country's second post-World War II generation of directors emerged. Ermanno Olmi (*Il posto* [*The Job*], 1961; *Un certo giorno* [*One Fine Day*], 1968; *L'albero degli zoccoli* [*The Tree of Wooden Clogs*], 1979) continued the Neorealist tradition in tales of ordinary people caught up in systems beyond their comprehension. Pier Paolo Pasolini, who had worked as a scriptwriter for Fellini, achieved international recognition for *Il vangelo secondo Matteo* (*The Gospel According to St. Matthew,* 1964), a brilliant semidocumentary reconstruction of the life of Christ with Marxist overtones. Before his murder in 1975, Pasolini went on to direct a series of astonishing, often outrageous films that set forth a Marxist interpretation of history and myth—*Edipo re* (*Oedipus Rex,* 1967), *Teorema* (*Theorem,* 1968), *Porcile* (*Pigsty,* 1969), *Medea* (1969), and *Salò* (1975). Like Pasolini, Bernardo Bertolucci is a Marxist intellectual whose films attempt to correlate sexuality, ideology, and history; his most successful films have been *Il conformista* (*The Conformist,* 1970), a striking dissection of the psychopathology of fascism, *Ultimo tango a Parigi* (*Last Tango in Paris,* 1972), a meditation on sex and death, and *Novecento* (*1900,* 1976), a six-hour epic covering 50 years of Italian class conflict.

Since the 1970s, the declining European economy has compelled many Italian directors to make co-productions with American, French, German, and Swedish companies. In order to maximize profits, several such films featured international stars in leading roles. This dependence on world markets—as well as the increased popularity of television throughout Italy—often led to the loss of national identity in Italian films, although such filmmakers as Roberto Benigni, Carlo Verdone, and Maurizio Nichetti were able to use the new situation to good advantage. Perhaps the most individual voice in recent Italian cinema has been Nanni Moretti, whose humorous, satiric works, such as *Caro diario* (*Dear Diary,* 1994), critique the social values of the late 20th century.

France. French cinema of the Occupation and postwar era produced many fine films (Marcel Carné's *Les Enfants du paradis* [*The Children of Paradise*], 1945; Jean

Cocteau's *La Belle et la bête* [*Beauty and the Beast*], 1946; René Clément's *Jeux interdits* [*Forbidden Games*], 1952; Jacques Becker's *Casque d'or* [*Golden Helmet*], 1952; Henri-Georges Clouzot's *Le Salaire de la peur* [*The Wages of Fear*], 1953), but their mode of presentation relied heavily on script and was predominantly literary. There were exceptions in the austere classicism of Robert Bresson (*Le Journal d'un curé de campagne* [*The Diary of a Country Priest*], 1950; *Un Condamné à mort s'est échappé* [*A Man Escaped*], 1956), the absurdist comedy of Jacques Tati (*Les Vacances de M. Hulot* [*Mr. Hulot's Holiday*], 1953; *Mon oncle* [*My Uncle*], 1958), and the lush, magnificently stylized masterworks of the German émigré Max Ophüls, whose *La Ronde* (1950), *Le Plaisir* (1952), *Madame de . . .* (1953), and *Lola Montès* (1955) represent significant contributions to world cinema. An independent documentary movement, which produced such landmark nonfiction films as Georges Rouquier's *Farrebique* (1948), Georges Franju's *Le Sang des bêtes* (*The Blood of the Beasts,* 1949), and Alain Resnais's *Nuit et brouillard* (*Night and Fog,* 1956), also emerged at this time. It provided a training ground for young directors outside the traditional industry system and influenced the independent production style of the movement that culminated the French postwar period of renewal—the *nouvelle vague,* or New Wave movement.

French New Wave movement

The most important source of the New Wave lay in the theoretical writings of Alexandre Astruc and, more prominently, of André Bazin, whose thought molded an entire generation of filmmakers, critics, and scholars. In 1948 Astruc formulated the concept of the *caméra-stylo* ("camera-pen"), in which film was regarded as a form of audiovisual language and the filmmaker, therefore, as a kind of writer in light. Bazin's influential journal *Cahiers du Cinéma,* founded in 1951, elaborated this notion and became the headquarters of a group of young *cinéphiles* ("film-lovers")—the critics François Truffaut, Jean-Luc Godard, Claude Chabrol, Jacques Rivette, and Eric Rohmer—who were to become the major directors of the New Wave. Bazin's basic principle was a rejection of montage aesthetics—both radical Eisensteinian cutting and Hollywood-style continuity, or invisible, editing—in favour of the long take and composition in depth, or what he called mise-en-scène. Borrowed from the theatre, this term literally means "the placing in the scene," but Bazin used it to designate such elements of filmic structure as camera placement and movement, the lighting of shots, and blocking of action—that is, everything that precedes the editing process.

The *Cahiers* critics embraced mise-en-scène aesthetics and borrowed the idea of authorship from Astruc. In proposing *la politique des auteurs* ("the policy of authors"), christened the auteur theory by the American critic Andrew Sarris, they maintained that film should be a medium of personal artistic expression and that the best films are those imprinted with their makers' individual signature. As a logical consequence of this premise, the *Cahiers* critics rejected mainstream French cinema and its "tradition of quality" in favour of the classical mise-en-scène tradition (exemplified in the films of Feuillade Murnau, Stroheim, Renoir, Welles, Ophüls), Hollywood studio directors who had transcended the constraints of the system to make personal films (Hawks, Sternberg, Hitchcock, Ford), and the low-budget American B-film in which the director usually had total control over production.

The first films of the New Wave were independently produced dramatic shorts shot in 16-millimetre by the *Cahiers* critics in 1956–57, but 1959 was the year that brought the movement to international prominence, when each of its three major figures made their first features. Truffaut's *Les Quatre cents coups* (*The 400 Blows*), Alain Resnais's *Hiroshima, mon amour,* and Godard's *À bout de souffle* (*Breathless*) were all in their different ways paradigms of a fresh new style based on elliptical editing and location shooting with hand-held cameras. This style was both radically destructive of classical Hollywood continuity and pragmatically suited to the New Wave's need to make its films quickly and cheaply. Its ultimate effect was to deconstruct the narrative language that had evolved over the previous 60 years and to create a reflexive cinema, or meta-cinema, whose techniques provided a continuous comment on its own making.

Truffaut, Resnais, and Godard

The critical and commercial success of the first New Wave features produced an unprecedented creative explosion within the French industry. Between 1960 and 1964, literally hundreds of low-budget experimental films were made by *cinéphiles* with little or no experience. Many of these ended in failure, and the New Wave as a collective phenomenon was over by 1965. But the three figures who had initiated the movement and a small group of sophisticated but less spectacular talents—Claude Chabrol, Louis Malle, Eric Rohmer, Agnès Varda, Jacques Demy, and Jacques Rivette—continued to dominate French cinema until well into the 1970s.

By courtesy of Janus Films, Inc.; photograph, from the Museum of Modern Art/Film Stills Archive, New York City



Jean-Pierre Léaud as Antoine Doinel (centre) in *The 400 Blows* (1959), directed by François Truffaut.

Truffaut was the most commercially successful of the original New Wave group, and through such films as *Jules et Jim* (1961) and the autobiographical "Antoine Doinel" series, which began with *Les Quatre Cents Coups,* he acquired a reputation as a romantic ironist. Truffaut's range also extended to parodies of Hollywood genres (*Tirez sur le pianiste* [*Shoot the Piano Player*], 1960), homages to Hitchcock (*La Mariée etait en noir* [*The Bride Wore Black*], 1967), historical reconstructions (*L'Enfant sauvage* [*The Wild Child*], 1970), reflexive narratives (*La Nuit américaine* [*Day for Night*], 1973), and literary adaptations (*L'Histoire d'Adèle H.* [*The Story of Adele H.*], 1975; *Le Dernier Métro* [*The Last Metro*], 1980).

Godard was the most stylistically and politically radical of the early New Wave directors. Some of his early films were parodies of Hollywood genres (*Une Femme est une femme* [*A Woman Is a Woman*], 1961; *Alphaville,* 1965; *Pierrot le fou,* 1965), but the majority treated political and social themes from a Marxist, and finally Maoist, perspective (*Le Petit Soldat* [*The Little Soldier*], 1960; *Vivre sa vie* [*My Life to Live*], 1962; *Les Carabiniers* [*The Riflemen*], 1963; *Bande à part* [*Band of Outsiders*], 1964); *Une Femme mariée* [*A Married Woman*], 1964). With *Masculin-féminin* (1966), Godard turned away from narrative toward the form of the *cinéma vérité*-style essay, and his later films became increasingly ideological and structurally random (*Made in U.S.A.,* 1966; *Deux ou trois choses que je sais d'elle* [*Two or Three Things I Know About Her*], 1967; *La Chinoise,* 1967; *Week-end,* 1967; *One Plus One,* 1968). During the 1970s, Godard made films for the radical Dziga Vertov production collective (*Pravda,* 1969; *Le Vent d'est* [*Wind from the East*], 1969; *Letter to Jane,* 1972) and experimented with combinations of film and videotape (*Numero deux* [*Number Two*], 1975; *La Communication,* 1976). In the 1980s Godard returned to theatrical filmmaking, purified of ideology but no less controversial for it, with such provocative features as *Sauve qui peut/La Vie* (*Every Man for Himself,* 1980), *Passion* (1982), and *Je vous salue, Mary* (*Hail Mary,* 1986).

Resnais was slightly older than the *Cahiers* group, but he identified with the New Wave through style and theme. His most famous film is the postmodern mystery *L'Année dernière à Marienbad* (*Last Year at Marienbad,* 1961), which questions the processes of thought and memory—

central concerns in Resnais's work. *Muriel* (1963), *La Guerre est finie* (*The War Is Over,* 1966), *Stavisky* (1974), *Providence* (1977), and *Mon oncle d'Amérique* (*My Uncle in America,* 1978) are all in various ways concerned with the effects of time on human memory from both a historical and a personal perspective.

Other important New Wave figures who remain influential are Claude Chabrol, whose entire career can be seen as an extended homage to Hitchcock (*La Femme infidèle* [*Unfaithful Wife*], 1968; *Que la bête meure* [*This Man Must Die*], 1969; *Le Boucher* [*The Butcher*], 1970; *Violette Nozière,* 1978); Louis Malle, a master of film types who relocated in the United States (*Le Feu follet* [*The Fire Within*], 1963; *Le Souffle au coeur* [*Murmur of the Heart*], 1971; *Lacombe, Lucien,* 1973; *Pretty Baby,* 1978; *Atlantic City,* 1980); Eric Rohmer, whose "moral tales," including *Ma Nuit chez Maud* (*My Night at Maud's,* 1968) and *Le Genou de Claire* (*Claire's Knee,* 1970), established the ironic perspective on human passion that he maintained in such later films as *Pauline à la plage* (*Pauline at the Beach,* 1983); *Le Bonheur* [*Happiness*], 1965); Jacques Demy, whose best films are homages to the Hollywood musical (*Les Parapluies de Cherbourg* [*The Umbrellas of Cherbourg*], 1964; *Les Demoiselles de Rochefort* [*The Young Girls of Rochefort*], 1967); and Jacques Rivette, the most austerely abstract and experimental of the *Cahiers* group (*La Religieuse* [*The Nun*], 1965; *L'Amour fou,* 1968; *Céline et Julie vont en bateau* [*Celine and Julie Go Boating*], 1974; *Duelle,* 1977).

Influence of the New Wave

Few national movements have influenced international cinema as strongly as the French New Wave. By promoting the concept of personal authorship, its directors demonstrated that film is an audiovisual language that can be crafted into "novels" and "essays"; and by deconstructing classical Hollywood conventions, they added dimensions to this language that made it capable of expressing a new range of internal and external states. In the process, the New Wave helped to reinvigorate such stylistically moribund cinemas as the British, West German, and American, and it created a current of "second waves" and "third waves" in the already flourishing Italian, Polish, Czech, Hungarian, and Japanese cinemas.

The New Wave made France the leading centre of Modernist and postmodern film and film theory, a position it continued to hold for many years. By the 1990s, France followed the lead of other European countries in assimilating itself into the world market. The influences of the New Wave were still evident, but increased demands for commercial fare resulted in several crime thrillers and period costume dramas, genres that were often specialties of young directors.

Unique among European filmmakers, however, many French directors remain unfettered by commercial demands. At the turn of the 21st century, Claude Chabrol was still a dominant force, with such films as *La Cérémonie* (*Judgment in Stone,* 1995) demonstrating his continued mastery of the psychological thriller. Prominent young directors included Manuel Poirier, who specialized in affectionate, offbeat romances and "buddy pictures," such as *Western* (1997); Claire Simon, who, after several years of directing documentaries, adapted her characteristic ironic humour to such fictional films as *Sinon, oui* (*A Foreign Body,* 1997) and *Ca c'est vraiment toi* (*That's Just Like You,* 2000); and Robert Guédiguian, a writer-producer-director known for works such as *Marius et Jeannette* (1997) and *À la place du coeur* (1998), which effectively blend affectionate character studies with biting social satire.

Great Britain. In Great Britain the post-World War II cinema was even more literary than in France, relying heavily on the adaptation of classics in the work of such directors as Laurence Olivier (*Henry V,* 1944; *Hamlet,* 1948; *Richard III,* 1955), David Lean (*Great Expectations,* 1946; *Oliver Twist,* 1948), and Anthony Asquith (*The Importance of Being Earnest,* 1952). Even less conventional films had literary sources (Carol Reed's *Outcast of the Islands,* 1951; Michael Powell's and Emeric Pressberger's *The Red Shoes,* 1948, and *The Tales of Hoffman,* 1951). There were exceptions to this trend in a series of witty irreverent comedies made for Michael Balcon's Ealing Studios (*The Lavender Hill Mob,* 1951; *The Man in the White Suit,* 1951; *Kind Hearts and Coronets,* 1949), most of them starring Alec Guinness, but on the whole British postwar cinema was elitist and culturally conservative.



Jean Simmons as Estella, Martita Hunt as Miss Havisham, and Anthony Wager as young Pip in David Lean's *Great Expectations* (1946).
By courtesy of the Museum of Modern Art/Film Stills Archive, New York City

In reaction, a younger generation of filmmakers led by Lindsay Anderson, Czechoslovak-born Karel Reisz, and Tony Richardson organized the Free Cinema movement in the mid-50s. Its purpose was to produce short, low-budget documentaries illuminating problems of contemporary life (Anderson's *O Dreamland,* 1953; Richardson's *Momma Don't Allow,* 1955). Grounded in the ideology and practice of Neorealism, Free Cinema emerged simultaneously with a larger social movement assailing the British class structure and calling for the replacement of bourgeois elitism with liberal working-class values. In the cinema this antiestablishment agitation resulted in the New Cinema or social realist movement signaled by Reisz's *Saturday Night and Sunday Morning* (1960), the first British postwar feature with a working class protagonist and proletarian themes. Stylistically influenced by the New Wave, with which it was concurrent, the social realist film was generally shot in black and white on location in the industrial Midlands and cast with unknown young actors and actresses. Like the New Wave films, social realist films were independently produced on low budgets (many of them for Woodfall Film Productions, the company founded in 1958 by Richardson and playwright John Osborne to adapt the latter's *Look Back in Anger*), but their freshness of both content and form attracted an international audience. Some of the most famous were Richardson's *A Taste of Honey* (1961) and *The Loneliness of the Long Distance Runner* (1962), John Schlesinger's *A Kind of Loving* (1962) and *Billy Liar* (1963), and Anderson's *This Sporting Life* (1963), and Reisz's *Morgan: A Suitable Case for Treatment* (1966).

British social realist movement

These films brought such prestige to the British film industry that London briefly became the production capital of the Western world, delivering such international hits as Richardson's *Tom Jones* (1963), Schlesinger's *Darling* (1965), Richard Lester's two Beatles films, *A Hard Day's Night* (1964) and *Help!* (1965), Schlesinger's *Far from the Madding Crowd* (1967), and Anderson's *If . . .* (1968), as well as such foreign importations as Roman Polanski's *Repulsion* (1965) and *Cul-de-sac* (1966), Truffaut's *Farenheit 451* (1966), Antonioni's *Blow-Up* (1966), and Stanley Kubrick's *2001: A Space Odyssey* (1968) and *A Clockwork Orange* (1971). This activity inspired a new, more visually oriented generation of British filmmakers—Peter Yates, John Boorman, Ken Russell, Nicolas Roeg, and Ridley Scott—who would make their mark in the 1970s; but as England's economy began its precipitous decline during that decade, so too did its film industry. Many British directors and performers defected to Hollywood, while the English-language film market simultaneously experienced a vigorous and unprecedented challenge from Australia. In the 1980s, amid widespread speculation about the collapse

of the industry, British annual production reached an all-time low.

Britain's film industry, however, has a long history of rebounding from periods of crisis. A major factor in the revival of British cinema during the late 20th century was the founding in 1982 of Channel 4, a television network devoted to commissioning—rather than merely producing—original films. Their success led to the establishment of a subsidiary, FilmFour Ltd., in 1998. Internationally acclaimed films produced or coproduced under either the Channel 4 or FilmFour banner include *A Room with a View* (1986), *The Crying Game* (1992), *Four Weddings and a Funeral* (1994), *Trainspotting* (1996), *The Full Monty* (1997), and *Elizabeth* (1998). Also contributing to the resurgence of British film is the National Lottery, established in 1994, which annually contributes millions of pounds to the film industry.

Germany. Germany's catastrophic defeat in World War II and the subsequent partitioning of the country virtually destroyed its film industry, which had already been corrupted by the Nazis. Rebuilt during the 1950s, the West German industry became the fifth largest producer in the world, but the majority of its output consisted of low-quality *Heimatfilme* ("homeland films") for the domestic market. When this market collapsed in the 1960s because of changing demographic patterns and the diffusion of television, the industry was forced to turn to the federal government for subsidies. In recognition of the crisis, 26 writers and filmmakers at the Oberhausen Film Festival in 1962 drafted a manifesto proclaiming the death of German cinema and demanding the establishment of a *junger deutscher Film,* a "young German cinema." The members of this Oberhausen group became the founders of *das neue Kino,* or New German Cinema, which was brought into being over the next decade through the establishment of the Kuratorium Junger Deutscher Film (1965; Young German Film Board, a grant agency drawing on the cultural budgets of the federal states), the Filmförderungsanstalt, or FFA (Film Subsidies Board, which makes production funds available by levying a federal tax on theatre tickets), and the independent distributing company Filmverlag der Autoren (1971; Authors' Film-Publishing Group), with additional funding from the two West German television networks.

New German Cinema

These institutions made it possible for a new generation of filmmakers to produce their first features and establish a vital new cinema for West Germany that attempted to examine the nation's *unbewältige Vergangenheit,* or "unassimilated past." The first such films, which were influenced by the New Wave, included Volker Schlöndorff's *Der junge Törless* (*Young Torless,* 1966) and Alexander Kluge's *Die Artisten in der Zirkuskuppel: ratlos* (*The Artists Under the Big Top: Disoriented,* 1968). In the 1970s, however, three major figures emerged as leaders of the movement—Rainer Werner Fassbinder, Werner Herzog, and Wim Wenders. Fassbinder was the most prolific, having made more than 40 features before he died in 1982. His films are also the most flamboyant. Nearly all of them take the form of extreme melodrama, ending in murder or suicide—*Warum läuft Herr R. amok?* (*Why Does Herr R. Run Amok?,* 1969), *Die bitteren Tränen der Petra von Kant* (*The Bitter Tears of Petra von Kant,* 1972), *Angst essen Seele auf* (*Fear Eats the Soul/Ali,* 1973)—and several are consciously focused on German wartime and postwar society (*Die Ehe der Maria Braun* [*The Marriage of Maria Braun*], 1979; *Lola,* 1981; *Veronika Voss,* 1982).

Herzog's films tended more toward the mystical and the spiritual than the social, although there is nearly always some contemporary referent in his work—the image of idealism turned to barbarism in *Aguirre, der Zorn Gottes* (*Aguirre, the Wrath of God,* 1972); the inability of science to address the human condition in *Jeder für sich und Gott gegen alle* (*Every Man for Himself and God Against All/Kaspar Hauser,* 1974); the destructive nature of technology in *Herz aus Glas* (*Heart of Glass,* 1977); the incomprehensible nature of pestilence in his remake of Murnau's *Nosferatu* (1979). Wenders, on the other hand, is profoundly postmodern in his contemplation of alienation through spatial metaphor. In such existential works as *Die Angst des Tormanns beim Elfmeter* (*The Goalie's Anxiety at the Penalty Kick,* 1971) and *Im Lauf der Zeit* (*In the Course of Time/Kings of the Road,* 1976), he addressed the universal phenomena of dislocation and rootlessness that afflict society.

The state subsidy system has enabled hundreds of filmmakers, many of whom are women (*e.g.,* Margarethe von Trotta) or members of minorities, to participate in the New German Cinema. With the exception of the work of Fassbinder, Herzog, and Wenders, however, the New German Cinema did not find a large audience outside of West Germany. Yet in terms of exploring and extending the audio-language system of film, it was to the 1970s and '80s very much what the New Wave was to the '60s, and its influence was widely felt.

Since the reunification of Germany in 1990, a national identity has yet to be forged in any of the various arts. Several outstanding German directors and production artists have emerged, however, most of them achieving their greatest success in Hollywood. Roland Emerich (*Independence Day,* 1996; *The Patriot,* 2000) has proven a skillful practitioner of the action-adventure genre; and Wolfgang Petersen, who received international acclaim for *Das Boot* (1982), has earned a reputation for tense thrillers (*In the Line of Fire,* 1993) and unrelenting visual spectacles (*The Perfect Storm,* 2000). German cinematographers (Michael Ballhaus, Karl Walter Lindenlaub) and composers (Hans Zimmer, Christopher Franke) have also been among the more notable artisans in Hollywood films at the turn of the 21st century.

Africa. The development of an indigenous film culture in Africa occurred at different moments in the history of the continent. The various time lines are related to the political, social, and economic situations in each country and to the varying effects of colonialism on the continent. Only Egypt had a truly active film industry for the first half of the 20th century; the development of cinema elsewhere on the continent was largely the result of individual efforts. One such example is that of Paul Soumanou Vieyra, the first African graduate of the French film school Institut des Hautes Études Ciné, who joined with friends to produce the short film *Afrique sur Seine* (1955), considered the first fiction film by black Africans.

Some countries, such as Morocco, have never developed a strong national cinema; others, such as Algeria and Tunisia, have nationalized all or parts of their film industries. Several African nations are members of the Fédération Pan-Africaine des Cinéastes (FEPACI; "Federation of African Filmmakers"), formed in 1969 to oversee the political and financial problems of the film industries throughout the continent.

At the end of the 20th century, many filmmakers and scholars began to examine the questions of, first, what constitutes an "African film" and, second, how film can best deal with the diaspora of the African people. On one hand, African filmmakers to some extent acknowledge and learn from the conventions of Western film. On the other, they often use film to highlight and preserve aspects of the African culture that has been threatened by Western colonialism. As part of this search to define the goals of African cinema, African filmmakers often use the medium as a means to explore the social issues plaguing postcolonial Africa. Directors such as Adama Drabo (*Ta Dona* [*Fire*], 1991) and Moufida Tlatli (*Les silences du palais* [*The Silences of the Palace*], 1994) explored such matters as education, the environment, and women's rights and suggested that traditional approaches to such issues must be adapted to the realities of contemporary Africa. Aspects of these realities were examined by such directors as Tsitsi Dangarembga (*Everyone's Child,* 1996) and Salem Mekuria (*Ye Wonz Maibel* [*Deluge*], 1995), who dealt with the AIDS crisis and political violence, respectively. Colonization itself was examined by such directors as Bassek ba Kobhio, whose satiric study of Albert Schweitzer, *Le Grand Blanc de Lambaréné* (*The Great White Man of Lambaréné,* 1995), shows how colonialism damages both colonizer and the colonized.

Japan. Although more than half of Japan's theatres were destroyed during World War II, most of its studio facilities

were left intact. Japan, therefore, continued to produce films in quantity during the Allied occupation (1945–52). Many traditional Japanese subjects were forbidden by the Allied Command as promoting feudalism, however, including all films classified as *jidai-geki.* Nevertheless, the film that first brought Japanese cinema to international attention belonged to that category: Kurosawa Akira's *Rashomon* (1950), which won the Golden Lion at the 1951 Venice Film Festival. The film, a meditation on the nature of truth set in the medieval past, marked the beginning of the Japanese cinema's unprecedented postwar renaissance. During this period, new export markets opened in the West, and Japanese filmmakers produced some of their finest work. Kurosawa, already well known in his homeland, became the most famous Japanese director in the West on the strength of his masterful samurai epics—*Seven Samurai* (1954), *The Throne of Blood* (1957), *The Hidden Fortress* (1958), and *Yojimbo* (1961)—which raised the *chambara,* or "sword-fight," film to the status of art. He made films in other genres, including literary adaptations (*The Idiot,* 1951; *The Lower Depths,* 1957), *gendai-geki* (*Ikiru* [*To Live/Living*], 1952; *Dodesukaden,* 1970), gangster films (*Stray Dog,* 1949; *The Bad Sleep Well,* 1960; *High and Low,* 1963), and period films that cannot be categorized at all (*Red Beard,* 1965; *Dersu Uzala,* 1975); but Kurosawa always returned to the samurai form for his most profound statements about life and art (*Kagemusha* [*The Shadow Warrior*], 1980; *Ran,* 1985).

Japanese cinema's postwar renaissance



By courtesy of Daiei Motion Picture Co.; photograph, the Museum of Modern Art/Film Stills Archive, New York City

Rashomon (1950), directed by Kurosawa Akira.

Two other established directors of the postwar period were Mizoguchi Kenji and Ozu Yasujirō. Both began their careers in the silent era and were more traditionally Japanese in style and content than Kurosawa. Mizoguchi's films, whether period (*Sansho the Bailiff,* 1954; *Crucified Lovers,* 1954) or contemporary (*Women of the Night,* 1948; *Gion Festival Music,* 1953), were frequently critiques of feudalism that focused on the condition of women within the social order. His greatest postwar films are *The Life of Oharu* (1952), the biography of a 17th-century courtesan, and *Ugetsu* (1953), the story of two men who abandon their wives for fame and glory during the 16th-century civil wars. Both are masterworks that clearly demonstrate Mizoguchi's expressive use of luminous decor, extended long takes, and deep-focus composition. As one of the great mise-en-scène directors, Mizoguchi can be compared to Murnau, Ophüls, and Welles, but his transcendental visual style makes him unique in the history of cinema.

Japanese social critique

Ozu, too, was a stylist, but the majority of his 54 films are *shomin-geki,* a variety of *gendai* film dealing with the lives of lower-middle-class families (*The Only Son,* 1936; *There Was a Father,* 1942; *Late Spring,* 1949; *Early Summer,* 1951; *Tokyo Story,* 1953; *Early Spring,* 1956; *Tokyo Twilight,* 1957; *Equinox Flower,* 1958; *Floating Weeds,* 1959; *An Autumn Afternoon,* 1962). They are all very much alike and, in a sense, are all part of a single large film, whose subject is the ordinary lives of ordinary people and the sacred beauty therein. Ozu's minimalist style—originating in both Zen Buddhist aesthetics and the fact that most of his films were shot within the confines of a typical Japanese house—is based on his use of low-angle long takes in which the camera is positioned about three feet off the floor at the eye-level of a person seated on a tatami mat. This practice led Ozu to an especially imaginative use of offscreen space and "empty scenes."

The second postwar generation of Japanese filmmakers was mainly composed of Kobayashi Masaki, Ichikawa Kon, and Shindo Kaneto. Kobayashi is best known for *The Human Condition* (1959–61), his three-part antiwar epic set during Japan's brutal occupation of Manchuria, the two graphic *jidai-geki Harakiri* (1962) and *Rebellion* (1967), and the beautiful ghost film *Kwaidan* (1964). Ichikawa's major works are the pacifist films *The Burmese Harp* (1956) and *Fires on the Plain* (1959) and his beautifully composed wide-screen films, *Conflagration* (1958), *The Key* (1959), and *Tokyo Olympiad* (1965). Shindo is best known for his poetic semidocumentary *The Island* (1960) and the bizarre, folkloristic *Onibaba* (1964).

The third generation of postwar directors was most active during the 1960s and '70s. They were deeply influenced by the French New Wave and included Teshigahara Hiroshi (*Woman in the Dunes,* 1964), Masumura Yasuzo (*The Red Angel,* 1965), Imamura Shohei (*The Pornographer,* 1966), Hani Susumu (*The Inferno of First Love,* 1968), Shinoda Masahiro (*Double Suicide,* 1969), Yoshida Yoshishige (*Eros plus Massacre,* 1970), and, quintessentially, Oshima Nagisa (*The Man Who Left His Will on Film,* 1970; *In the Realm of the Senses,* 1976). In the mid-1960s, however, competition from television and American distributors forced Japan's film industry into economic decline. A decade later, two major studios were bankrupt, and film production was dominated by two domestic exploitation genres, the *yakuza-eiga,* or urban gangster film, and the semipornographic "eroduction" film, which mixed sex and sadism. During the 1980s and '90s, Japan continued to produce the highest annual volume of films of any nation in the world, but the studios remained in decline and most serious productions, such as Kurosawa's *Kagemusha,* were funded by foreign interests. At the turn of the 21st century, funding for films remained low, although the market for films was greater than ever. This situation led to the mass production of low-budget films, as well as to the increased popularity of amateur and experimental films.

Decline of the Japanese film industry

China, Taiwan, and Korea. Other Asian nations have had spotty cinematic histories, although most developed strong traditions during the late 20th century. The film industries of China, Taiwan, and Korea were marked by government restrictions for most of the 20th century, and the majority of their output consisted of propaganda films. The loosening of many restrictions in the 1980s and '90s resulted in a new wave of Asian directors who have attained worldwide prominence. China's "Fifth Generation Cinema" is known for such outstanding young directors as Zhang Yimou, who specializes in tales of political oppression and sexual repression. Korea's cinematic history is difficult to assess, as virtually no films made prior to World War II exist today, but works produced during the 1950s and '60s—the "golden age" of Korean cinema—have gained a strong international reputation. The most successful Asian director of the late 20th century was Taiwan's Ang Lee, who has directed films ranging from American morality tales (*The Ice Storm,* 1997; *Ride with the Devil,* 1999) to the lavish and widely popular martial-arts fantasy *Crouching Tiger, Hidden Dragon* (2000).

India. Serious postwar Indian cinema was for years associated with the work of Satyajit Ray, a director of singular talent who produced the great Apu trilogy (*Pather panchali* [*The Song of the Road*], 1955; *Aparajito* [*The Unvanquished*], 1956; *Apur sansar* [*The World of Apu*], 1959) under the influence of both Jean Renoir and Italian Neorealism. Ray continued to dominate the Indian cinema

through the 1960s and '70s with such artful Bengali films as *Devi* (*The Goddess,* 1960), *Charulata* (*The Lonely Wife,* 1964), *Aranyer din ratri* (*Days and Nights in the Forest,* 1970), and *Ashanti sanket* (*Distant Thunder,* 1973).

In 1961 the Indian government established the Film Institute of India to train aspiring directors. It also formed the Film Finance Commission (FFC) to fund independent and experimental films. The National Film Archive was founded in 1964. These organizations encouraged the production of such important first features as Mrinal Sen's *Bhuvan Shome* (*Mr. Shome,* 1969), Basu Chatterji's *Sara akaash* (*The Whole Sky,* 1979), Mani Kaul's *Uski roti* (*Daily Bread,* 1969), Kumar Shahani's *Maya darpan* (*Mirror of Illusion,* 1972), Avtar Kaul's *27 Down* (1973), and M.S. Sathyu's *Garam hawa* (*Scorching Wind,* 1973) and promoted the development of a nonstar "parallel cinema" centred in Bombay. During the 1970s the regional industries of the southwestern states—especially those of Kerala and Karnātaka—began to subsidize independent production, resulting in a "southern new wave" in the films of such diverse figures as G. Aravindan (*Kanchana sita* [*Golden Sita*], 1977), Adoor Gopalakrishnan (*Elipathayam* [*Rat-Trap*], 1981), and Girish Karnad (*Kaadu* [*The Forest*], 1973). Despite the international recognition these films have earned, the Indian government's efforts to raise the artistic level of the nation's cinema have been largely unsuccessful. India remains a land of some one billion people, most of them illiterate and poor, whose exclusive access to audiovisual entertainment is film; television is the medium of the rich and powerful middle class. The Indian film industry therefore continues to be the world's largest producer of low-quality films for domestic consumption, releasing 1,000 features per year in 16 languages. (For coverage of recent trends in Indian cinema, see the *Micropædia* article BOLLYWOOD.)

Development of Australian cinema

Australia. Australia was a country virtually without a film industry until the late 1960s and early '70s, when the federal government established the Australian Film Development Corporation (after 1975, the Australian Film Commission) to subsidize the growth of an authentic national cinema, founded a national film school (the Australian Film and Television School, or AFTS) to train directors and other creative personnel, and initiated a system of lucrative tax incentives to attract foreign investment capital to the new industry. The result was a creative explosion unprecedented in the English-language cinema. Australia produced nearly 400 films between 1970 and 1985—more than had been made in all of its prior history.

With financing from the Film Commission and such semiofficial bodies as the New South Wales Film Corporation (by the end of the decade each of the federal states had its own funding agency), the first films began to appear in the early 1970s, and within the next few years several talented directors began to receive recognition, including Peter Weir (*Picnic at Hanging Rock,* 1975), Bruce Beresford (*The Getting of Wisdom,* 1977), Fred Schepisi (*The Chant of Jimmy Blacksmith,* 1978), George Miller (*Mad Max,* 1979), and the first AFTS graduates, Phillip Noyce (*Newsfront,* 1978) and Gillian Armstrong (*My Brilliant Career,* 1979). Unlike the productions financed with foreign capital by the Canadian Film Development Corporation during the same period, these new Australian films had indigenous casts and crews and treated distinctly national themes. By the end of the 1970s, Australian motion pictures were being prominently featured at the Cannes International Film Festival and competing strongly at the box office in Europe. In 1981 Australia penetrated the American market with two critical hits, Beresford's *Breaker Morant* (1980) and Weir's *Gallipoli* (1981), and the following year achieved a smashing commercial success with Miller's *Mad Max II* (1981; retitled *The Road Warrior,* 1982). In the 1980s and '90s many Australian directors came to work for the American film industry, with varying degrees of success. Despite this temporary talent drain and a decline in government tax concessions, the Australian cinema remains one of the most influential and creatively vital in the world. Prominent younger directors who have helped maintain Australia's world status include Baz Luhrmann, noted for his flamboyant visual style on such films as *William Shakespeare's Romeo + Juliet* (1996) and *Moulin Rouge* (2001).

Russia, eastern Europe, and the former Soviet bloc countries. After World War II the Soviet Union's film industry experienced greater stagnation than that of any other nation except Germany. The socialist realism doctrine imposed during Stalin's dictatorship caused film production to fall from 19 features in 1945 to five in 1952. Although Stalin died the following year, the situation did not improve until the late 1950s when such films as Mikhail Kalatozov's *The Cranes Are Flying* (1957) and Grigory Chukhrai's *Ballad of a Soldier* (1959) emerged to take prizes at international film festivals. Some impressive literary adaptations were produced during the 1960s, but the most important phenomenon of the decade was the graduation of a whole new generation of Soviet directors from the VGIK, many of them from the non-Russian republics. By far the most brilliant of the new directors were Sergey Paradzhanov and Andrey Tarkovsky, who both were later persecuted for the unconventionality of their work. Paradzhanov's greatest film is *Shadows of Forgotten Ancestors* (1964), a hallucinatory retelling of a Ukrainian folk legend of ravishing formal beauty. Tarkovsky created a body of work whose seriousness and symbolic resonance had a major impact on world cinema (*Ivan's Childhood,* 1962; *Andrey Rublev,* 1966; *Solaris,* 1971; *Mirror,* 1974; *Stalker,* 1979; *Nostalgia,* 1983; *The Sacrifice,* 1986), even though it was frequently tampered with by Soviet censors.

During the 1970s, the policy of socialist realism (euphemized as "pedagogic realism") was again put into practice, so that only two types of films could safely be made—literary adaptations (Andrey Mikhalkov-Konchalovsky's *Uncle Vanya,* 1970; Nikita Mikhalkov's *Oblomov,* 1980) and *bytovye,* or films of everyday life (Georgy Danelia's *Autumn Marathon,* 1979; Vladimir Menshov's *Moscow Does Not Believe in Tears,* 1980). The Soviet cinema then experienced a far-reaching liberalization under the regime of Party Secretary Mikhail Gorbachev, whose policy of *glasnost* ("openness") took control of the industry away from bureaucratic censors and placed it in the hands of the filmmakers themselves. The Soviet cinema began to be revitalized as formerly suppressed films, such as Elem Klimov's *Agoniya* (1975), were distributed for the first time, and films that dealt confrontationally with Stalinism, such as Tengiz Abuladze's *Repentance* (1987) were made without government interference.

Liberalization of Soviet cinema

Of the eastern European nations that fell under Soviet control after World War II, all except East Germany and Albania produced distinguished cinemas. Following the pattern set by the Soviets, these countries nationalized their film industries and established state film schools. They experienced a similar period of repressive government-imposed restrictions between 1945 and 1953, with a "thaw" during the late 1950s under premier Nikita Khrushchev. In Poland the loosening of ideological criteria gave rise to the so-called Polish School led by Jerzy Kawalerowicz (*Mother Joan of the Angels,* 1961), Andrzej Munk (*Eroica,* 1957; *Passenger,* 1963), and, preeminently, Andrzej Wajda (*A Generation,* 1954; *Canal,* 1956; *Ashes and Diamonds,* 1958). Wajda's reputation grew throughout the 1960s and '70s, when he was joined by a second generation of Polish filmmakers that included Roman Polanski (*Knife in the Water,* 1962), Jerzy Skolimowski (*Barrier,* 1966), and Krzysztof Zanussi (*Structure of Crystals,* 1969; *Illumination,* 1972). The Polish cinema expressed its support of the Solidarity trade union in the late 1970s through films by Wajda (*Man of Marble,* 1977; *Without Anesthesia,* 1978; *Man of Iron,* 1981), Zanussi (*Camouflage,* 1977; *The Constant Factor,* 1980), and such younger directors as Krysztof Kieslowski, Agnieszka Holland, and Feliks Falk.

The example of the Polish School encouraged the development of the Czech New Wave (1962–68), which became similarly entangled in politics. The Czechoslovak films that reached international audiences during this period were widely acclaimed for their freshness and formal experimentation, but they faced official disapproval at home and many were suppressed for being politically subversive. Among the directors who were most critical of President

Czech New Wave

Antonín Novotný's hard-line regime were Věra Chytilová (*Daisies,* 1966), Jaromil Jireš (*The Joke,* 1968), Ján Kadár (*The Shop on Main Street,* 1965), Miloš Forman (*Firemen's Ball,* 1967), Jiří Menzel (*Closely Watched Trains,* 1966), Evald Schorm (*Everyday Courage,* 1964), and Jan Němec (*The Party and the Guests,* 1966). When Alexander Dubček became president in January 1968, the Czechoslovak cinema eagerly participated in his brief attempt to give Socialism "a human face." After the Soviet invasion of August 1968, many New Wave films were banned, the Czechoslovak film industry was reorganized, and several prominent figures, including Forman and Němec, were forced into exile.

In Hungary, the abortive revolution of 1956 forestalled a postwar revival until the late 1960s, when the complex work of Miklos Jancsó (*The Round-Up,* 1965; *The Red and the White,* 1967; *Red Psalm,* 1972) began to be internationally recognized. The rigorous training given students at the Budapest Film Academy ensured that the younger generation of Hungarian filmmakers would rise to prominence, as has been the case for István Szábo (*Mephisto,* 1981), István Gaál (*Falcons,* 1970), Márta Mészáros (*Adoption,* 1975), and Pál Gábor (*Angi Vera,* 1978), many of whose films—as do Jancsó's—involve ideological interpretations of the national past.

Yugoslavia, Romania, and Bulgaria, unlike their more sophisticated Warsaw Pact allies, did not begin to develop film industries until after World War II. Yugoslavia was the most immediately successful and produced the countries' first internationally known director: the political avant-gardist Dušan Makavejev (*The Tragedy of the Switchboard Operator,* 1967; *W.R.—Mysteries of the Organism,* 1971). Makavejev belonged to the late-1960s movement known as *novi film* ("new film"), which also included such directors as Puriša Djordjević, Aleksandar Petrović, and Živojin Pavlović, all of whom were temporarily purged from the film industry during a reactionary period in the early 1970s. This dark period came to an end in 1976 when the filmmakers of the Prague school made their debuts. Goran Marković, Rajko Grlić, Srdjan Karanović, Lordan Zafranović, and Emir Kusturica were all graduates of the FAMU film school in Prague who had begun their careers working for Yugoslav television. Their offbeat, visually flamboyant social comedies brought a new breath of life into Yugoslav cinema and won a number of international prizes. Like Czechoslovakia, whose Jiří Trnka brought puppet animation to a state of perfection in the 1950s, Yugoslavia also became world famous for its animation, especially that of the "Zagreb School" founded by Vatroslav Mimica and Dušan Vukotić.

For decades, state money was readily available for filmmaking throughout the bloc countries, providing the films were ideologically acceptable. This of course changed with the collapse of the Soviet Union in January 1992, whereupon funding became the chief obstacle to filmmaking in the region. By the late 1990s, fewer than two dozen films per year were produced in Russia. Adding to the decline were such factors as theatres that were closed or converted into businesses such as car dealerships, a home-video industry that was barely in its inceptive stages, and the popularity of American and Asian films. Although such directors as Sergei Bodrov and Vladimir Khotinenko have received a degree of international acclaim, the financial situation of the film industries throughout Russia and eastern Europe suggests that it will be many years before these nations establish a degree of prominence in world cinema.

Spain and Mexico. Of the smaller film industries of the West, Spain's should be noted because it produced one of the world's greatest satirists in Luis Buñuel, and Mexico's should be commended because it allowed Buñuel to work after he was forced out of Spain by the Fascists. (Buñuel also worked frequently in France.) In a career that spanned most of film history, Buñuel directed scores of brilliantly sardonic films that assaulted the institutions of bourgeois Christian culture and Western civilization. Buñuel deeply influenced Carlos Saura, another Spanish filmmaker whose work tends toward the grotesque and darkly comic (*La caza* [*The Hunt*], 1966; *La prima Angélica* [*Cousin Angelica*], 1974; *Bodas de sangre* [*Blood Wedding*], 1981), as well as an entire generation of younger directors who began to work after Spanish dictator Francisco Franco's death in 1975 (*e.g.,* Victor Erice, Manuel Gutiérrez Aragón, Jaime Chavarri, and Pilar Miró). Hailed as Spain's most innovative director since Buñuel is Pedro Almodóvar, whose provocative, postmodernist works include *Mujeres al borde de un ataque de nervios* (*Women on the Verge of a Nervous Breakdown,* 1988) and *Todo sobre mi madre* (*All About My Mother,* 1999).

Buñuel's controversial satires

Sweden. The Scandinavian film industries are small, state-subsidized, and (since the introduction of sound) oriented largely toward the domestic market; however, the post-World War II Swedish cinema, like the Spanish, is noted for producing a single exceptional talent: Ingmar Bergman. Bergman first won international acclaim in the 1950s for his masterworks *The Seventh Seal* (1956), *Wild Strawberries* (1957), and *The Virgin Spring* (1960). His trilogies of the 1960s—*Through a Glass Darkly* (1961), *Winter Light* (1963), and *The Silence* (1963); *Persona* (1966), *Hour of the Wolf* (1968), and *Shame* (1968)—were marked by a deep spiritual and intellectual probing, and later films, such as *Cries and Whispers* (1972) and *Fanny and Alexander* (1984), confirmed that he is essentially a religious artist.

RECENT TRENDS IN U.S. CINEMA

In the United States, as elsewhere, the last half of the 1960s was a time of intense conflict between generations and of rapid social change. Deeply involved with its own financial crisis, Hollywood was slow to respond to this new environment, and the studios made increasingly desperate attempts to attract a demographically homogeneous audience that no longer existed. The stupendous failure of 20th Century-Fox's blockbuster *Cleopatra* (1963) was briefly offset by the unexpected success of its *The Sound of Music* (1965), but over the next few years one box-office disaster after another threatened the studios' independence until most were absorbed by conglomerates. The impact of such mergers was pronounced because they reduced filmmaking in the United States to a subordinate role; in the profit-making machinery of multinational corporations, film production was often less important than the production of such items as refined sugar, ball bearings, field ammunition, rubber tires, and soft drinks.

Corporate acquisition of Hollywood studios

Before conglomeration restructured the industry, however, there was an exciting period of experiment as Hollywood tried various things to attract new audiences. In an effort to lure members of the first "television generation" into theatres, the studios even recruited directors from the rival medium, such as Irvin Kershner (*A Fine Madness,* 1966), John Frankenheimer (*Seconds,* 1966), Sidney Lumet (*The Pawnbroker,* 1965), Robert Altman (*Countdown,* 1968), Arthur Penn (*Mickey One,* 1965), and Sam Peckinpah (*Major Dundee,* 1965). These directors collaborated with film-school-trained cinematographers (including Conrad Hall, Haskell Wexler, and William Fraker), as well as with the Hungarian-born cinematographers Laszlo Kovacs and Vilmos Zsigmond, to bring the heightened cinematic consciousness of the French New Wave to the American screen. Their films frequently exhibited unprecedented political and social consciousness as well.

The years 1967–69 marked a turning point in American film history as Penn's *Bonnie and Clyde* (1967), Stanley Kubrick's *2001: A Space Odyssey* (1968), Peckinpah's *The Wild Bunch* (1969), Wexler's *Medium Cool* (1969), and Dennis Hopper's *Easy Rider* (1969) attracted the youth market to theatres in record numbers. (Altman's *M*A*S*H* [1970] provided a novel comedic coda to the quintet.) The films were unequal aesthetically (the first three being major revisions of their genres, the latter two canny exploitations of the prevailing mood), but all shared a cynicism toward established values and a fascination with apocalyptic violence. There was a sense, however briefly, that such films might provide the catalyst for a cultural revolution. Artistically, the films domesticated New Wave camera and editing techniques, enabling once-radical practices to enter the mainstream narrative cinema. Financially, they were so successful that producers quickly

Success of "youth-culture" motion pictures



Michael J. Pollard, Faye Dunaway, and Warren Beatty in a scene from Arthur Penn's *Bonnie and Clyde* (1967).

From the motion picture *Bonnie and Clyde*, copyright © 1967 by Warner Bros. Seven Arts, Inc.; photograph, from Pictorial Parade

saturated the market with low-budget youth-culture movies, only a few of which achieved even limited distinction.

Concurrent with the youth-cult boom was the new permissiveness toward sex made possible by the institution of the MPAA ratings system in 1968 (and modified slightly throughout the years). Unlike the Production Code, this system of self-regulation did not proscribe the content of films but merely categorized them according to their appropriateness for young viewers. (G designates general audiences; PG recommends parental guidance for children under 17; PG-13 suggests parental guidance for children under 13; R indicates that the film is restricted for persons under 17, unless they are accompanied by a parent or guardian; and X or NC-17 signifies that no one under 17 may be admitted to the film. In practice, the X rating is usually given to unabashed pornography and the G rating to children's films, which had the effect of concentrating sexually explicit but serious films in the R and NC-17 categories.) The introduction of the ratings system led immediately to the production of serious, nonexploitative adult films, such as John Schlesinger's *Midnight Cowboy* (1969) and Mike Nichols' *Carnal Knowledge* (1971), in which sexuality was treated with a maturity and realism unprecedented on the American screen.

MPAA ratings system

Despite increasing costs, the unprecedented popularity of a few films (Francis Ford Coppola's *The Godfather,* 1972; Steven Spielberg's *Jaws,* 1975; George Lucas' *Star Wars,* 1977) produced enormous financial profits and stimulated a wildcat mentality within the industry. In this environment, it was not uncommon for the major companies to invest their working capital in the production of only five or six films a year, hoping that one or two would be extremely successful. At one point, Columbia reputedly had all of its assets invested in Spielberg's *Close Encounters of the Third Kind* (1977), a gamble that paid off handsomely; United Artists' similar investment in Michael Cimino's financially disastrous *Heaven's Gate* (1980), however, caused the sale of the company and its virtual destruction as a corporate entity.

The new generation of directors that came to prominence at this time included many who had been trained in university film schools—Francis Ford Coppola and Paul Schrader at the University of California at Los Angeles, George Lucas and John Milius at the University of Southern California, Martin Scorsese and Brian De Palma at New York University, Steven Spielberg at California State College. These filmmakers brought to their work a technical sophistication and a sense of film history eminently suited to the new Hollywood, whose quest for enormously profitable films demanded slick professionalism and a thorough understanding of popular genres. The directors achieved success as highly skilled technicians in the production of cinematic thrills, although many were serious artists as well.

The graphic representation of violence and sex, which had been pioneered with risk by *Bonnie and Clyde, The Wild Bunch,* and *Midnight Cowboy* in the late 1960s, was exploited for its sensational effect during the '70s in such well-produced R-rated features as Coppola's *The Godfather,* Friedkin's *The Exorcist* (1973), Spielberg's *Jaws,* Scorsese's *Taxi Driver* (1976), De Palma's *Carrie* (1976), and scores of lesser films. The newly popular science-fiction/adventure genre was similarly supercharged through computer-enhanced special effects and Dolby sound, as the brooding philosophical musings of Kubrick's *2001* gave way to the cartoon-strip violence of Lucas' *Star Wars,* Spielberg's *Raiders of the Lost Ark* (1981), and their myriad sequels and copies. There was, however, originality in the continuing work of veterans Robert Altman (*McCabe and Mrs. Miller,* 1971; *Nashville,* 1975; *Three Women,* 1977), Stanley Kubrick (*A Clockwork Orange,* 1971; *The Shining,* 1980), and American Film Institute graduate Terrence Malick (*Badlands,* 1973; *Days of Heaven,* 1978). In addition, Coppola (*The Godfather, The Godfather, Part II,* 1974; *Apocalypse Now,* 1979) and Scorsese (*Mean Streets,* 1973; *Raging Bull,* 1980) created films of unassailable importance. Some of the strongest films of the era came from émigré directors working within the American industry—John Boorman's *Deliverance* (1972), Roman Polanski's *Chinatown* (1974), Miloš Forman's *One Flew over the Cuckoo's Nest* (1975), and Ridley Scott's *Alien* (1979). In general, however, Hollywood's new corporate managers lacked the judgment of industry veterans and tended to rely on the recently tried and true (producing an unprecedented number of high-budget sequels) and the viscerally sensational.

To this latter category belong the spate of "psycho-slasher" films that glutted the market in the wake of John Carpenter's highly successful, low-budget chiller, *Halloween* (1978). The formula for producing films of this type begins with the serial murder of teenagers by a ruthless psychotic and adds gratuitous sex and violence, with realistic gore provided by state-of-the-art makeup and special-effects artists. Its success was confirmed by the record-breaking receipts of the clumsily made *Friday the Thirteenth* (1980). There were precedents for psycho-killer violence in Hitchcock's *Psycho* (1960) and Tobe Hooper's *The Texas Chainsaw Massacre* (1974), but for decades the exploitation of gore had existed only at the periphery of the industry (in the "splatter" movies of Herschell Gordon Lewis, for example). The slasher films took the gore and violence into the mainstream of Hollywood films.

Growth of exploitation films

During the 1980s, the fortunes of the American film industry were increasingly shaped by new technologies of video delivery and imaging. Cable networks, direct-broadcast satellites, and half-inch videocassettes provided new means of motion-picture distribution, and computer-generated graphics provided new means of production, especially of special effects, forecasting the prospect of a fully automated "electronic cinema." Many studios, including Universal and Columbia, devoted the majority of their schedules to the production of telefilms for the commercial television networks, and nearly all of the studios began the practice of preselling their theatrical features for cable and videocassette distribution. In fact, Tri-Star, one of Hollywood's major producer/distributors, was a joint venture of CBS Inc., Columbia Pictures, and Time-Life's premium cable service Home Box Office (HBO). HBO and Showtime both function as producer/distributors in their own right by directly financing films and entertainment specials for cable television. In the '80s, for the first time since the 1910s, independent film producers released more motion pictures than the major studios, largely to satisfy the demands of the cable and home-video markets.

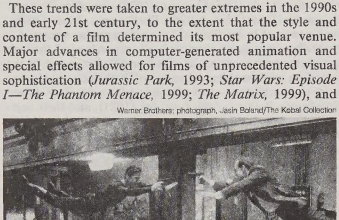
Influence of video technology

The strength of the cable and video industries led producers to seek properties with video or "televisual" features that would play well on the small television screen (*Flashdance,* 1983; *Footloose,* 1984), or to attempt to draw audiences into the theatres with the promise of spectacular 70-millimetre photography and multitrack Dolby sound (*Amadeus,* 1984; *Aliens,* 1986). Ironically, the long-standing 35-millimetre theatrical feature survived in such unexpected places as "kidpix" (a form originally created to

exploit the PG-13 rating when it was instituted in 1984—*The Breakfast Club,* 1985; *Stand by Me,* 1986) and, more dramatically, the Vietnam combat film (Oliver Stone's *Platoon,* 1986; Coppola's *Gardens of Stone,* 1987; Kubrick's *Full Metal Jacket,* 1987).

These trends were taken to greater extremes in the 1990s and early 21st century, to the extent that the style and content of a film determined its most popular venue. Major advances in computer-generated animation and special effects allowed for films of unprecedented visual sophistication (*Jurassic Park,* 1993; *Star Wars: Episode I—The Phantom Menace,* 1999; *The Matrix,* 1999), and

Warner Brothers; photograph, Jasin Boland/The Kobal Collection



Keanu Reeves and Hugo Weaving in *The Matrix* (1999), directed by Andy Wachowski.

audiences preferred the experience of seeing such films on large theatre screens. Computer animation was also put to good use in films that play equally well on theatre or television screens, such as *Toy Story* (1995), *Antz* (1998), and *Chicken Run* (2000). Independent producers, especially those who specialized in low-budget films of intimate subject matter, regained strength under the new regime of home video and created some of the most unconventional and interesting work the American cinema had seen in some time; they included Joel and Ethan Coen (*Blood Simple,* 1984; *Fargo,* 1996; *O Brother, Where Art Thou?,* 2000), Spike Jonze (*Being John Malkovich,* 1999), and Quentin Tarantino (*Pulp Fiction,* 1994; *Jackie Brown,* 1997). It was also an era in which low-cost marketing via the Internet could turn a $50,000 independent film into a $100,000,000 blockbuster (*The Blair Witch Project,* 1999). These "indie" films were too original to have been made in the studio era and too eccentric for the mass-market economies of the late 20th century. They hark back to the vitality and integrity of the pre-studio age—to the work of Griffith, Keaton, Stroheim, and Chaplin—when anything was possible because everything was new. (D.A.C.)

Rise of independent production

The art of film

ESSENTIAL CHARACTERISTICS OF MOTION PICTURES

In its short history, the art of motion pictures has frequently undergone changes that seemed fundamental, such as that resulting from the introduction of sound. It exists today in styles that differ significantly from country to country and in forms as diverse as the documentary created by one person with a hand-held camera and the multimillion-dollar "epic," involving hundreds of performers and technicians. Despite its diversity, however, an essential unchanging nature can be discerned in most of its manifestations.

A number of factors come to mind in connection with the motion-picture experience. For one thing, there is something mildly hypnotic about the illusion of movement that holds the attention and may even lower critical resistance. The accuracy of the film image is compelling because it is made by a nonhuman, scientific process. In addition, the motion picture gives what has been called a strong sense of being present; the film always appears to be in the present tense. There is also the concrete nature of film; it appears to show actual people and things.

No less important are the conditions under which the movie ideally is seen, where everything helps to dominate the spectators. They are taken from their everyday environment, partially isolated from others, and seated in a dark auditorium. The darkness concentrates their attention and prevents comparison of the image on the screen with surrounding objects or people. For a while, spectators live in the world the motion picture unfolds before them.

Still, the escape into the world of the film is not complete. Only rarely does the audience react as if the events on the screen were real; for instance, by ducking before an onrushing locomotive in a special three-dimensional effect. Moreover, such effects are considered to be a relatively low form of the art of motion pictures. Much more often, viewers expect a film to be truer to certain unwritten conventions than to the real world. Although spectators may sometimes expect exact realism in details of dress or locale, just as often they expect the film to escape from the real world and make them exercise their imaginations, a demand made by great works of art in all forms.

The unwritten conventions

The sense of reality most films strive for results from a set of codes, or rules, that are implicitly accepted by viewers and confirmed through habitual filmgoing. The use of brownish lighting, filters, and props, for example, has come to signify the past in films about American life in the early 20th century (*The Godfather,* 1972; *Days of Heaven,* 1978). The brownish tinge that is associated with such films is a visual code (one that may have some basis in reality; brown was a leading decorative element in clothing and furniture of the time). Storytelling codes are even more conspicuous in their manipulation of actual reality to achieve an effect of reality. Audiences are prepared to skip over huge expanses of time in order to reach the dramatic moments of a story. *La battaglia di Algeri* (*The Battle of Algiers,* 1966), for example, begins in a torture chamber where a captured Algerian rebel has just given away the location of his cohorts. In a matter of seconds that location is attacked, and the drive of the search-and-destroy mission pushes the audience to believe in the fantastic speed and precision of the operation. Furthermore, the audience readily accepts shots from impossible points of view if other aspects of the film signal the shot as real. For example, the rebels in *The Battle of Algiers* are shown inside a walled-up hiding place, yet this unrealistic view seems authentic because the film's grainy photography plays on the spectator's unconscious association of poor black-and-white images with newsreels.

Fidelity in the reproduction of details is much less important than the appeal made by the story to an emotional response, an appeal based on innate characteristics of the motion-picture medium. These essential characteristics can be divided into those that pertain primarily to the motion-picture image, those that pertain to motion pictures as a unique medium for works of art, and those that derive from the experience of viewing motion pictures.

Qualities of the film image. The primary unit of expression in film is the image, or the single shot. The attribution of magical properties to images has a long history; this association is well documented among many primitive peoples, and it is even reflected in the term magic lantern as a synonym for the film projector. Any image taken out of the everyday world and projected onto a screen to some extent appears to become magically transmuted. This magical quality helps to explain the enthusiastic reception accorded such early films as *La Sortie des ouvriers de l'usine Lumière* ("Workers Leaving the Lumière Factory"), which were merely photographic records of commonplace scenes in France in the 1890s by the French film pioneers, the Lumière brothers.

Intensity, intimacy, ubiquity. The qualities of intensity, intimacy, and ubiquity have been singled out as the salient characteristics of the motion-picture image. Its intensity derives from its power to hold the complete attention of the spectator on whatever bit of reality is being shown. Outside the theatre, a person's attention is usually dispersed in the endless reality around him, except for sporadic moments of concentration on what he selects for closer scrutiny. In the cinema he is compelled to look at something that not he but the filmmaker has selected, for reasons that are not always immediately apparent. This quality of intensity becomes most noticeable when the camera remains fixed on something for a longer time than seems warranted,

Focusing the viewer's attention

and the spectator gradually becomes acutely conscious of his loss of volition over his own attention. This technique is not often used but is very effective when used well.

The intimacy of the film image is related to the camera's ability to see things in greater detail than the eye can. This ability is demonstrated in long-distance shots through a telephoto lens as well as in close-ups. At the beginning of the Japanese film *Woman in the Dunes* (1964), for example, a pervading theme of the film is indicated by shots of grains of sand many times enlarged.

The impression of ubiquity—being everywhere at once—is achieved in part by the camera's apparent freedom to move from place to place or to approach or withdraw instantaneously. No less important to this illusion of ubiquity is the effect achieved by editing, which allows countless images representing a long, elaborate action to be presented in a comparatively short film or sequence, such as that exemplified by the opening of *The Battle of Algiers*. The geographic and temporal authority of the image even permits credibility to be given to sequences representing the past, the future, and dreams.

Particularity. Other equally important characteristics of the film image may be singled out. One of these is its particularity. The language of words lends itself to generalization and abstraction. In themselves, words such as man or house do not suggest a particular man or a particular house but men and houses in general; and more abstract terms such as love or dishonesty have even less precise associations with specific things. Motion pictures, on the other hand, only show particular things—a particular man or a particular house. In this way a film image may be less ambiguous than the language of words but also less evocative, less likely to be enriched by imagination, association, or recollection. Despite its particularity, however, the motion-picture image may also be ambiguous in that it shows but does not explain. It does not in itself tell what it means, and people instinctively search for meanings in images. This is why commentary is thought to be essential in tying down precise meaning in educational films. On the other hand, many evocative documentaries, from Robert Flaherty's *Nanook of the North* (1922) to Frederick Wiseman's *High School* (1968), abjure commentary, thus forcing the spectator to take in the remarkable and untranslatable specific sights and sounds they collect. The particular insistence of given photographed objects also explains why the juxtapositions of montage are so effective—the spectator compulsively searches for the reason behind a particular sequence of images.

The mind and the eye

Neutrality. Another characteristic of the film image is its neutrality. The world people see around them is strongly influenced by their emotions and their interests. A plumber fixing pipes in a museum may not see the masterpieces around him, while an angry man may hear an insult where none was intended. The camera and the microphone, however, are thought to reproduce images and sounds without feeling. Although focus, directionality, and other technological factors limit what can be seen and heard, audiences are prepared to believe that the motion picture itself is nonhuman or even superhuman in its passive reception of information. Courts of law, for example, are more likely to accept film as evidence of an occurrence such as a bank robbery than they are to accept an artist's sketch or a journalist's report of the same incident. When a film appears to be charged with emotion, it is usually because the director has carefully manipulated the images to give this illusion. In everyday life, the eyes follow the mind; in the cinema, the mind follows the eyes.

Characteristics of the medium. Four characteristics may be stressed as factors that differentiate the motion-picture medium, either in degree or in kind, from other mediums for works of art: luminosity, movement, realism, and montage.

Luminosity. The intense brightness of the picture projected by powerful light onto a coated screen in itself transforms the most mundane element of reality. The appeal of a luminous picture is attested by efforts of advertisers to achieve luminous effects in posters and displays and in the popularity of viewing still photographs as transparencies rather than as ordinary prints. The luminosity of the motion-picture image also results in a considerable range of tone, between the brightest highlight and the deepest black. Both in black-and-white and in colour films, the most delicate gradations in the image are therefore possible.

Movement. As a feature of the motion picture, movement is so obvious that its central importance is sometimes forgotten. The motion picture has much in common with the graphic arts, but the added dimension of movement transforms it, allowing a narrative or a drama to unfold in time, in a way no other graphic art can. Both in filmmaking and in film appreciation, movement must constantly be borne in mind: composition in the motion picture is kinetic rather than static. It is not a single colour but the cumulative effect that matters, not a single situation but a developing plot. The composition within any frame, or exposure, of a motion picture is less important than the relationship of that frame to those that precede and follow it.

Realism. Another essential element of the motion-picture image is that it gives an impression of reality. Whether in a drama enacted expressly for the camera or in a documentary film of an event at which the camera just happened to be present, this feeling of realism deriving from motion-picture photography accounts for much of the force of motion pictures. Animated films, which lack this element of photographic realism, tend to be taken as fantasies.

The attempt of the motion picture to reproduce three-dimensional reality on a flat screen presents the same problems and opportunities that are encountered in still photography and in painting. The standard camera lens, in fact, is constructed to produce visual effects precisely similar to those achieved by painters using the principles of perspective that were developed during the Renaissance.

Cinematic realism is most fully heightened when the images are accompanied by synchronous sound, whereby a second sense, hearing, ratifies what the eyes see. Although reproduced sound can be manipulated with regard to distance, timbre, clarity, and duration, in combination with photographed moving images, it forcefully brings alive its subject as present in a way unavailable to the other arts of representation.

Montage. Perhaps the most essential characteristic of the motion picture is montage, from the French *monter*, "to assemble." Montage refers to the editing of the film, the cutting and piecing together of exposed film in a manner that best conveys the intent of the work. Montage is what distinguishes motion pictures from the performing arts, which exist only within a performance. The motion picture, by contrast, uses the performances as the raw material, which is built up as a novel or an essay or a painting, studiously put together piece by piece, with an allowance for trial and error, second thoughts, and, if necessary, reshooting. The order in which the segments of film are presented can have drastically different dramatic effects.

Several major contributions to the theory of montage were made by Soviet directors. After the Russian Revolution of 1917, Soviet films were encouraged for their propaganda value, but film stocks were scarce. Soviet directors carefully studied the films of D.W. Griffith and other masters to make the most effective use of their own meagre resources. One of these early Russian directors, Lev Kuleshov, conducted an experiment involving identical shots of an actor's expressionless face. He inserted it in a film before a shot of a bowl of soup, again before a shot of a child playing, and still again before one of a dead old woman. An unsuspecting audience, which was asked to evaluate the actor's performance, praised his ability to express, respectively, hunger, tenderness, and grief.

Kuleshov's experiment

Sergey Eisenstein, who excelled both as a director and as a teacher, based much of his theory of film on montage, which he compared to the compounding of characters in Japanese writing. The character for "dog" added to the character for "mouth," he noted, results not merely in "dog's mouth" but in the new concept of "bark"; similarly, film montage results in more than the sum of its parts. Still another great Russian director, Vsevolod I. Pu-

dovkin, also stressed the importance of the carry-over in the spectator's mind. Only if an object is presented as part of a synthesis, he said, is it endowed with filmic life.

Three types of montage may be distinguished—narrative, graphic, and ideational. In narrative montage the multifarious images and scenes involve a single subject followed from point to point. In a fiction film, a character or location is explored from multiple angles while the audience builds a comprehensive image of the situation being explored or explained. Graphic montage occurs when shots are juxtaposed not on the basis of their subject matter but because of their physical appearance. Some avant-garde works depend on the spectator's ability to match the graphic relations of assorted images, such as the people, objects, and the shapes of numerical and alphabetical figures in Fernand Léger's *Le Ballet mécanique* (1924) or the torpedoes, swimming seals, and blimps in Bruce Conner's *A Movie* (1958). In graphic montage cutting usually occurs during shots of movement rather than ones of static action. This cutting on motion facilitates the smooth replacement of one image by the next. In ideational montage, two separate images are related to a third thing, an idea that they help to produce and by which they are governed. In *Strike* (1924), for example, the director Eisenstein, to whom the theory of ideational montage is credited, effectively conveys the idea of slaughter by intercutting a shot of cattle being butchered with shots of workers being cut down by cavalry.

These three types of montage seldom appear in their pure form. Most ideational montage proceeds on the basis of the graphic similarity of its components, as does narrative montage when relying on graphic cutting to cover its movement. Similarly, the graphic matches between torpedoes, seals, and blimps in *A Movie* ultimately construct an idea of movement toward explosion and destruction. Besides the complications brought about by the intermixing of these types, the addition of the sound track multiplies the possibilities and effects of montage. Eisenstein and Pudovkin referred to such possibilities as "vertical" montage, opposing it to the "horizontal" unrolling of shot after shot. Because sound permits the establishment of relations between what is seen and heard at each moment, the film image can no longer be said to be a self-contained unit; it interacts with the sound that accompanies it. Sound relations (including dialogue, music, and ambient noise or effects) may be built in constant rapport with the image track or may create a parallel organization and design that subtends what is seen. In all, montage appears to be the most extraordinary factor differentiating the motion picture from the other arts, and it is the one often singled out as the basis of the medium. Nevertheless, many films, including those of Mizoguchi Kenji of Japan, Roberto Rossellini of Italy, and Miklós Jancsó of Hungary, rely not on montage but on the medium's unique qualities of luminosity, movement, and realism to convey their power and beauty.

The motion-picture experience. Other distinguishing characteristics of the motion picture are more closely related to the conditions under which they are normally seen.

The Kinetoscope, a peep-show motion picture that could be seen by only one person at a time, became obsolete soon after it was introduced by Thomas A. Edison in 1894, because it could not compete with projected films, which could accommodate audiences. Since that time, an atmosphere of group entertainment has been associated with films. Even for films being seen on broadcast or cable television, this aspect of community viewing remains significant; although the audience before any particular set may be as small as a single individual, each spectator brings to it past associations of films seen in the theatre and the realization that millions of other people are watching the same broadcast.

Collective versus private film viewing

Since 1980, however, this tradition has been reversed and the peep show has returned in the guise of the videocassette. The proliferation of videocassette recorders (VCRs) and portable television sets demonstrates that films serve multiple functions in culture. The function usually deemed primary might be termed "concentrated entertainment." The private viewing conditions provided by the VCR can enhance this function and may be preferred by some viewers in the same way that a stereo recording of a Beethoven symphony is preferred by some to the concert hall experience. The less socially acceptable function of pornography, which has been represented in motion pictures since their inception, is also well served by the anonymity and privacy characteristic of VCR viewing. Other, more public, functions of motion pictures contribute to sociability. Although the movie theatre remains a key site for such activity, television serves a significant population that prefers to stay at home either because of convenience or because the more casual viewing conditions permit them to participate in additional activities. This latter quality is also found in older phenomena, such as the drive-in theatre, where families or small groups maintained their own cohesiveness while viewing a motion picture. Such epiphenomena as talking and eating, which were encouraged by the drive-in venue, are replicated in living rooms where movies are watched on cassettes. In sum, the motion picture raises questions of the privacy and sociability of artistic representations more insistently



The concluding montage from *Strike!* (1924), directed by Sergey Eisenstein. (Top and bottom) Shots of the massacre of the strikers and their families are intercut with (centre) images of cattle being slaughtered.

Photographs from David Cook and the Museum of Modern Art/Film Stills Archive, New York City

than any other medium, but few generalizations about its "pure" state stand up. Different eras and different cultures use motion pictures in different ways. Its connection to both personal and collective vision is always relevant and is always affected by the site of its exhibition.

Although the motion-picture experience is most often a group experience, it is exceptional for its impersonal nature. In this respect the cinema is quite different from live theatre, for example, in which the audience feels the presence of the actors and the equally compelling presence of the audience. Whether at home in front of a television set or in a movie theatre, the film viewer feels less inhibited. People come and go as they please, generally unnoticed, in an easy, relaxing atmosphere. Especially in the heyday of the large movie palaces there was little feeling of association with the other members of the cinema audience, whereas at a ballet, opera, or play, members of the audience sense a collective ritual that is reinforced by intermissions during which they mingle with one another. The impersonality of the motion-picture experience enhances its private function, although the informality of the cinema has probably contributed to the tendency to regard it less seriously than other performing arts.

Another basic feature of motion pictures is their accessibility to an audience of vast size. A drama presented in a theatre can be attended by no more than a few hundred persons at a time. In a film, however, the same drama and the same performers may be seen throughout the world by millions of people almost simultaneously. Accessibility has been a determining characteristic of films. From the start, they were a sidewalk attraction, and with the advent of television in addition to cinemas, motion pictures are available almost anywhere at almost any time.

Effect of the mass audience

This mass audience allowed the motion-picture industry to develop vast production and distribution organizations, but it also limited the artistic development of films, since it was commercially safer to present the simplest and least demanding entertainment that would appeal to the widest audience. After television took over much of this mass audience in the 1950s, many motion pictures were taken more seriously by a more discriminating audience. Since the days of the *film d'art* movement in France (*c.* 1910), many films have claimed the status of art, but the "art films" that are shown in specialized art theatres are a product of this competition with television. After 1980 cable distribution as well as the videocassette market decentralized distribution, providing potential outlets targeting limited audiences. Despite these developments, the motion picture, and critical or artistic attitudes toward it, has been greatly shaped by its seemingly universal appeal.

EXPRESSIVE ELEMENTS OF MOTION PICTURES

Many observers have seen in films a means of expression comparable to a language. The French poet and filmmaker Jean Cocteau (1889–1963), for example, called the cinema "picture writing." The language of motion pictures, however, is not the language of words, even though spoken dialogue has been an integral part of motion pictures since the late 1920s and written captions were usually required to explain the action before that. It is primarily in the qualities of its images and sounds that the expressivity of the cinema must be sought. Certain basic traits of motion pictures may operate with the logic of natural language, but few theorists have held that cinematic expression follows rules like those of natural language. As Christian Metz, one of the foremost modern theorists, argued, it is not linguistics so much as poetics that should serve as a model for those interested in understanding or explaining how a film works; making and watching a film is far closer to writing or appreciating a novel or symphony than a sentence or discourse.

Various codes of expression have, nevertheless, been shown to operate naturally or to have been inculcated, and their effects can be calculated. Such codes and effects occur in all aspects of the medium and can most readily be categorized into those affecting cinematography, editing, sound, the script, acting, and design.

Cinematographic expression. The filmmaker has a number of ways of modifying the camera's neutrality and thereby the "reality" that is conveyed to the audience. It is largely by means of these devices that the motion picture becomes such an expressive medium. Several of these expressive techniques should be emphasized. First, there is framing; that is, carefully selecting what will be included within each frame of the film and what will be excluded. Second, there is scale, the size and placement of a particular object or a part of a scene in relation to the rest, a relationship that is determined by the placement of the camera. Third is camera movement, or the lack of it, during shooting. Fourth, there are the peculiar advantages of either colour or black-and-white photography that can be exploited. Finally, through the cinematographer's skill and knowledge of laboratory processes, other highly expressive techniques can be achieved. Each of these means of expression will be discussed below.

Framing. The process of framing is intended to eliminate what is unessential in the motion picture, to direct the spectator's attention to what is important, and to give it special meaning and force. Each frame of film, which corresponds in shape to the image projected on the screen, forms the basis for a graphic composition in the same way as the frame of a painting encloses the area in which the painting must be organized. Several different ratios of frame width to frame height (called "aspect ratios") have been used in motion pictures. The most common, known as the Academy ratio, is 1.33 to 1, or 4 to 3, a ratio corresponding to the dimensions of the frame of 35-millimetre film. By using 70-millimetre film or a special CinemaScope lens, an image with wider horizontal and shorter vertical dimensions is achieved—a proportion of about 5 to 2, or between 2.2 to 1 and 2.65 to 1. A similar effect, called wide screen, was sometimes achieved without the expensive equipment required for CinemaScope by using 35-millimetre film and masking the top or bottom, or both, giving a ratio of 1.75 to 1, or 7 to 4. Although some theatres in the 1970s were enlarged and widened to accommodate 70-millimetre images, a trend toward smaller theatres fixed the image ratio close to 1.85 to 1 in the United States and 1.66 to 1 in Europe.

The aspect ratio

The moderate elongation provided by the Academy ratio has proved most versatile for achieving standard compositional effects. For example, an expansive feeling is easily rendered when small-scale figures in the foreground are shot against a towering sky, as in *Days of Heaven.* In the wide CinemaScope dimension, the tension established between the outward movement of the composition and the rectangle of the screen can readily be lost; nevertheless, early fears about wide screen's insensitivity to intimate love scenes proved to be unfounded, at least in the hands of careful cinematographers. A number of foreign directors, notably Kurosawa Akira (Japan), François Truffaut (France), and Miklós Jancsó (Hungary) achieved stunning effects in CinemaScope by overcoming the fear of moving the camera, as seen in, respectively, the battle scenes of *Seven Samurai* (1954), the bicycle ride in *Jules et Jim* (1961), and the nonstop camera dance of *Red Psalm* (1972). Wide screen calls for an altered aesthetic, because the spectator's eye is invited to roam the visual field, making connections that in the standard ratio are more tightly determined.

Regardless of its ratio, the frame may be divided to show two or more scenes at the same time. This technique is generally reserved for credit sequences, musical interludes, or moments when the presentation on a single screen of two or more simultaneous occurrences results in comic interrelationships.

An effective use of framing consists of temporarily or permanently excluding a vital part of the action. Offscreen space may be said to function more actively in cinema than in painting or the theatre. For example, the camera may remain fixed on the hero while the villain is perceived only by a voice saying "Hands up!"; or in a science-fiction film, the camera may linger on the horror expressed by the victim before revealing the monster that is causing it.

Use of offscreen space

Finally, very strong dramatic effects may be obtained by oblique framing; that is, by turning the camera sideways so that the image on the screen appears askew. This was done in the early Russian film *The Ghost That Never*

Returns (1929), in which a prison riot shown by oblique framing gives the impression that the building is being pushed over. Some directors, such as Britain's Carol Reed, have made this a trademark (*The Third Man,* 1949).

Scale. Since scale in the cinema constantly changes from shot to shot, the spectator can easily be deceived about the size of objects. When appearing next to enormous tables and chairs, for instance, the actors can be made to look like midgets or children, as in the Stan Laurel and Oliver Hardy comedy *Brats* (1930). By contrast, in *King Kong* (1933) a small-scale model of New York City was used to give the illusion of the actual city under attack by a giant gorilla. Scale may have a marked effect on the emotional tone of a scene. In the distance an actor may seem lonely, remote, helpless, pathetic; close up, he may appear powerful, threatening, bestial. The scale of shots for artistic purposes ranges from an extreme long shot (the widest view on the smallest scale), with houses or ships appearing as tiny dots on the horizon, through medium shots, two shots (*i.e.,* a shot of convenient size to include two actors) and others, to the close-up, with part of a face, an eye, or a fist filling the screen (the most restricted view on the largest scale). Telescopic or microscopic shots beyond these extremes are usually of scientific rather than of artistic interest.

Scale of shots

Different scales are occasionally juxtaposed in a single shot to produce an unmistakable dramatic or rhetorical effect. In Orson Welles's *Citizen Kane* (1941) significant characters are repeatedly framed in the right or left foreground while in the background an action takes place which disturbs that character or which that character somehow controls. The gigantic political poster of Kane that rises behind the podium on which he, in the foreground, makes a speech promising to ruin his rival, Gettys, becomes suddenly the size of a postage stamp when the shot changes to one in which Gettys is in the foreground looking down from a balcony on the insignificant speaker. Through this use of different scales, Gettys is shown to have power over the action.

By courtesy of RKO Radio Pictures, a division of RKO General; photograph from the Museum of Modern Art/Film Stills Archive, New York City



Orson Welles in *Citizen Kane* (1941).

As has been noted, the camera exaggerates perspective, and this exaggeration adds to the dramatic effect. It is most striking in an ordinary still photograph of an enormous hand or a sunbather's giant feet that were close to the camera lens. In cinematography, the director ordinarily minimizes the effect of this distortion, but occasionally he uses it in an extreme form. In *Easy Rider* (1969), for instance, it was used to give an atmosphere of hallucination and nightmare to a drug-taking session, and in *Brazil* (1985) it was used continuously to promote an atmosphere of paranoia and nightmare.

Finally, scale is affected by what precedes and follows. The close-up has its most dramatic impact coming after long or medium shots, and after many close-ups, it is a relief to escape to the middle or far distance.

Shooting angle and point of view. Another element in motion-picture language is shooting angle. In common language, the phrases "to look up to" and "to look down on" have connotations of admiration and condescension in addition to their obvious reference to physical viewpoint. In one sense or another, children, dogs, and beggars are often looked down upon, while the preacher in his pulpit, the judge on the bench, and the policeman on his horse are looked up to. Even a slight upward or downward angle of a camera is enough to express a mood of inferiority or superiority.

Upward or downward shooting angles lead to questions of objectivity and subjectivity. In most motion pictures, both for variety and for breadth of treatment, the camera's viewpoint switches from one character to another and sometimes is associated with none of the characters but merely looks on. The camera may take the viewpoint of the heroine, looking with dismay at the villain as he breaks into her room; in this case, an upward camera angle gives a subjective impression of her fear. Similar subjectivity may be seen in a shot of buildings reeling in the way they might appear to a drunken man, as in the German classic *The Last Laugh* (1924), or in a rapid camera movement from a window to the pavement below to express a thought of suicide, as in the Italian Neorealist film *Umberto D.* (1952). Occasionally, an entire motion picture may be shot from one person's point of view, often with a personal narration accompanying the images. Very rarely does this point of view literally take over the optical view of the character for an extended period. (One noted exception is the 1946 film directed by the actor Robert Montgomery, *Lady in the Lake,* in which the camera actually plays the main character. The entire film is seen from the camera/character's point of view so that the audience sees only what the camera/character sees. The movie is an interesting experiment in the use of subjective camera, but it is considered an artistic failure.) More often voice-over, music, or other elements are combined with shooting angle to render a particular character's feelings throughout a film. Alfred Hitchcock is generally considered the master of point of view, controlling (and even misguiding) viewer sympathy.

The camera's viewpoint

Extreme upward or downward angles are too far removed from ordinary experience to have many applications in motion pictures, but they may express exceptional situations—a sick man on his back, a baby's or a dog's point of view, a man in a pit or in a coffin, a spy covertly looking down on an enemy meeting. As with scale, the shots that precede and follow alter the effect of the shooting angle. Upward angles are stronger following a level or downward-looking camera, and vice versa.

Camera movement. Framing, scale, and shooting angle are all greatly modified by the use of camera movement. Filmmakers began experimenting with camera movement almost immediately after the motion-picture camera was developed. In 1897 photographers employed by Auguste and Louis Lumière floated a *cinématographe,* the combination camera/projector devised by the French brothers, in a gondola through Venice to give viewers all over the world a dynamic view of that much-painted city.

One of the simplest and most common movements is to turn, or pan (from the word panorama), the camera horizontally so that it sweeps around the scene. It can also be tilted up or down in a vertical panning shot, or in a diagonal pan, as when it follows an actor up a stairway. Panning was possible quite early in film history, but methods of physically conveying the camera itself through a scene developed more slowly. Initially, the camera was mounted on a dolly, truck, or other hand-propelled wheeled vehicle to facilitate smooth movement. Later, tracks were laid for the dolly or truck to ride on, providing even smoother, more effortless motion. Trucking, dollying, and tracking can even be combined with panning in a complex movement that may require the adjustment of focus or aperture en route. One such camera movement that is often used imitates the gaze of a traveler who turns in a moving automobile or train to focus on a stationary point of interest.

Panning and tracking

Often commercial vehicles, such as trolleys, automobiles, or airplanes, are used to transport the camera; the relatively jerky ride they supply simulates real movement more accurately than does the steady motion provided

by a specially designed apparatus. Nevertheless, the film industry has long sought equipment that would allow the camera (and the viewer) to weave in and out of action in the most ethereal way. The crane, which facilitates aerial movement, was developed in the late 1920s, replacing the jerry-built movable platforms, the slings, and the sleds that ingenious directors, such as Abel Gance (for *Napoléon,* 1927) and Marcel L'Herbier (for *L'Argent,* 1929), both in France, had devised to achieve vertical or elevated swinging movements. A host of such special camera supports now exists, many of which were originally developed for use on medical and scientific films. The most advanced equipment can be operated from a distance with electronic viewfinders, allowing the camera to follow vigorous, continuous action with unprecedented ease and intimacy, as in the pre-credit sequence of *Raiders of the Lost Ark* (1981). The look and style of film art is constantly changing as technological advances increase the mobility of the camera and consequently the flexibility of the spectator's viewpoint.

By courtesy of Paramount Pictures Corporation. *Raiders of the Lost Ark,* copyright © 1981, by Lucasfilm Ltd.; all rights reserved; photograph from the Museum of Modern Art/Film Stills Archive, New York City



Harrison Ford in the opening sequence of *Raiders of the Lost Ark* (1981), directed by Steven Spielberg.

Regardless of the state of technical capability, the effect of camera movement depends on the context and on the pace of movement. At a deliberate pace the camera can explore a scene and reveal significant details. If it is raised well above the ground, the movement has a dreamlike power, and, when combined with slow motion, it may give a somnolent impression or express recollection or hallucination. The camera movement may end dramatically on a dagger, on a gun half-hidden in an assailant's hand, or on a suspicious bulge in a pocket. It may link the hero walking in the garden and the heroine watching him with loving eyes from a window. It may bring a dramatic surprise, as in the American western *Stagecoach* (1939), when director John Ford had the camera, mounted high above a rocky defile, move slowly from the stagecoach below to reveal a band of Indians waiting in ambush. On the other hand, the camera may simply turn away from a scene to leave the remainder to the spectator's imagination, as when it withdraws from a torture scene or from a love scene. In filming a conversation, the director may turn the camera from one speaker to the other, thus animating the scene with movement and showing the expression of the speaker, or listener, more closely than would be possible with a static two shot. Camera movement can even be used to change the scene to a distant place, to a different period of time, or to an imaginary world.

Very rapid camera movements may express a sudden surge of emotion or a contemplated action, as in the suicide example from *Umberto D.* In *The Rains Came* (1939), as the heroine realizes with horror that she has drunk from a glass that may be contaminated with typhus, the camera rushes forward to a close-up on the fatal glass, shining in the darkness. These movements are often effected without physically moving the camera, by means of a zoom lens, a lens of variable focal length that

Zooming

simulates the effect of moving toward or away from a subject by increasing or decreasing the size of the subject as the focal length changes. Although a zoom shot is generally smoother than a tracking shot, it always results in pictorial distortion. To zoom in from a distance to a close-up, the focal length of the lens is changed from, for example, 18 millimetres to 125 millimetres. The former length curves the picture anamorphically on the sides, giving great depth to the background, while the latter tends to flatten the background. All objects within view are enlarged at the same rate. Tracking in from a distance to a close-up requires careful adjustment of focus, but depth and dimension appear more realistic.

Camera movement is one of the key indicators of the presence of a narrator. When the camera moves independently of the action, the narrator can be thought of as hovering above the action, poetically reacting to it or commenting on it. When the camera moves instead to keep the action in view, to follow as many elements as possible, the narrator can be thought of as a reporter investigating but not commenting on what is seen. The documentary tradition, particularly since 1959 when lightweight cameras and tape recorders first permitted extended hand-held filming, represents this investigative function of cinema and of camera movement.

Montage versus mise-en-scène

Directorial styles may be cataloged on the basis of an overall predilection for linking elements in a scene via cuts (montage) or camera movement. Eisenstein has already been cited as a master of montage. One of the directors most acclaimed for the expressive use of camera movement is Japan's Mizoguchi Kenji. Although Mizoguchi was not beyond making strongly rhetorical points by juxtaposing shots, the overall impression his films convey derives from the use of a seemingly floating camera to join not only elements within a scene but also the scenes themselves. In *Ugetsu* (1953) the hero, seduced in a hot spring by a beautiful ghost woman, moves screen right to join her, while the camera pans left across the pool and then tracks along the ground. The shot dissolves imperceptibly into one in which the camera pans up to reframe the couple picnicking in an extreme long shot. The magical mixture of spaces and the conflation of time sensuously express the erotic imagination that both the hero and the audience have fallen prey to. Mizoguchi is known as a mise-en-scène director, one who is primarily concerned with the relationships within a shot rather than those between shots. He employs long takes, camera movement, and the expressive use of elements within the film frame to convey mood and emotion. The possibility of movement was so important to Mizoguchi that at the end of his career he invariably directed from a crane, even during static scenes.

Colour and black and white. A practical, accurate commercial system of colour cinematography was not perfected until Technicolor was introduced in Walt Disney's animated short *Flowers and Trees* (1932) and in the feature film *Becky Sharp* (1935). The introduction of colour was less revolutionary than the introduction of sound; the silent film soon disappeared, but even though most feature films made since the 1960s have been in colour, the black-and-white film has continued to be made. In fact, directors such as Woody Allen (*Manhattan,* 1980) and Martin Scorsese (*Raging Bull,* 1979) have chosen to film in black and white to give their movies a calculated tone.

Use of black and white for realism

A black-and-white motion picture is not merely a picture that lacks colour but rather is an artistic creation with positive qualities of its own. An ample range of effects can be obtained—from precise images in which every hair, every grain can be clearly seen, to a smudged charcoal effect. Oddly, black and white often gives a stronger impression of realism than colour does, perhaps because of associations with newsreels and newspaper photographs. Black and white may suggest the hard news of the daily paper, while colour may connote the fantasies of glossy fashion magazines, advertisements, and comic strips. In the cinema, black-and-white composition is often stronger and more dramatic than colour.

Nevertheless, colour introduced a new world into the cinema and steadily grew more effective. It can be used to produce a powerful dramatic impression. The German

director Rainer Werner Fassbinder, for example, used garish colours in films such as *Despair* (1977) to lend a seductive but finally suffocating tone to his melodramas. The Italian director Michelangelo Antonioni claimed to have studied colour for years before venturing to make his first colour film, *The Red Desert* (1964). In that film he used disturbing yellows, pinks, grays, and greens, even going so far as to paint dump heaps and fruit gray for one scene, to express a neurotic woman's sensibility and the oppressiveness of her industrial environment. He changed film stock for a sequence in which the woman tells her child a story about a girl on the beach. The bright postcard colours seen in that sequence contrast dramatically with the sickly grays and greens of the rest of the film. Colour can be employed even more symbolically than this—in Eisenstein's *Ivan the Terrible, Part II* (1946), red turning to a bluish shade represents the fear of a pretender about to be assassinated.

Role of the cinematographer. Cinematographers remain virtually unknown outside the motion-picture industry even though their contribution sometimes matches that of the director in importance. Although the director has ultimate control over the visual image, the cinematographer actually records that image on film, translating the director's ideas and creating the atmosphere and the look of the film. The association between the cinematographers and the processing laboratory is also of highest importance because the cinematographer often spends hours there after shooting, checking the negative. On most feature films a camera team (often consisting of a director of photography, cameraman, and assistant cameraman) shares the responsibilities.

Cinematographers are responsible for exact framing, sometimes for screens of more than one type. They also must decide upon the use of masking, the choice of lens, the camera angle, and the control of camera movement. They must either keep the focus sharp or put all or part of the picture out of focus if this effect is required. Cinematographers also control slow motion or accelerated motion; with early hand-cranked cameras, the camera operator simply slowed down or cranked faster, but later special controls and cameras were developed. Trick photography was once effected by simple manipulation of the camera: magical transformations were made simply by stopping it and changing the scene; and the impression of backward motion was achieved by turning the camera upside down and reversing the film. More elaborate processes now at the cinematographer's command involve laboratory technicians as much as the camera crew. Many effects require the actors to perform against a background of previously prepared film. The cinematographer must be in command of all these processes. The best cinematographers give a motion picture a visual style that is peculiarly their own.

Editing. The process of trimming and piecing together lengths of film in order to make an artistically concise and complete motion picture is certainly the most obvious technique of film language and the one most often discussed. The terms editing, cutting, and montage are often applied interchangeably to the process. In montage the emphasis is on the juxtaposition of ideas resulting from this process, cutting stresses the physical work with the actual strips of film, and editing encompasses both.

Editing, cutting, and montage

A single shot (*i.e.*, the length of film exposed at one time, without interruption, by one camera), makes a visual and aural record of some segment of the physical world; by effective editing, this record can be taken apart, restructured, and shaped into an imaginative world or a discourse about the world. While all viewers presumably notice that a film is made up of a number of scenes, few realize that fiction films contain on the average approximately 600 cuts, one every 10 seconds. Editors strive to hide their work by cutting on action, so that the movement of a character's arm in one location flows into another such movement elsewhere, masking the change of shot. More important is the principle by which an editor anticipates the spectator's line of inquiry. By releasing information just as the spectator needs it, the editor constructs a natural drama whose seams are invisible.

Invisible editing

Probably the most common convention of this sort is the "accordion" sequence wherein, for example, a drawing room conversation between two people is introduced in an establishing shot of the setting and the actors. The editor will cut to a full shot of the actors once they begin their dialogue, because their speech gives them prominence over the setting. To help viewers understand the nuances of the dialogue, the editor will move in for a medium shot, showing both characters from the waist up. While many directors and editors stop here, Hollywood has traditionally gone in even closer, using alternating close-ups of each character (generally from over-the-shoulder shots) to convey innuendos and reactions. In the earlier days of cinema, an editor was likely to back out of the sequence in the reverse order, going from close-up to medium shot, to full shot, and finally to long shot, thus making the structure of the sequence resemble the in-and-out movement of an accordion. Most contemporary, faster-paced films skip some of these "logical" steps, but they nevertheless usually include other strategies that let the viewer glide into and out of the action unconsciously.

Unforgettable moments in films are often made possible through shocking juxtapositions. When an initially smooth progression is disrupted by a quick cut to a close-up, as in the *Halloween* cycle of horror films, the effect can be startling and frightening. In such cases the editor insists upon a strange or important connection in a scene.

Beyond rendering scenes in unobtrusive or striking ways, editing connects scenes into sequences and larger units. It serves as a system of punctuation. In the standard Hollywood film a straight cut between two scenes suggests that the scenes are close in space or time, whereas other more visible forms of transition signal more distant relations. The picture may fade out and fade in, the screen being left dark for a moment. Or it may dissolve, or mix, to a new scene, one image showing on top of the other for a moment. The filmmakers may use other devices, such as a wipe (*i.e.*, a line moving across the screen that wipes out the preceding image while introducing the next), irising (gradually reducing the old image from the edges to a pinpoint size and then expanding the new one in the reverse way), or a turnover (in which the entire screen seems to turn over, with the new image seeming to appear on what was the reverse side).

The director may introduce creative touches in cutting. The German-born director Max Ophüls, for example, connected the separate episodes of *La Ronde* (1950) by means of the musical leitmotiv of a hurdy-gurdy tune. In *Vivre sa vie* (1962), Jean-Luc Godard, one of the outstanding French New Wave directors of the late 1950s, introduced chapter headings marking the heroine's step-by-step involvement in prostitution and, ultimately, her murder, as if it were a didactic 19th-century novel. Alfred Hitchcock, probably the greatest director of suspense films, in his British film *The Thirty-nine Steps* (1935) cut from a woman's scream to the similar sound of a train whistle, an effect so dramatic that it was frequently imitated thereafter.

Editing permits highly dramatic effects that could never be staged in a single shot. In the American western film *Butch Cassidy and the Sundance Kid* (1969), for example, the title characters are seen cornered by lawmen on a high cliff overlooking a river, into which they make an almost suicidal leap to their escape. Actually, the scenes involving the two leading actors on the cliff and those of the dives were shot weeks apart, and they involved different crews and even different rivers, yet the audience readily accepts the illusion created by the editing. *The Stunt Man* (1978) takes such editing as its very theme. The main character is engaged in the rigged dangers and tricks involved in making a movie, while the audience is fooled by the greater tricks of the film that it is watching. Editing opens up a bagful of ingenious tricks of substitution, tricks that allow a marvelous or tragic experience to appear as a natural occurrence in the filmed world.

Illusions created by editing

The common illusionistic experience of motion pictures depends on editing for its force and excitement, but editing can play an even more important role in films that bypass or refuse the illusion of realism. The use of graphic and ideational montage demonstrates that some filmmakers

purposely flaunt the fabrication involved in motion pictures. Many films incorporate extraneous material within their fictions in order to set the illusion of the story they tell against the hard reality of other types of images. In Warren Beatty's *Reds* (1981), for example, interviews with "witnesses" to the events portrayed in the film open, and occasionally interrupt, the story in order to validate the fiction being re-created as history. Editing permits the juxtaposition of very different kinds of material for a variety of rhetorical effects.

The editor's function. Like camera-work, editing is a function that is ordinarily hidden from the audience, but it is vital to the finished picture. It is the editor's job to judge the length of each shot, choosing the exact moment to cut. The length of a shot may depend upon the amount of detail it contains, its scale, its dramatic impact, or its context in relation to the shots that precede and follow it. Though the audience is unconscious of these judgments, the impact of the finished film depends on how well they are made.

The director generally views the day's rushes (*i.e.,* advance prints of the film shot that day) and, in consultation, selects what is to be used. Some directors spend a good deal of time in the cutting room; others spend none at all. Often, the editor is influential in rearranging shots, discarding them, or even ordering reshooting or additional shooting. An important factor in the work of the editor is the cutting ratio—the proportion of film shot to that used in the final film. Some directors shoot as little as three times as much as is required, while others may shoot 10 times as much or even more. In its widest sense, editing includes mixing the sounds and correlating them with the visual film.

Cutting ratio

Cinema time. The motion picture has been defined as a series of images of space that are arranged in time. The time of film language is quite different from that of reality and that conveyed by the other arts, such as drama and literature. Movement on the screen is produced by showing the spectator 24 frames, or still photographs, with dark intervals between them, every second. The movement seems to be at the same rate as that of ordinary life only if the pictures are taken and shown at the same speed. Slow motion may be achieved either by speeding up the camera or slowing down the projector, and accelerated motion is obtained in the opposite way. In common practice, the speed of the projector is constant, and the speed of the camera is varied to achieve these effects. Like extremes of scale, extremes of speed—such as in accelerated-motion films of plant growth or slow-motion films of bullets, explosions, or materials being broken—are of less interest to the art of motion pictures than to science. Moderate slow motion has been used, however, to give a mythic or legendary quality to scenes of destruction and violence, as in Arthur Penn's *Bonnie and Clyde* (1967) and the films of Sam Peckinpah. It can also be used to express dreams or ecstasy, while accelerated motion is often very effective in comedy. The cinema can give the illusion of reversing time by showing events happening backward, or of holding time still by showing the same image again and again.

Time conventions. Despite the possibilities for manipulating it, the time presented in a single shot of film is ordinarily the time of the real world. From shot to shot, however, the time is presented according to certain conventions. In most motion pictures, the story may be assumed to be presented in chronological order and in real time except when certain conventions are invoked, such as ellipsis, repetition for emphasis, flashbacks, or dream sequences.

The narrative may be advanced with immense speed and economy simply by the omission, or ellipsis, of what is not essential. A straight cut may be used between a shot of a girl dressing for a ball and a shot of her at the ball itself. To show a lapse of years, however, it may be necessary to fade one shot slowly from the screen and fade the next in, or to use a dissolve, or mix, which shows both shots superimposed as one supersedes the other.

To emphasize important scenes of short duration, repetition is an effective device. Such a scene may be shown from different angles, from a distance and then close up, and it may occupy much more time on the screen than would the actual event. By emphasizing what is important and eliminating the rest, a motion picture can give the illusion of covering a lifetime in only 90 minutes.

A flashback is an interruption of the actual chronology of a story to relate a significant event of an earlier time. The flash forward, a much less used device, interjects future events in the same way. These devices require special optical effects, such as fades, dissolves, or irising, to stress the break in continuity. The break can also be stressed by the use of a melody associated with the past, or by an unusual camera movement, as well as by the more obvious devices of using noticeably different period styles in the settings or having the actors made up to look much older or younger.

Flashback and flash forward

A thought or dream sequence requires similar emphasis on the departure from chronology of real time. Nearly all of *La Rivière de l'Hibou* (1962), a prize-winning French short film adapted from Ambrose Bierce's 1891 short story, *An Occurrence at Owl Creek Bridge,* consists of the fleeting last thoughts of a man about to be hanged. By not indicating a break between the actual events of the hanging and the fantasy of the condemned man, the film deceives the audience, until the very end, into thinking he is making an escape.

Tempo. The tempo or pace that an audience senses in a film may be influenced in three ways: by the actual speed and rhythm of movement and cuts within the film, by the accompanying music, and by the content of the story. For most people, time seems to pass quickly during moments of happiness, excitement, or exhilaration, and slowly during sadness or boredom. In films, it is possible to reverse this apparent cause-and-effect relationship and to induce a feeling of happiness, excitement, or exhilaration by making the picture seem to move quickly. Means of accomplishing this include lively music, quick cutting, or fast action. Conversely, a sense of sadness or boredom can be induced by solemn music or immobility of the images.

A feeling of suspense is unusual in combining excitement with a sense that time is passing slowly. Much of the suspense depends upon the audience's awareness of a danger unknown to the characters in the film. Conversely, the sense of serenity and wisdom achieved by directors such as India's Satyajit Ray or Japan's Ozu Yasujirō emanates from the deliberateness with which they pace even the most dramatic of actions.

Tempo is not necessarily related to the actual length of a motion picture. A poorly made short film may seem long, for example, while *Intolerance* (1916), D.W. Griffith's 3½-hour masterpiece, can command the full attention of connoisseurs.

Sound. Mechanical reproduction of sound was developed as early as the first motion pictures, but the problems of amplifying sound sufficiently for an audience and synchronizing it with the film image were not solved until the late 1920s. Although sound attracted crowds to the cinema to hear the new miracle, the artistic levels of the best silent pictures were not reached immediately. The new "talkies" were mostly poor imitations of theatrical plays, with dialogue and sound used indiscriminately. Sound equipment was cumbersome and imperfect. The mobile camera of the silent film lost its freedom, and the editing of film tied to a sound track became stodgy and slow.

Sound also resulted in great advantages, however. The cumbersome captions of the silent film could be dropped; certain strained methods of showing sound in pictures, such as shots of factory whistles, guns firing, or rows of clapping hands, became unnecessary. Music could be composed for a film and enjoyed in the humblest as well as the grandest cinema. Just as the visual image in the frame of a motion picture was elevated from the profusion of nature and could be seen fresh, so could sound be isolated for artistic purposes—the screech of automobile tires, the ticking of a watch, the baying of hounds, the whinny of a horse. The dramatic effect of sound could be tremendous. The rushing, crackling sound of a great fire in the last scene of Robert Bresson's *Trial of Joan of Arc* (1962) is as terrifying as any visual effect could be. In Hitchcock's *Torn Curtain* (1966) there is a desperate struggle in the

Dramatic effect of sound

kitchen of a lonely farmhouse; as the doomed man's head is held in an oven, and his hands (the only thing in the picture) convulsively twitch, the sound of hissing gas dominates the scene. The introduction of sound also made it possible to use silence with a dramatic effect that is more telling than either words or music.

Like images, sounds can be used to represent subjective thoughts, indicating not what the character is saying but what is in his mind. For example, in Hitchcock's *Blackmail* (1929), the first English sound film, the words "knife, knife, knife" are repeated in the thoughts of a frightened girl who thinks that she has committed a murder.

In terms of montage, sound, dialogue, and music are used in combination not only with one another but also with the visual image. They can overlap and vary in intensity in a flexible and complex pattern. The finished sound track may involve mixing together tracks of dialogue, background noises, and music recorded at different times; the tracks must be matched to one another and to the visual film. Though the audience may hear it simply as an accompaniment to what they see, the sound may be the most expensive and difficult part of a motion picture.

Music. The live music that accompanied silent films varied from a full orchestra to a honky-tonk piano, according to the size of the cinema. Music was effectively used on the film set to improve an actor's performance. With sound, music became an integral part of the picture on the screen. Early mood music was so expressive that often it now seems overblown. Conscientious filmmakers soon learned the virtue of restraint, using music less frequently but with more effect. Since the 1960s, electronic music, as in *Close Encounters of the Third Kind* (1977), has come to be commonly used.

Music often has an important function in emotional climaxes of motion pictures. It can be used effectively to relieve or sublimate intolerable intensity—of grief, pain, or ecstasy. *The Gospel According to St. Matthew* (1964) by the Italian director Pier Paolo Pasolini reveals how expressive periods of silence can be, and how great music can ennoble scenes like those of Christ's persecution and agony on the cross. Music may also be used symbolically. In *Léon Morin, prêtre* (*Leon Morin, Priest,* 1961), for example, a sequence of harsh chords represents the German occupation forces, and a dancing bugle motif represents the Italian troops. Organ music is used in scenes showing the heroine with the priest in church, and piano music when they are in his flat. Hurdy-gurdy music represents two gossiping spinsters, and in a climactic scene louder and louder electronic music represents the heroine's obsessive sexual feeling for the priest, until she reaches out to take his hand.

Sound engineering. It is the function of the sound engineer to select and modify sound as the cameraman selects visual images. Since the noise of crockery, cutlery, or paper or the chirping of crickets would be intolerable transferred in full volume to the screen, the sound engineer must tone them down. Treble and bass must be balanced. In other cases, in order to get the effect needed, sound has to be built up and orchestrated as if it were music. Again, sound need not correspond exactly with the visual images. Artistic use can be made of asynchronism; that is, contrasting the sound to the visual image. Motion-picture sound is capable of remarkable delicacy, richness, and variety. Sound libraries put most conceivable sounds readily at the disposal of filmmakers. Instruments and voices can be modified, overlapped, echoed, or given a resonance and volume that transform them. Dialogue can be crystal clear, bringing the audience far closer to an actor than in the theatre, or it may deliberately reproduce the careless enunciation of everyday speech.

The script. Although conventions vary from one country to another, the script usually develops over a number of distinct stages, from a synopsis of the original idea, through a "treatment" that contains an outline and considerably more detail, to a shooting script. Although the terms are used ambiguously, script, or screenplay, usually refers to the dialogue and the annotations necessary to understand the action; a script reads much like other printed forms of dramatic literature, while "shooting script" or "scenario" more often includes not only all of the dialogue but also extensive technical details regarding the setting, the camera work, and other factors. Moreover, a shooting script may have the scenes arranged in the order in which they will be shot, a radically different arrangement from that of the film itself since, for economy, all of the scenes involving the same actors and sets are ordinarily shot at the same time. Some scripts are subsequently modified into novels and distributed in book form, such as the U.S. best-seller *Love Story* (1970) by Erich Segal, and, in the instance of Dylan Thomas' *The Doctor and the Devils* (1953), a script became a literary work without ever having been made into a motion picture. Generally, more elaborate productions require more elaborate shooting scripts, while more personal films may be made without any form of written script. The script's importance can vary greatly, however, depending on the director. Griffith and other early directors, for example, often worked virtually without a script, while directors such as Hitchcock planned the script thoroughly and designed pictorial outlines, or storyboards, depicting specific scenes or shots before shooting any film.

Shooting script

Adaptation from other art forms must take into account differences of complexity and scale in film. A film often must omit characters and incidents in the novel from which it is adapted, for example, and the pace usually must be accelerated. Ordinarily, only a fraction of a novel's dialogue can be included. In an adaptation of a play, the curtailment is less severe, but much dialogue still must be cut or expressed visually.

Film adaptations of literary works

Well over half of all fiction films made since 1920 have been adapted from plays or novels, and it is understandable that certain formulas have been tacitly accepted to facilitate the remaking of literature into moving pictures. Adaptation has been thought of as an aesthetically inferior exercise, because most such films merely illustrate the classics or reshape a literary text until it conforms to standard cinematic practice. The particular qualities that made the original interesting are often lost in such a process. Certain films and filmmakers, however, have achieved an aesthetic premium by accepting the literariness of the original and then confronting this with the technology and methods of the cinema. Since the 1970s numerous directors have explored literature in an almost documentary manner. The artifice of the French director Eric Rohmer's *Die Marquise von O.* (1976), for example, aptly expresses the literary sensibility of Heinrich von Kleist's romantic, ironic work. On the other hand, less adventurous, big-budget adaptations continue to reshape the literary works they are based on into conventional "Hollywood" movies, as some critics complained about Sidney Pollack's *Out of Africa* (1985). The delicate and changing sensibility of the main character, evident in the prose of the original, was not reflected in the film's traditional, albeit grand, presentation.

Although many eminent literary authors, including F. Scott Fitzgerald and William Faulkner, have worked on film scripts, the ability to write a good original script, especially under strict studio conditions, frequently belongs to lesser-known scenarists with a strong visual sense. Some writers, particularly in France, have tried to narrow the gap between the written and cinematic modes of expression. Marguerite Duras and Alain Robbe-Grillet became leaders of a new kind of author who is able and willing to "write" directly on film. Both have directed their own films, which they see as equivalent to their novels and plays.

Motion-picture acting. Of all the artists involved in films, the actors and actresses are closest to the audience. The public more often goes to see a motion picture for its stars than for any other single reason. The divergent techniques of stage and film acting are well understood, and there are many leading players who excel in both. But the greatest film stars have a talent peculiar to the screen alone. This talent often seems to be related not to how well they act, but to the sort of person they appear to be.

Being oneself

Film acting requires restraint. "Don't act, think," was the advice of the eminent German director F.W. Murnau. While stage actors may be praised for a performance that is highly wrought, film stars usually must appear to be themselves. Close-ups accentuate the more intimate rela-

tionship the actor can establish with a film audience, an audience that has often followed the actual life of certain actors whom the industry promotes as "stars." The German theorist Walter Benjamin argued that the image of the star compensated the film audience for the loss of direct access to live performance. For this reason film actors from movie to movie are likely to be cast in similar roles, as the case of John Wayne makes clear.

Some actors, however, have deliberately tried to avoid being typecast. Robert De Niro, for example, is well known for the violent, obsessive characters he played in such films as *Taxi Driver* (1976) and *Raging Bull,* but he has been equally effective in more quiet, controlled roles, such as the charismatic hero in *The Deer Hunter* (1977) or the romantic movie producer in *The Last Tycoon* (1976). In his films, De Niro downplayed his own personality to "become" the characters he portrayed, even transforming himself physically by gaining excessive weight for his role in *Raging Bull.* Actors who have been strongly identified with one role have found it harder to change their image. Sean Connery, for example, has appeared in more than 40 films, playing such diverse characters as an eccentric poet in *A Fine Madness* (1966), an Arab chieftain in *The Wind and the Lion* (1975), a medieval monk in *The Name of the Rose* (1986), and a Prohibition-era Chicago policeman in *The Untouchables* (1987), but he remains most recognized for the seven films in which he starred as the sophisticated British secret agent James Bond.

A motion-picture performance can be synthesized bit by bit, by the joint efforts of the actor, the director, the cameraman, and others. The conditions of film production, however, are such that some actors find them trying. They may have to put up with long hours on the set and endless repetition, they must adapt to shooting scenes out of sequence, and in close-ups they often have to respond to the camera rather than to another actor. They require a talent different from, but equal to, that of theatrical performers.

Styles of acting

Throughout the history of the art, acting styles have frequently led to major revolutions in film style. Most of the shifts in acting have been toward what is deemed a more "realistic" approach. Often this realism is the result of the studied application of acting precepts, as when Marlon Brando brought to *On the Waterfront* (1954) the lessons he had digested at the Actors Studio (the professional workshop in New York City). In the 1960s several successful Czechoslovak films featured effective performances by what appeared to be average citizens; but in truth the players' long silences, their bumbling, and the foibles that seemed so natural were the result of lifelong practice and interminable rehearsals. Some films, however, have exploited the documentary power of the medium to reveal the behaviour of untrained but expressive individuals. Many of the masterpieces of the postwar Italian Neorealist movement relied on absolute amateurs, who were frequently picked up off the streets by the casting director.

Side by side with the never-ending quest for naturalness in acting, an opposite impulse has brought to the screen both stylized and histrionic performances of great power. Cinematic expressionism (largely identified with German films from the 1920s but also evident in Eisenstein's *Ivan the Terrible*) depends on contorted bodily and facial gestures, which are amplified by decor and camera angle. Eminent actors, including Laurence Olivier and Orson Welles, have shown that some types of film thrive on expansive theatrical voicing and gesture.

By courtesy of Paramount Pictures Corporation. *The Untouchables*; copyright © 1987, by Paramount Pictures Corporation, all rights reserved; photograph by Zade Rosenthal



Sean Connery and Kevin Costner in *The Untouchables* (1987), directed by Brian De Palma.



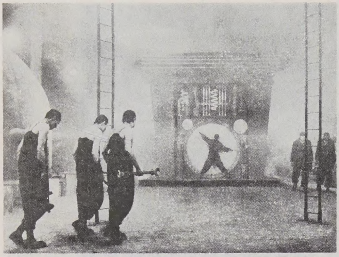
Marlon Brando and Eva Marie Saint in *On the Waterfront* (1954), directed by Elia Kazan.

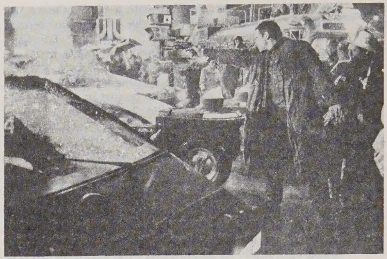
By courtesy of Columbia Pictures. © Columbia Pictures Corporation, renewed 1982, all rights reserved; photograph from the Museum of Modern Art/Film Stills Archive, New York City

Comedy requires other considerations. The impassive visages of the silent star Buster Keaton and the French comic Jacques Tati helped transform their bodies into expressive machines that interacted with the greater machine of the films they starred in. The Marx Brothers, on the other hand, depended on loose cinematic construction, dialogue, and zany, spontaneous action. In short, there can be no single theory of film acting.

Motion-picture design. Under the heading of design, all of the elements of a picture's setting may be included—art direction, scenic composition, set design, costume, and makeup. At its simplest and most naturalistic, the camera can choose and frame ordinary people in a real location. At its most elaborate, motion-picture production may involve the expenditure of vast sums to put up gigantic sets that require building houses, ships, churches, and monuments, or re-creating lost cities, bygone landscapes, or ancient battles, and dressing thousands of extras in period costumes. Thunderstorms, tornadoes, snowstorms, earthquakes, volcanic eruptions, and tidal waves may be simulated, or monsters, spaceships, and cities of the future created.

Film sets are constructed more solidly than stage scenery, but of the lightest, cheapest materials that will both look authentic and photograph well. Whether for black and white or for colour, their shades, proportions, and shapes are chosen for the camera rather than the eye. The camera can deceive the viewer about scale, however, and the model makers and special effects technicians can reproduce virtually anything in miniature, from the aurora borealis shining on an igloo to a tempest destroying the Spanish Armada. A whole series of film monsters have attracted goggle-eyed audiences since the French pioneer Georges Méliès' formidable man-in-the-moon of 1902. Miracles can be achieved in film, either in the colossal form of the crossing of the Red Sea by the children of Israel in Cecil B. deMille's epic *The Ten Commandments* (1956) or in the comparatively simple treatment of angels and miracles in Frank Capra's *It's a Wonderful Life* (1946) or Warren Beatty's *Heaven Can Wait* (1978). Film publicity makes much of the creations of epics such as *Cleopatra* (1963) or *Apocalypse Now,* but, even on a more





Use of sets to depict the bleak life of the future generation.
(Left) *Metropolis* (1926), directed by Fritz Lang; and (right) *Blade Runner* (1982), directed by Ridley Scott, with Harrison Ford as detective Rick Deckard.

By courtesy of Warner Brothers, Inc., *Blade Runner*, copyright © 1982 the Blade Runner Partnership, all rights reserved; photographs from the Museum of Modern Art/Film Stills Archive, New York City

modest scale, sets can contribute enormously to a motion picture, as in Ken Adam's sets for *Dr. Strangelove* (1964), *Sleuth* (1972), and the James Bond series.

The Expressionist influence on set design

The strongest single artistic influence in motion-picture set design was the German Expressionist cinema of the 1920s, which combined elements of Max Reinhardt's theatre, a Wagnerian philosophy of doom, and Expressionist painting and graphics. Expressionist films such as *The Cabinet of Dr. Caligari* (1919), *The Golem* (1920), *Nosferatu* (1922), and *Metropolis* (1926) created a world of fantasy and horror peopled with menacing, shadowy figures. In other German Expressionist motion pictures, such as *The Student of Prague* (1926) or *The Nibelungen* (1924), there was a baroque beauty of architectural, woodland, and floral settings. The influence of Expressionism can be seen in later cinema in the work of the directors Orson Welles and Carl Dreyer, and in many gangster movies.

Subject matter and how it is treated is reflected in all the elements of design in a motion picture. In the hectic atmosphere of a horror movie or a thriller, a studio set may pass unnoticed, even though it would seem disconcertingly artificial in another film. In a musical everything may look artificial: a chambermaid's bedroom may be a model of daintiness and taste. Some films, however, depend on realistic sets for dramatic effect. Accordingly, some directors, especially the French master Jean Renoir in his 1930s films, went to great lengths to be authentic, avoiding the use of rear screen projection, or process shots (*i.e.*, a shot in which new action is filmed in front of a screen on which previously filmed background footage is projected). All of the train sequences in Renoir's *La Bête humaine* (1938), for example, were shot on a moving engine, except the final scene, in which the hero, played by Jean Gabin, leaps to his death. Another French director of the same era, Marcel Pagnol, had his cast and crew construct the farmhouse for his masterpiece, *Angèle* (1934), not to save production money but to increase the naturalness of their behaviour on the set during shooting.

In historical epics, such as *A Passage to India* (1984), or science fiction films, such as *Blade Runner* (1982), settings vie with actors and story for the viewer's attention. In carefully constructed, intimate dramas, such as those by Robert Bresson (*L'Argent,* 1983) or Jim Jarmusch (*Stranger Than Paradise,* 1984), the setting can embody the tone of the film. Numerous stylistic options are attached to decor: its richness or sparseness; its naturalness or artificiality; its contemporaneity or period look; its cleverness or simplicity. Because all these factors are related to the full conception of the film, the set designer is one of the first artistic collaborators called in by the director in the quest for a strong, forceful production.

Lighting. In a medium consisting of the projection of impressions on a light-sensitive material, lighting is of special importance. Daylight is the readiest, cheapest, and strongest source of lighting. Hollywood was said to owe its preeminence as a motion-picture production centre to its sunny climate. Even in daylight shooting, however, artificial aids may be necessary to reduce the highlights or to lighten the shadows.

Lighting as a method of composition

Lighting, a part of camera-work, is under the control of the chief cameraman or lighting cameraman. In black-and-white films, lighting is of paramount importance in giving the overall light or dark tone of the scene and in providing for dramatic contrasts or emphasis within the scene. In colour, the lighting works indirectly to bring out or modify the colour. Lighting in the cinema is a method of composition, used to complement and reinforce the dramatic situation. Generally, dark lighting is associated with tragedy and bright light with romance or comedy, but overlighting gives ghastly or unearthly effects, as in the memory sequence at the beginning of the Swedish director Ingmar Bergman's *Sawdust and Tinsel* (1953; also called *Naked Night*). Lighting an actor from above gives his face a spiritual effect; from below, an uncanny or evil appearance. Front lighting blurs faults but takes away character; side lighting gives relief and solidity but may show wrinkles and defects. Lighting from behind tends to idealize a subject and give it an ethereal quality.

Fashions in film lighting have fluctuated through the years. Early films tended to be flat and uniform. Later, especially in German Expressionist films of the 1920s, strong contrasts of light and shade were favoured for their highly dramatic effect. Still later, this tendency was modified toward more balanced lighting. Even in dramatic scenes, the centre of interest now tends to be more discreetly emphasized.

Occasionally, different types of lighting are used for dramatic effect in a single film. For his Shakespearean adaptation *Henry V* (1944), Laurence Olivier employed uniform, bright light for the sequences modeled on medieval book illustrations, but in the contemplative sequences (Falstaff's death and Henry's solitude the night before the battle) he used single-source lighting from the side, which allows extensive gradation of light and shadows, making the images look like paintings by Rembrandt. The elegiac humanity of the latter scenes contrasts with the brittle, eternal quality of the former. More often, directors choose a single look. Stanley Kubrick's decision to film *Barry Lyndon* (1975) in candlelight is a notable example.

Related to lighting is the development of the print in the laboratory, where sections of film shot under different conditions can be modified to avoid a violent contrast where none is desired. Finally, the lighting of the projector that shows the picture and the brilliance of the screen are important. As light sources for the projector, both the traditional carbon arc and the modern Xenon lamp have advocates; what matters most is that the light be powerful, brilliant, and unvarying throughout the projection of the picture.

Settings. A salient feature of the cinema is its ability to reproduce natural scenery. From the earliest years filmmakers have mixed outdoor footage with scenes shot

inside the studio to give audiences the impression that the carefully calculated dramas they are witnessing are faithful records of events that occurred spontaneously in the real world. Just after World War I the Swedish directors Mauritz Stiller and Victor Sjöström stunned audiences with their films featuring simple folktales set in the mountains. The seasons of the year, the weather, and the Swedish streams, lakes, and waterfalls were active participants in these tales. After the success of such documentary features as those by Robert Flaherty (*Nanook of the North*), even Hollywood made room for films in which the natural setting was clearly the main protagonist, with the fictional drama used as a way to convey the audience around the landscape. More often the landscape provides an alternative attraction, allowing viewers to see favourite stars in exotic locations, as in *Out of Africa*. Another trend has been the use of familiar surroundings as the sets for futuristic dramas. Jean-Luc Godard's *Alphaville* (1965) turned Paris into an oppressive metropolis on another planet, and *Blade Runner* made contemporary Los Angeles look like a city of the 21st century.

Location filming

With the invention of lighter, more portable equipment, filming on location—that is, in an actual setting like the one in which the story takes place rather than in a studio set—has become less difficult and expensive and more often used. As a result, many earlier motion pictures now look artificial, since no studio set can equal the authenticity of a real location. Nonetheless, films may have to be shot in a studio when natural settings are unavailable, as in historical films, or are too remote. On the other hand, the effect of certain films can be utterly lost when inauthentic locations are substituted for genuine ones. The 1948 British Technicolor epic *Scott of the Antarctic*, for example, was shot in the Swiss Alps, which facilitated filming but ruined the documentary aspect of the film. In some cases, rear screen projection can be used to provide a background setting against which the actors perform.

Costume. Actors in motion pictures have been dressed in noticeable and often significant ways since the beginning of film history. The Italian epics made before World War I displayed Roman and Egyptian styles that the public had come to expect from popular paintings and stage plays dealing with these ancient subjects. After World War I, Ernst Lubitsch gained fame directing historical dramas, such as *Madame Dubarry* (1919), that were termed "costume dramas" even in their own day. From the 1920s to the 1950s various national cinemas, but particularly those in France and the United States, vied with one another in using the cinema to promote fashion. Christian Dior's rise in the world of haute couture was accelerated by his experiments with, and his advertising of, costumes in motion pictures. In Hollywood a motion picture was often an opportunity for an actress to wear one gorgeous costume after another, and many screen designs initiated popular offscreen fashion trends. After World War II the Italian Neorealist movement proved that audiences could also be drawn by authenticity of dress. Since then, many films attempting to convey a realistic effect have been outfitted not from the costume shop but from second-hand clothing stores.

Costume and the actor's identity

Costume also once played a more important role in an actor's identity. Charlie Chaplin, Buster Keaton, Mae West, and other stars of the 1920s and '30s all created characters in which costume was an integral part of the total identity. Audiences were often able to discern the type of character an actor was portraying—hero, villain, comic foil, romantic rival—by the clothes that he was wearing.

Makeup. Film makeup differs significantly from that of the stage, where heavy lines are required to convey a characteristic expression to the audience. By means of the camera, the motion-picture audience can study the actor's face quite closely. The makeup must be flawless to stand up under such scrutiny, but since it need not be applied nightly for several months running, as in theatre, elaborate preparations are feasible. Many of the greatest filmmakers, such as Carl Dreyer and Robert Bresson, have favoured naturalism in makeup—the unadorned lines of old age or a face caked with dust, running with perspiration. Whatever the style of makeup, its purpose is to make the face a more photogenic object, whether monster or ingenue. The efforts of wig makers, dentists, and plastic surgeons, as well as cosmeticians, are aimed at a heightened reality.

The cosmetics industry grew up in the 1920s alongside motion pictures. Max Factor's fame owes much to the work his company did in modifying makeup to adjust to new types of film and lighting, including the shift to colour cinematography. With changing audience perceptions, caused by television and other factors, more natural makeup styles became just as popular as the "idealized" methods applied to the great studio stars. Sylvester Stallone is one actor whose makeup is exceedingly important in emphasizing his craggy, often sweating features. Ironically, the "natural look" is often the result of extensive makeup tests.

While makeup generally is meant to remain unnoticed or to play servant to the beauty of a face, in science fiction and horror films it may take centre stage. Although it is an art as old as society itself, makeup is, like the other aspects of cinema, subject to technological development. Advances in contact lenses, in prosthetics, and in chemistry have made possible such magnificent and startling displays as *2001: A Space Odyssey* (1968), *Planet of the Apes* (1968), *Time Bandits* (1981), and the never-ending flow of creatures that terrorize horror-film audiences.

(R.St./D.A.)

© The HandMade Films Partnership; photograph from the Museum of Modern Art/Film Stills Archive, New York City



Peter Vaughan, in costume and makeup, for the role of Ogre in Terry Gilliam's *Time Bandits* (1981).

Authority of the director

Motion-picture directing. The modern motion-picture director is the person most responsible for the ultimate style, structure, and quality of a film. Cinema is an art of collaboration, and in some instances someone other than the director may come to dominate (for example, a producer with authority over the final cut, or an actor whose box-office popularity gives him the power to direct the director), but in general it is assumed that the person assigned to direct the picture must take the credit or blame for its form and content.

While the function the director serves has always been filled by someone, the priority of that function has not always been recognized. Georges Méliès, for example, thought of himself as a "producer" of films, and indeed from 1896 to 1912 he took care of all aspects of the making of the films bearing his name, including set design, acting, and camera-work. Charles Pathé, in turn-of-the-century France, was one of the first producers to assign an assistant (Ferdinand Zecca) specifically to direct the pictures of his rapidly expanding film empire. At France's Gaumont Pictures, Louis Feuillade and Alice Guy, the first woman to take on a key position in cinema, shared the task of directing, each specializing in separate genres. In the United States as in Europe, many of the first

film directors were cameramen (Edwin S. Porter) or actors (D.W. Griffith) until circumstance compelled them to take on various directorial duties. The movie industry was growing rapidly, however, and by 1910 the number of films required to fill the many newly constructed movie theatres was such that production had to be delegated. The director's role was to work with the actors, designers, technicians, and others involved in the moviemaking process, coordinating and overseeing their efforts in order to rapidly turn out interesting and comprehensible movies within given financial and material strictures.

As early as the 1920s those who wrote seriously about motion pictures had no qualms about attributing successes and failures to the director. Some directors, notably F.W. Murnau and Fritz Lang in Germany and Victor Sjöström in Sweden, were virtually as famous as the stars who acted in their films. In 1926 William Fox paid Murnau $1,000,000 to relocate in Hollywood in the hopes that he would make the greatest movies the world had yet seen. The primary issue of this marriage of art and money, *Sunrise* (1927), remains an anomaly in the history of the film industry, for Murnau was given unusual control and virtually unlimited resources. The film still astounds critics, but it was not a commercial success and it stunted for a time the growing stature of the director. Erich von Stroheim's more dramatic encounters with producers such as Irving Thalberg further encouraged this businesslike attitude, which led to the practice of quickly typing directors as either workmanlike or difficult.

In the great age of the studio system (1927–48), strong directors vied with the factory conditions in which films were made. Those directors with powerful personalities (such as Frank Capra, Howard Hawks, John Ford, and Ernst Lubitsch) were given great freedom, but they still had to work with actors and actresses contracted to the studio, with union personnel following time-honoured routines, with scripts and scriptwriters selected by the studio, and with deadlines that discouraged experimentation.

The auteur theory

The "auteur theory," which was propagated by French film theorists in the 1950s, offered a powerful method for studying and evaluating the films of the studio era. The word "auteur" (literally "author" in French) had been employed in France in the 1930s in legal battles over the rights to artistic property. This legal struggle to determine whether a film "belonged" to its scriptwriter, director, or producer strengthened the belief held by many critics and theorists that it was the director alone who deserved credit for a film, just as an architect could be credited for a building even though it was built and used by other people. While this view made eminent sense when strong directors were concerned, it tended to ignore average filmmakers.

Auteurs are defined as directors with solid technique, a well-defined vision of the world, and a degree of control over their productions. Some directorial situations are easy to evaluate. Griffith and Chaplin had complete financial control over their major efforts; European art directors, such as Ingmar Bergman, enjoyed similar freedom. Indeed their films were often marketed as the expressions of important artistic personalities. The auteur theory, however, was developed to encourage the reevaluation of countless films by directors operating in the middle of suffocating studio situations. Directors such as Leo McCarey, Gregory La Cava, and Anthony Mann stylistically and thematically imbued their films, whatever the genre, with a consistent, personal aesthetic. Their output, even when unsuccessful, is deemed immeasurably more valuable than the undistinguished films of weaker directors who merely translated the words and actions indicated in a script into routine screen images. (Scriptwriters in the studio years worked mainly in teams. A single script often passed through the hands of several different writers so that most films are more recognizable as the product of a particular studio than of an individual writer.)

The tension between director and genre or studio is thought to be productive of films that appeal to the public while expressing the vision of an individual. Thus, through the auteur, the popular art of cinema is able to achieve the traditional goals of poetry and the fine arts, goals of authentic expression and of genius.

The auteur theory was especially influential in the 1960s and arguably was instrumental in creating not only the French New Wave but also similar movements in Britain and the United States. Directors such as Lindsay Anderson, Joseph Losey, Stanley Kubrick, John Cassavetes, Francis Ford Coppola, and Arthur Penn thought of themselves as budding auteurs and earned critical and popular acclaim for their distinctive styles and themes. With the fall of the studio system in the 1950s there was indeed room for a single personality to take control of a film and to market it on the basis of personal vision.

Artisanal format of filmmaking

After 1960 first-rank American motion-picture directors began to make films under conditions that had been in practice in Europe throughout the century. The insignificant studio system of France, for example, had enabled and encouraged individual entrepreneurs to put together film projects on a onetime basis. Such projects generally revolved around an *équipe*, or team of creative personnel, with the director at its head. The director could then truly shape the work of the designer, composer, and (most importantly) the scenarist, so that the film had a consistent and relatively personal style from beginning to end. In this artisanal format, a producer depends on the director to develop a distinctive way of handling scenes. The director may even be required to rewrite the scenario in order to achieve a particular effect. As a result of this personal commitment, the well-publicized arguments that occur during the production of many important films almost always involve the director.

Alfred Hitchcock was one director who disdained arguments. He kept the blueprint of his films in his head and provided detailed instructions for each shot, without any discussion. His producers were not given the opportunity to offer alternative suggestions or to recut the film. The scenes fit together in one way only, Hitchcock's way. While some critics have complained that the acting in a Hitchcock film is often stilted, that the sets are artificial, and that the rear-projection shots are obvious, the Hitchcock style is immediately recognizable. Most people admire the effectiveness of Hitchcock's direction, some even claiming that in his films can be found profound moral and metaphysical insight.

Major directors throughout the world have often enjoyed such respect. Among others, Mizoguchi Kenji and

North by Northwest, © 1959 Loew's Incorporated; photograph from the Museum of Modern Art/Film Stills Archive, New York City



Cary Grant in *North by Northwest* (1959), directed by Alfred Hitchcock.

Kurosawa Akira of Japan, Satyajit Ray of India, Federico Fellini of Italy, Luis Buñuel of Spain, and Carl Dreyer of Germany have been given rare opportunities to make individual artistic statements. Some have been treated as virtual national treasures whose films bring cultural glory to the countries within which they work.

Television versus film directing

Despite these exceptions, most directors labour under great restrictions, particularly in the age of the television industry. A conventional television series rotates directors episode after episode so that the producers, actors, and production crew, who work continuously on the show, have much greater control over the product. Each scene of a television program is typically filmed from three different camera setups. The director strives to get the best performances possible from the actors, confident that the crew is delivering appropriate images, and an editor later chooses the best shots to use to tell the story. In comparison, powerful film directors have often involved themselves deeply in editing and postproduction. The television industry has accentuated the assembly-line features of the studio system, while independent film production today often distinguishes itself by according the director dictatorial power.

Whether granted complete or restricted control, every director must approve the screenplay and then concentrate on the scene being filmed in its relation to the overall design of the film. The management unit (an assistant director and script girl) concerns itself with the details of organization so that the director can interact with the creative personnel on the set (cinematographers, lighting and sound crews, set decorators, and, of course, actors). As for postproduction, all directors look with the editor at daily rushes from the lab, but only some follow through and become involved with the editing, music, and mixing phases. In all cases, the director is the one person to maintain a complete view of the project, drawing the best from all the personnel, from writer through sound mixer, and shaping their efforts so that the film attains a consistent look and meaning.

Successful directing has much to do with intangible social relations, such as keeping harmony (or productive competition) alive on the set, drawing the best possible performances from actors, shaping a script into a form that takes advantage of the talents of the director of photography or of the main actor, or beseeching the producer for the money needed for a special shot. Beyond such routine expectations, the great director is identified for a unique or ingenious approach to the medium. Directors have earned praise for their audacious handling of stories. Refusing to be hemmed in by the standard requirements of a two-hour drama dealing with a few central characters, Francis Ford Coppola, for example, pieced together a truly epic fresco in his two-part masterpiece *The Godfather,* as did Robert Altman in such collage narratives as *Nashville* (1975). Italian directors have experimented with the epic form, as in Ermanno Olmi's *The Tree of Wooden Clogs* (1979) or Bernardo Bertolucci's *1900* (1976), and with narrative structure, as in Rossellini's *Paisà* (1946) and Ettore Scola's *Le Bal* (1983), which abandon traditional plot construction and a single story line in favour of separate short episodes that are thematically or historically linked.

Some directors gain more fame for their visual style than for their narrative acuity. Bertolucci's films, for example, are not always well received, but his fluid, saturated images and their "psychoanalytic" effect have made their mark in films such as *The Conformist* (1970) and *Luna* (1979). The same might be said for Federico Fellini, Andrey Tarkovsky, and Werner Herzog. Some critics feel that Coppola's *One from the Heart* (1982) projects an intense, personal vision, which is much more interesting from the directorial point of view than his more commercially successful efforts, including *The Godfather.* Although many directors credit their cinematographers for achieving such notable visions, most cinematographers claim merely to solve technical problems at the behest of the director.

The same can be said of effects achieved in postproduction. The incredibly dense aural ambience surrounding Coppola's *Apocalypse Now,* for example, resulted from the concatenation of scores of individual sound tracks mixed by a team of talented experts, but Coppola himself had already evinced a powerful understanding of the possibilities of sound in his much smaller film *The Conversation* (1974). Similarly, a good share of Robert Altman's fame must go to the engineers who coordinated the radio miking of as many as a dozen characters in a single scene in *Nashville.* It was, however, Altman who recognized the total effect that two hours of overlapping conversations would have on the spectator. Martin Scorsese's rugged editing in *Taxi Driver* and *Raging Bull* was a function not only of an editor's ingenuity but also of a total conception of script, acting style, camera-work (including harsh black-and-white tones for the latter film), and music.

The director as problem solver

A director might best be thought of as a problem solver. Seldom concerned with technology, the director takes the resources at hand (the technological capabilities and the conventions of filmmaking operating at the moment) and searches for effective solutions to dramatic or visual problems. A style emerges when these solutions, or "techniques," are applied consistently across a series of films. For example, Robert Bresson's penchant for employing off-camera sound to signal important events (a car wreck in *Au Hasard Balthasar,* 1966; a bank robbery in *L'Argent*) defies standard filmmaking conventions and reaches toward a peculiarly valuable way of understanding an interior or spiritual drama. Bresson's sound techniques have become part of his austere and evocative style.

Directors may be characterized by the solutions they regularly arrive at when a story or scene is presented to them. Murnau and Mizoguchi preferred the languorous tracking shot to editing a dramatic situation, so that the drama could be seen to arise in the midst of the shot. Antonioni let the camera continue to shoot well after the characters were out of range, so that the spectator could observe the way a dramatic scene disappeared or sense its smallness in the landscape that remained. Most American directors have employed hard-hitting, swift techniques to give power to the gritty stories that dominated world cinema after 1970. Close-up sound, pounding music, and abrupt editing keep the spectator interested and excited. Within this general American style, however, individual directors have found different methods to achieve similar effects, and they have discovered that using similar techniques does not guarantee similar results. It is generally acknowledged that the best directors are those who consistently contribute not only ingenious techniques but also an effective, coherent, personal style or theme to their films. Brian De Palma's use of point-of-view strategies, for example, gives a particular horror to such films as *Carrie* (1976) and *Body Double* (1984), and his technique has been compared to that of Hitchcock. Most critics agree, however, that Hitchcock is the more significant director because the rigorous point-of-view strategy that Hitchcock employed in such films as *Rear Window* (1954) was far more than a tour de force of moviemaking technique; it was an expression of the director's thoughts on vision and knowledge. (D.A.)

TYPES OF MOTION PICTURES

Film modes

Most connoisseurs of the art of motion pictures feel that the greatest films are the artistic and personal expression of strong directors. The cinema exists, however, for many social functions, and its "art" has served many types of film that do not set out to be artistic. In practical terms these functions divide films into what are usually termed modes, including the documentary, the experimental, and the fictional. The documentary mode incorporates those films relying primarily on cinema's power to relay events in the world automatically. The experimental includes the variety of approaches that have tested and played with the technological limits and capabilities of the medium, including animated (nonphotographic) and computer-generated images. The fictional is the mode most often thought of as simply "the movies." It has adopted the forms of storytelling that have always existed in culture, creating various cinematic languages to convey its tales. Each of these three modes can in turn be subdivided into genres (*i.e.,* commonly recognized types of stories or forms).

The documentary. The turn of the century witnessed

not only the invention of the motion picture but also tremendous growth of popular interest in journalism, picture postcards, lectures by travelers (frequently illustrated with slides), and so forth. The motion picture quickly came to serve society's need to learn about the geography and social conditions of the world at large. Some of the first motion pictures depicted exotic locations, contemporary events (battles, coronations), and unknown cultures. Indeed as late as 1908 such a major company as Biograph actually produced more nonfiction films than narratives. This would soon change, in part because the production of documentary films is dependent on world events and is therefore more haphazard and more difficult than the fully controlled process of making fiction films in studios. The decline of the nonfiction film has also been attributed to the belief that, after a decade, audiences were saturated with "views" and "actualities," as such films were called. Moviegoers were no longer drawn to the sheer recording ability of motion pictures; they demanded imaginative entertainment instead.

Travelogues and ethnographic films. One sort of film that has had continuous appeal, albeit for a specialized audience, has been the travel film. Much of the attraction of such films—from the crude pictures cranked out by Lumière cameramen in Japan, Africa, and the Arctic, to Robert Flaherty's films about the Eskimos, the South Sea Islands, and the wild western coast of Ireland, to National Geographic presentations on television—results simply from the thrill of seeing a foreign culture or a distant location. Flaherty proved, however, that there could also be tremendous artistry in such films. His unforgettable compositions matched the harmonious rhythm of his editing to render the lives of his subjects in a gloriously romantic tone.

Influence of travel films on fiction films

Both anthropologists and Hollywood producers immediately recognized the value of Flaherty's work, initiating several long-lived genres. In Hollywood *King Kong* (1933), one of the most famous monster movies ever made, was conceived by producer-director Merian C. Cooper, who was inspired by his experience shooting travel documentaries. The surprising success of *The Gods Must Be Crazy* (1981), a comedy about life in the Kalahari desert of Botswana, shows that audiences continue to enjoy the mixture of foreign locations and familiar dramas. The Bushmen (San) of the Kalahari are also the subject of an important ethnographic film, John Marshall's *The Hunters* (1958). Marshall's tradition dates to the 1930s and to the films the anthropologists Margaret Mead and Gregory Bateson made in the Pacific.

Most scholars prefer that all artistry be eliminated from ethnographic films so that the visual data recorded by the camera remains as fresh and uninterpreted as possible. The audience for these films typically consists of members of a university or museum community for whom entertainment is less significant than authenticity. When such films are prepared for mass television audiences, however, many concessions may be necessary, including the addition of extensive explanatory narration, musical accompaniment, and scenic photography.

Newsreels and documentaries. The argument over the role of art and artlessness in travelogues and ethnographic films is also pertinent to newsreels, where the standard principles governing journalism must apply. In the first years of cinema, reconstructions of such events as *The Dreyfus Affair* (Méliès, 1899) and *L'Assassinat de McKinley* (Pathé, 1901) were commonly accepted. Since then, viewers have required that newsreel material be neither prearranged nor fabricated, and they have become aware of the effects of the intrusiveness of the reporter and the limitations of point of view on the objectivity of any documentary film.

Newsfilms, more than any other type of motion picture, depend on their timeliness. Hence, for all of its ability to show the actual world, the motion picture failed to provide genuine news until it did so by means of television. Too stale and infrequent for day-to-day coverage, newsreels showed not news but parades, ceremonies, sporting events, bridge building, and similar events. *The March of Time,* inspired by *Time* magazine and produced by Louis de Rochemont from 1935 to 1951, was a series in which a topic of political or social importance was discussed in depth in a 30-minute film. The series was an immediate and continued success. It is television, however, that has developed the screen presentation of news, comment, and discussion beyond anything known before.



Scene from *Nanook of the North* (1922), documentary film directed by Robert Flaherty.

By courtesy of International Film Seminars, Inc.; photograph, the Museum of Modern Art/Film Stills Archive, New York City

It is less in the straight presentation of reality than in its creative interpretation that the documentary has produced works of lasting value. Among the pioneers of the documentary besides Flaherty were the Russian theorist Dziga Vertov, whose films include *The Man with the Movie Camera* (1929), and the British director John Grierson, whose *Drifters* (1929) inspired a school of fine directors to produce a succession of memorable documentaries through the 1930s. With the outbreak of World War II, Humphrey Jennings' *Fires Were Started* (1943) and Harry Watt's *Target for Tonight* (1941), two among many outstanding British wartime documentaries, dramatized Britain's war effort better than fictional films could.

The British documentarists

In the United States, Pare Lorentz made dramatic documentaries about soil erosion and the dust bowl, such as *The Plow That Broke the Plains* (1936) and *The River* (1937) during the era of the Great Depression, and, during World War II, Frank Capra, who had been an outstanding director of Hollywood comedies, made a series of documentaries under the title *Why We Fight.* The later French movement, *cinéma vérité,* made films that are much closer to journalism than to the careful compositions of the English documentary school. Though often untidy, they are fresh and realistic. Television deeply affected the development of the documentary film in two major ways: by providing a training ground for documentary directors, and by building a supply of news film that could be adapted to documentary form. *Point of Order* (1964), a U.S. documentary film that ran successfully in motion-picture theatres, was made from television films of the U.S. Senate hearings on the charges and countercharges made by Senator Joseph McCarthy and the U.S. Army.

The Vietnam War gave rise to a plethora of documentary essays, some of them politically committed, some attempting a balanced exploration of the situation. American *cinéma vérité,* sometimes called "direct cinema," matured during the war, though not only in response to it. The first of the rock concert films, D.A. Pennebaker's portrait of Bob Dylan, *Don't Look Back,* first played theatrically in 1967, and that same year Frederick Wiseman's *Titicut Follies,* which exposed the horrendous conditions in a Massachusetts institution for the mentally ill, caused such an uproar that it was banned in that state. Excitement over public events and celebrations permitted this spate of documentaries to compete with fiction films for screens in larger cities. The films, which were often of inflammatory content, were kept off television but nonetheless influenced that medium tremendously. *Hearts and Minds* (Peter Davis, 1974), for example, a powerful, though one-sided, attack on U.S. Vietnam policy, had an enormous

impact just because it could not be shown on television. Conversely, in the 1980s, many documentaries were increasingly seen on television rather than on movie-theatre screens. Claude Lanzmann's *Shoah* (1985), for example, a nine-and-a-half-hour examination of the Nazi concentration camps, received limited theatrical distribution in many areas because of its length but still managed to reach wide audiences through the distribution markets provided by the growing cable-television and videocassette industries.

By courtesy of New Yorker Films. *Shoah*. © 1985 Claude Lanzmann; photograph from the Museum of Modern Art/Film Stills Archive, New York City



Henrik Gawkowski, a Polish locomotive engineer in *Shoah* (1985), Claude Lanzmann's documentary of the Nazi concentration camps. The film uses no archival footage of the camps, relying on oral descriptions from eyewitnesses and participants to create its impact.

Propaganda. In presenting a background, an environment, and characters who behave in a certain way, every motion picture may be said to be propaganda. The term is usually restricted, however, to pictures made deliberately to influence opinion or to argue a point. The most powerful and most consistent use of the cinema for propaganda was seen in the Soviet Union. After the 1917 revolution, Soviet films exploded on the screen with fervent conviction. Gradually, however, the pictures became lifeless, and in the 1930s and 1940s, during the Stalin regime, great directors such as Eisenstein and Aleksandr Dovzhenko worked under severe restraints. Nazi Germany produced its own brand of propaganda in the 1930s, the most striking being Leni Riefenstahl's *Triumph of the Will* (1936), a terrifying spectacle of a huge Nazi rally that had in effect been staged for the film made about it.

Propaganda in film

Few filmmakers would admit to making propaganda, although, in effect, many so-called educational films and all advertising or promotional shorts, whether featuring consumer products, vacation sites, or religious sects, may be seen as examples of propaganda. This form of film bears a stigma owing to its undisguised aim: to influence ideas and change behaviour. Cinematic artistry serves merely as a tool in propaganda. (R.St./D.A.)

The experimental and animated film. Films of all kinds may be the results of experiments or may contain attempts to overturn traditional genres, but the mode of experimental film has always been reserved for those endeavours produced and exhibited with the aim of questioning or revolutionizing the medium itself. The mode is by definition limited, because no real traditions can develop that do not soon cease to be experimental.

The first significant experimental film movements emerged during the 1920s, when sophisticated artists began to play with the film medium and when film societies, specialized theatres, journals, and museum lectures began to cater to audiences wanting to be disturbed or surprised. In France at that time a true avant-garde led by painters such as Marcel Duchamp, Man Ray, Fernand Léger, and Salvador Dalí scorned the mass market and sought exhibition in clubs and museums. French directors of the time, including Jean Epstein, Marcel L'Herbier, and Abel Gance, experimented with narrative structure in their films but were still involved in creating feature films for theatrical release. Although these films, especially Gance's *Napoléon* (1927), are full of experimental camera and editing techniques, they are not considered to be experimental films because of their exhibition histories.

The experimental film has been forged out of two impulses. The first has stemmed from movements in the fine arts, such as Futurism, Constructivism, Dada, Surrealism, Minimalism, and Abstract Expressionism. Artists working in these movements have often shifted to cinema as new terrain for their ideas, radically rethinking the medium to make a personal or cultural point. The other impulse has been technological. The experimentalist, curious to see what the medium can do, has explored and expanded the basic processes and techniques involved in filmmaking. The early films of Méliès were precursors of this type of cinema.

Influence of fine arts and technology on experimental films

The two impulses have rarely been seen separately. Luis Buñuel's scandalous *Un Chien andalou* (*The Andalusian Dog*, 1928) arose as much from his curiosity about film and narrative as it did from his association with the Surrealist movement. The same can be said of Maya Deren, founder of the American avant-garde during the 1940s. Other artists have rejected narrative altogether and linked up with traditions in poetry and the visual arts. During the 1950s and 1960s, the heyday of the American avant-garde, Stan Brakhage manipulated focus, lighting, and sequence in a range of distinctively personal and often mythic films. His most radical technical strategy was to eliminate photography altogether—by scratching directly on film, gluing particles on the emulsion, and even growing algae on the film before copying it—in an attempt to express himself without the mediation of character, plot, or objects. Like other filmmakers of the period, he called on the theories of action painting to justify his excesses.

Nonphotographic techniques can also be used to produce representational objects and even stories, as the experimentalist Len Lye proved with his short animated films of the 1930s. Laboriously drawing black-and-white (and later polychrome) figures on every film frame, he achieved a lightness of effect impossible in photography. Imaginative animation can also be used to demonstrate movements or changes that are difficult or impossible to photograph. It can produce striking, eye-catching effects or make a dull subject interesting and entertaining. In addition, information is often conveyed more quickly and clearly through animation than through live action. For these reasons, animated films are widely used for instructional and advertising or other promotional purposes. Animated films can, of course, exist simply to amuse, and the best-known works of animation are undoubtedly the cartoon comedies.

Whatever their length or purpose, animated films have a motion and characterization more succinct than live action. They can more freely contract or distort both time and space and defy the forces of gravity; they can be as realistic or as fantastic as their designers wish. The potentialities of animation have fascinated filmmakers since the earliest days of the motion picture.

The graphic style of early animated entertainments followed at first that of the cartoon strips of the period—hard outlines, little or no modeling, and the flat application of paint when colour was introduced. Walt Disney was responsible for improving the professionalism of the animated film and for getting it into the standard theatrical distribution system. He also helped to develop and popularize the animated feature film. Disney's feature-length *Snow White and the Seven Dwarfs* (1937) contained about 477,000 photographed drawings; it was the leading international box-office favourite of 1938, and its sound track was dubbed into 13 foreign languages.

The symbolic political fable *L'Idée* (1934), by the Austro-Hungarian animator Berthold Bartosch, represented a rare use of animation to present a serious, as distinct from a comic or legendary, subject; the approach was first achieved at feature length by the British husband-and-wife team of John Halas and Joy Batchelor in their adaptation of George Orwell's novel *Animal Farm* (1954). More recently, cartoons were used on occasion in certain Communist countries to make social statements in the guise of highly stylized anecdotes or fables. Some of the most advanced, most inventive work of this kind was done in such countries as Yugoslavia, Czechoslovakia, and Poland. In the United States, highly individual styles were pioneered in the 1940s by the United Productions

Use of serious subject matter



An illustration from Walt Disney's first animated feature film, *Snow White and the Seven Dwarfs* (1937).

Snow White and the Seven Dwarfs, © 1937, The Walt Disney Company; photograph from the Museum of Modern Art/Film Stills Archive, New York City

of America (UPA) group under the direction of Stephen Bosustow. Among their creations were the series that featured Mr. Magoo and Gerald McBoing Boing.

Later, various kinds of graphic fantasy found expression through animation, and the older style of cartooning associated with Walt Disney was completely overtaken by artists using a diversity of contemporary graphic styles, often extremely elaborate. The work of Jiří Trnka and Karel Zeman exemplified the long-established Czech leadership in animated puppetry. Trnka's *Old Czech Legends* (1951) and *The Good Soldier Schweik* (1955) used stylized puppets in naturalistic settings to dramatize social satires, folk legends, and classics. Zeman's work used both puppets and live actors moving within real sets.

Since the 1950s, the experimental filmmakers Robert Breer and Norman McLaren, among others, have developed new styles and techniques of animation, including collage and pixilation (a technique that makes human movements look like those of animated automatons). In the 1960s the cartoon film appeared to lose ground as pure entertainment, except in the Communist countries, but it has steadily advanced in the fields of education and public relations. The growing use of computers in graphic design has further emphasized this use of animation.

(R.M./D.A.)

Fictional genres. Motion pictures are the most important narrative art form of the 20th century, having taken on the functions served earlier by dime novels, serial novels, staged melodramas, wax museum displays, epic paintings, and professional storytelling. These earlier forms continued into the century and were supplemented by comic books, radio, and television, but it is the motion picture that came to dominate them all. Still, most films can be seen as descendants and variants of types of stories and storytelling that predated the invention of the cinema.

Production advantages of genre films

Always plagued by the need for a constant flow of new products to satisfy patrons returning to the movies week after week, film companies quickly began to rely on genres to help regularize production and to help presell their motion pictures. A studio that decided to make half a dozen police thrillers in one year could organize its production schedule efficiently, saving time and money by reusing sets, costumes, and other items. More important, the studio could assign the same personnel to certain genres, allowing writers, directors, technical crews, and actors to establish a routine that often resulted in quicker and improved filmmaking from work to work. In addition, it was found that the initial success of a new film was frequently enhanced by the popularity of previous films in the same genre. Viewers knew, to a great extent, what to expect from a genre film; they recognized the stars, or at least the characters, in it, and they were sensitive to music, lighting, and plot devices because of long familiarity with the type of story being portrayed.

Although the movies have created their own genres, most have been derived from prototypes in the other arts, especially literature. The western, for example, has important precursors in popular painting, Wild West shows, and pulp fiction. It does not matter, however, if audiences are unfamiliar with these other media; viewers quickly learn the rules of the genre, acquiring the ability to recognize the hero from his costume, to anticipate the final shoot-out, and so forth. Genres epitomize the dilemma of the fiction film, in that they promise to deliver to a waiting audience something that is similar to what that audience has enjoyed in the past and yet something that is also quite new and different. Often the most highly acclaimed films are those that invoke the conventions of a genre only to break them down in the pursuit of ideas and visions never attained in that form before. Examples include John Ford's western *The Searchers* (1956), the comedies of Preston Sturges, Arthur Penn's gangster film *Bonnie and Clyde* (1967), and Robert Altman's comedy *M*A*S*H* (1970).

Well-formed genres typically characterize the production of highly centralized studio systems such as those of Hollywood, of Japan, or of India. They play a lesser role in countries where individual producers dominate. In France, for example, most films are treated as single-effort productions, a practice that can permit far more revolutionary films to develop, as was seen during the French New Wave of the late 1950s and early '60s. François Truffaut, Jean-Luc Godard, Claude Chabrol, Eric Rohmer, and other New Wave directors utterly overturned standards of storytelling and visualization to the delight of an international audience tired of old formulas. These directors were not oblivious to genres; rather they played with conventions, mixing comedy and pathos, suspense and spectacle. Their highly personal films confirmed the importance of genre to the fictional mode.

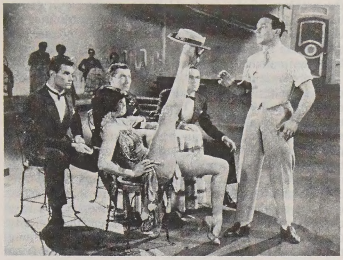
Hollywood genres. Most genres can be defined by their subject matter or setting—*e.g.,* the western, gangster film, police thriller, science-fiction film, or social problem film. Others are classified according to the type of narrative form they exhibit. The musical, for example, often has a show business setting or theme, but it is not so narrowly restricted; it can be about almost any subject. The melodrama also encompasses many subjects and styles; it has even been combined with other genres—for example, with the western in *Rancho Notorious* (1952) and with the problem film in *Ordinary People* (1980).

Evolution of genres

The evolution of genres can be used to trace the history of Hollywood cinema and 20th-century American popular culture. Different genres have achieved popular success in different periods. Some, termed "cycles," are short-lived (*e.g.,* the disaster cycle of the 1970s, which included *Earthquake* [1974] and *The Towering Inferno* [1974]); but even lasting genres go through phases of popularity. The western, for example, was well-established as a genre by the 1920s. It was particularly strong in the late 1940s and early '50s but not during the '30s. It resurged in the 1960s but subsided later in the '70s. Musicals came into prominence with the introduction of sound. They remained important until the late 1960s, when a number of expensive, overblown productions flooded theatres and met financial failure. Most film historians were ready to proclaim the genre dead, but several astounding successes in the late 1970s and early '80s caused them to revise their view of the musical and the culture it addresses.

The internal mutation of a genre reflects the changing tastes and mores of the public. The modern musical (*All That Jazz,* 1979; *Fame,* 1980; *Coal Miner's Daughter,* 1980) is more socially conscious and more serious than the colourful, vividly stylized, self-conscious musicals of the 1940s and '50s (*Singin' in the Rain,* 1952; *The Band Wagon,* 1953), which in turn are derived from, but upend, such early escapist masterpieces as *42nd Street* (1933) and *Top Hat* (1935). Each phase can be seen as a response to the prevailing political, social, and economic conditions of its time.

The western is the genre most scrutinized for this evolution. Its classical phase (*Stagecoach,* 1939) mutated after World War II into a variant capable of dealing with social problems (*High Noon,* 1952) or with tortured heroes (*Winchester 73,* 1950). In the 1960s the Italian "spaghetti western" announced a decadent phase. *The Good, the Bad, and the Ugly* (1966) inverted character roles and culminated in a three-man gunfight. Audiences applauded



Cyd Charisse and Gene Kelly in a dance sequence from the musical film *Singin' in the Rain* (1952).

Singin' in the Rain: © 1952 Loew's incorporated, renewed 1979, Metro-Goldwyn-Mayer, Inc. photograph from the Museum of Modern Art/Film Stills Archive, New York City

both the attenuated spectacle of these films and their ironic perversion of the codes operating in the standard genre. Some scholars, citing the *Star Wars* trilogy (1977, 1980, 1983) as an example, have argued that in the 1970s the mutation went so far as to leap across the boundary of subject matter toward science fiction. Although some science-fiction films may share fascinating properties with the western, it is unlikely that the production or reception of such films was consciously affected by westerns. Genres with strong, well-defined iconographies rarely consciously influence or combine with one another, even when they are clearly related. When Hollywood remade Kurosawa's *Seven Samurai* (1954) into the western *The Magnificent Seven* (1960), production personnel and audiences were far more conscious of the new film's relationship to previous westerns than of its similarities to Japanese samurai pictures.

The serial. While genres implicitly rely on an audience's interest in and familiarity with earlier movies of a certain kind, the serial is a type of movie that explicitly requires an audience to return episode after episode. Also called the chapter-play or cliff-hanger, the serial flourished in the days of silent films, when cinema going was a weekly habit. Perhaps the most famous were Louis Feuillade's *Fantômas* (1913–14) and *Judex* (1916) in France and the U.S. series of the same period with Pearl White, such as *The Perils of Pauline.* Old serials have been revived since the 1960s as period pieces of popular art, with their improbable plots, exaggerated acting, and old-fashioned decor appealing to modern, sophisticated audiences. The French director Georges Franju made a modern pastiche *Judex* in 1963. Since the late 1970s new serials have appeared in the form of multiepisode sagas shown on television. *Roots* (1977) in the United States had its counterpart in Rainer Werner Fassbinder's 16-hour *Berlin Alexanderplatz* (1980), which aired in installments on German television and then played as a serial in art house theatres around the world. (D.A.)

Interpretations

Films of art and the art cinema. For want of a better term, "interpretation" may be used to describe the type of motion picture in which a play, a ballet, an opera, or some other work of another art form is kept virtually intact and recorded by the camera and microphone. Adaptations of novels or plays re-create the work in motion-picture form, but interpretations merely give the performance a wider audience. The English director Tony Richardson's version of *Hamlet* (1970) is an example of such a filmed record of a theatrical performance. Most motion pictures of operas and ballets may be classed as interpretations. Public and cable television have become obvious sponsors and disseminators of this type of film, although some interpretations, including Joseph Losey's *Don Giovanni* (1979), and numerous films of rock concerts continue to thrive in theatrical distribution.

At one time the recording of an already established work of art was deemed "uncinematic" and thought to be a doubtful use of the medium. Such arguments were made as early as 1911 in response to the French Film d'Art company, which photographed high-class stage plays. Recently, however, imaginative and innovative cinematic techniques have been employed to record operas, ballets, and stage plays. The complexity of the resulting hybrid works, such as Arnold Schoenberg's *Moses and Aaron* as filmed by Jean-Marie Straub and Danièle Huillet (1975), have made the validity of the early generalizations questionable. Important filmmakers, including Robert Altman in the United States, Eric Rohmer in France, and Carlos Saura in Spain, have turned to the filming of works of other art forms as ways to open up the motion picture to new types of experiences.

Art films versus popular films

The motion-picture recording of the acknowledged artistic successes of other media raises the important issue of the artistic stature of the cinema. As early as 1920 an audience of film connoisseurs could be identified in Europe. Ever since that time it has been possible to divide the cinema audience of any nation into a mass audience that seeks entertainment and a smaller group that is consciously concerned with artistic values in the motion picture. The films that appeal to these two groups, however, vary from one nation to another and from one period to another. The Hollywood comedies of the 1920s by Charlie Chaplin, Buster Keaton, and others, for example, were originally popular entertainment, but they were later taken up by the art film audience. The comedies of Jerry Lewis received little serious critical attention in their native United States but a great deal in France. The low-budget thrillers of directors who were adopted by auteur critics met a similar experience. The distinction between popular entertainment and high art seems indisputable in most instances, but confusions of fashion and conflicts in artistic standards resulting from experiment and change make it difficult to generalize about them.

Although there may be disagreements over what constitutes cinematic art, certain institutions have developed that foster the art of film. In the United States after World War II, "art houses" catered to sophisticated audiences in large cities, screening primarily European films, such as those directed by Fellini, Bergman, Buñuel, and Antonioni. The distribution of 16-millimetre films to museums and college campuses sparked interest in avant-garde films as well. In one sense art films represent a genre; the audience that seeks them out has precise expectations which producers have been known to exploit. In 1951 Daiei films of Japan, for example, expressly aimed to conquer the export market by winning awards at international festivals. The company, which generally produced cheap domestic genre motion pictures, reserved a portion of its budget to make lavish historical spectacles, such as Mizoguchi's *Ugetsu* (1953), that would appeal to the art audience outside of Japan. The art film usually cannot be characterized in advance, however; it does not follow prescribed conventions but prides and sells itself on its uniqueness or distinctiveness.

THE STUDY AND APPRECIATION OF MOTION PICTURES

Film criticism

Criticism of motion pictures generally follows the pattern of the other arts, though it has some peculiar features. In the criticism of painting, music, theatre, and literature, some technical knowledge of the medium has generally been required. Motion-picture reviewers, however, rarely have any experience of filmmaking. A lack of experience in filmmaking is not necessarily a handicap. Film is such a complex medium that a technician is unlikely to be expert in every aspect of it and may well be overly conscious of his specialty. In addition, even though the technique is complex, the results are plain to view, and an intelligent critic may well appreciate such technicalities as fine camera-work, tight editing, authentic location shooting, or competent direction without knowing in detail how the result was achieved.

Film periodicals and books

Besides reviews in the daily and weekly press, there are specialized monthlies and quarterlies that engage scholars, students, and enthusiasts of the medium. In the United States *Film Quarterly, Wide Angle, Quarterly Review of Film Studies,* and *Cinema Journal* have great influence, just as *Screen* does in England and *Bianco e nero* in Italy.

As a country France has made cinema a central part of its culture. The French *Cahiers du Cinéma* sustains several times the circulation of the U.S. *Film Quarterly* and is rivaled by several other serious journals and countless magazines. Aiming at a less specialized but still avid film audience, glossy magazines such as *American Film* in the United States and *Sight and Sound* in England mix serious reviews, interviews, and features. There are similar publications in Poland and India. Popular magazines, which lure a large readership with their blend of pictures and gossip, have always been a part of movie culture, as have trade papers such as *Variety*, one of the most reliable and thorough sources of information about the international film business.

Books about the cinema range from serious studies of its economic, sociological, and technical aspects to light memoirs, ephemeral gossip, and innumerable biographies and autobiographies of actresses, actors, producers, and directors. Monumental film histories and theories written by Sergey Eisenstein, Vsevolod Pudovkin, André Bazin, Lewis Jacobs, Georges Sadoul, and others have triggered a remarkable industry of book publishing on these topics in many countries. The U.S.-based Society for Cinema Studies enrolls more than 500 teachers of film, who read these books and recommend titles to students. Most major university libraries now routinely collect film books and periodicals, although certain centres of research house the most complete collections. In the English-speaking world these include the British Film Institute, the special collections libraries at the University of California at Los Angeles and the University of Southern California, the Margaret Herrick Library of the Academy of Motion Picture Arts and Sciences in Beverly Hills, Calif., and the Lincoln Center Library in New York City. Other institutions house important documentation along with archives of films. The International Museum of Photography at George Eastman House in Rochester, N.Y., is particularly rich in material on the early cinema, while the Wisconsin Center for Film and Theater Research in Madison has gathered data pertaining to its collection of films produced by Warner Bros., RKO, and United Artists.

Preservation of film. The permanence of the motion-picture medium—the fact that films can be stored and reproduced indefinitely—not only makes it an enduring theatrical art but also a vivid record of past life. Despite the fact that motion pictures can theoretically last forever, relatively few have been preserved and many of these are in poor condition. One reason is that inflammable nitrate film stock, which was generally used until the 1940s, when it was replaced by acetate, is chemically unstable. Also, as film runs through a projector, it is eventually worn, scratched, or damaged. Still another factor is that commercial conditions of filmmaking discouraged preservation; the stress was on the present and the future, not on preservation of the past. Early motion pictures were best preserved when filmmakers such as Chaplin or Disney had control over their own work and a personal interest in preserving and representing it. During the 1960s and 1970s, however, there developed a tremendous interest in old movies. Revival houses sprang up in most major U.S. cities, and distribution companies were established solely for the reissue of old films.

Film preservation that allows access to old motion pictures is costly, requiring careful scientific control of storage conditions. Few private organizations or governments have been willing to spend the necessary funds. The earliest film archive was the Swedish Film History Collection begun in 1933. Archives in Paris, London, and New York City followed shortly afterward. An international federation (FIAF; Fédération Internationale des Archives du Film) was founded with headquarters in Paris in 1938.

Problems of the archivists

The archivists' problems are many: first, selecting the motion pictures to be preserved; second, acquiring copies (a negative or a fine-grain positive if possible) in good condition; third, storing them under the best possible conditions of temperature and humidity; fourth, cataloguing them and keeping some record of their contents; and fifth, allowing them to be viewed or letting stills or extracts be taken, without damaging the copies. The ideal solution to the problem of choice would be to preserve everything, but the cost would be prohibitive. Even with a limited selection, acquisition and storage are expensive and difficult, and nitrate film requires regular testing to see whether it has deteriorated enough to require copying.

The preservation of colour films has become perhaps the most serious problem. While Technicolor films (mostly made before 1953) can be reproduced faithfully and endlessly, virtually all colour films made since 1953 are subject to fading that can be arrested only by storing prints at very low temperatures. Video technology has been used to help preserve some colour motion pictures; computer-driven viewers are able to read the original tints of films and reproduce them on videotape. Nevertheless, until the development of a suitable and inexpensive base onto which colour films can be transferred, the majority of colour motion pictures made after 1953 will continue to deteriorate.

(R.St./D.A.)

Film societies, film festivals, and awards. Predating and indispensable to the academic study of motion pictures are the linked phenomena of film societies and film festivals. These social institutions provided readership for film journals and serious film books, which eventually led to the acceptance of film study in universities. The first and most lasting function of film societies has been to foster the appreciation of the art of film. The second function has been to emphasize the social dimension of film in culture, sometimes using the film as a prop for the examination and propagation of moral and political ideas.

Functions of film societies

These two directions were evident by the 1920s. Louis Delluc and Ricciotto Canudo are credited with forming the first important *ciné-club* (as such societies are frequently called, especially when devoted to film art). The list of adherents to these clubs contains many luminaries from the film world (Epstein, Gance, L'Herbier, Germaine Dulac) and the other arts (Colette, André Gide). The Film Society of London, for example, was founded in 1925 by H.G. Wells, George Bernard Shaw, Augustus John, John Maynard Keynes, and other dignitaries who wanted to see French, German, and Soviet pictures that commercial exhibitors did not handle. The movement spread rapidly, and cinema was included in several international art forums, beginning with the 1925 Paris Exposition des Arts Décoratifs et Industriels Modernes that launched Art Deco. There, for several months, a history of cinema played in the Grand Palais and was accompanied by lectures on technique and appreciation of motion pictures.

Specialized theatres in major cities began to cater to *ciné-club* audiences. One of Jean Renoir's first films, *La Petite Marchande d'allumettes* (*The Little Match Girl*, 1928) was actually commissioned by a theatre and shot on its premises. *Ciné-clubs*, too, sponsored films made by their own members until the invention of sound made such amateur productions too expensive and technically intricate.

The political power of film societies was first recognized by Léon Moussinac, an official in Delluc's club who traveled to the Soviet Union in the 1920s and recognized immediately the importance of motion pictures in the education of the masses. Through his writing and organization, he was responsible for thousands of "average citizens" joining film clubs that featured controversial and sometimes revolutionary films. In 1928 Les Amis de Spartacus purportedly enrolled more than 75,000 subscribers. The mayor of Paris found it necessary to prohibit some of their meetings, the most important being a scheduled appearance by Sergey Eisenstein, whose *Battleship Potemkin* (1925) was officially banned in some countries.

In the 1930s enthusiasm for film societies waned, perhaps due to the Depression, although it was in this decade that the Roman Catholic Church developed networks of societies for the projection and discussion of exemplary films, particularly in parishes in Italy and France. After World War II, a resurgence of film societies occurred internationally. The French film theorist André Bazin was associated with both an artistic club headed by Jean Cocteau and a trade union club, indicating that the old split between "film art" and "film and social issues" remained. In the United States, clubs were devoted primarily to film art, fostering the American underground film movement. This

postwar flourishing must be credited in part to the marketing of convenient 16-millimetre equipment.

Decline of film societies

The importance of such societies inevitably declined after universities and museums regularly began to include motion pictures as part of their collections, and in most countries film societies eventually attached themselves to universities. In the 1980s the availability of videocassettes further dissolved the strength of the *ciné-club* by allowing would-be members to select their own films for viewing at times convenient to them.

Film festivals provide a forum for promotion and recognition of artistic achievements of national film industries. The first festival was founded at Venice in 1932. It remained unique until after World War II, when the Cannes Festival was founded, and festivals began to assume their modern-day importance. Struggling nations, rebuilding their shattered film industries, saw in festivals a chance for world recognition. The growing interest everywhere in film imports made the festivals an international marketplace for distributors. Festivals were initiated at Berlin; Moscow; Karlovy Vary, Czech.; London; San Francisco; Chicago; and New York City. Through the early 1960s, the U.S. film industry remained wary of festivals; films that won festival awards did not necessarily do well at the box office, though a poor reaction at a festival might reduce the audience for a serious film. After 1965, however, distributor attitudes changed as investments increased in films for specialized audiences, particularly in "foreign" films backed by U.S. companies, and favourable critical acclaim became a vital promotional aid. Interest in the festivals persisted, and they continued to increase in number and in size. By the early 1980s there were more than 100 scheduled annually in some 25 different countries.

Functions of film festivals

Film festivals serve several functions. They provide an international marketplace where producers and distributors can exchange ideas, view films, and sign contracts. For example, the phenomenon of the international coproduction, so important to European cinema, arose at the Cannes festivals of the late 1940s. Festivals also provide an opportunity for fans to see popular stars and other celebrities. A further function of film festivals has been to provide a cultural rendezvous for those interested in the art and influence of the movies. Festivals often showcase new films or movements, as when the Venice festivals of the early 1950s introduced the stunning accomplishments of the Japanese film industry, which had been previously unknown in the West. At other times festivals are sites of artistic and political contention. At the Cannes festivals of 1958 and 1959, for example, advocates and opponents of the French New Wave heatedly exchanged diatribes and manifestos. A decade later several key New Wave directors, most notably François Truffaut and Jean-Luc Godard, helped close the festival to protest government policies during the events of May 1968. The Venice Film Festival, generally deemed more serious and less commercial than Cannes, ceased its juried competition from1969 to 1979 because of political strife.

Festivals are regulated by the Fédération Internationale des Associations de Producteurs de Films (FIAPF), which licenses those who want to award prizes. The competition that is associated with most festivals is in many instances, however, only a publicity device. Film screenings are often not even announced. The real purpose of the festival is to allow distributors to view and bid on the latest movies.

Academy Awards

The best known of all competitions, the Academy Awards, does not take place at a festival at all. The U.S. industry, with its overwhelming control of the world's screens, long had virtually no interest in film awards except for the awards voted each year since 1929 by the Academy of Motion Picture Arts and Sciences. The academy, which represents various artistic and technical disciplines, originally intended its annual awards as modest, peer-group citations within the tightly knit Hollywood industry. After media coverage created widespread interest, however, there was an increase in box-office revenues for winning films, and the Academy Awards, or "Oscars," became valuable in merchandising. The prestige of the academy's artistic judgments, however, has failed to keep pace with its economic power. Serious students of the film tend to place more credence in the awards of the New York Film Critics (founded in 1935), and the National Society of Film Critics (1966), as well as in the oldest U.S. reviewing organization, the National Board of Review of Motion Pictures (1909). (R.St./A.D.M./D.A.)

Technology

Motion-picture technology is a curious blend of the old and the new. In one piece of equipment state-of-the-art digital electronics may be working in tandem with a mechanical system invented in 1895. Furthermore, the technology of motion pictures is based not only on the prior invention of still photography but also on a combination of several more or less independent technologies; that is, camera and projector design, film manufacture and processing, sound recording and reproduction, and lighting and light measurement.

HISTORY

Motion-picture photography is based on the phenomenon that the human brain will perceive an illusion of continuous movement from a succession of still images exposed at a rate above 15 frames per second. Although posed sequential pictures had been taken as early as 1860, successive photography of actual movement was not achieved until 1877, when Eadweard Muybridge used 12 equally spaced cameras to demonstrate that at some time all four hooves of a galloping horse left the ground at once. In 1877–78 an associate of Muybridge devised a system of magnetic releases to trigger an expanded battery of 24 cameras.

Eadweard Muybridge

The Muybridge pictures were widely published in still form. They were also made up as strips for the popular parlour toy the zoetrope "wheel of life," a rotating drum that induced an illusion of movement from drawn or painted pictures (see Figure 1). Meanwhile, Émile Reynaud in France was projecting sequences of drawn pictures onto a screen using his Praxinoscope, in which revolving mirrors and an oil-lamp "magic lantern" were applied to a zoetrope-like drum, and by 1880 Muybridge was similarly projecting enlarged, illuminated views of his motion photographs using the Zoöpraxiscope, an adaptation of the zoetrope.

Although a contemporary observer of Muybridge's demonstration claimed to have seen "living, moving animals," such devices lacked several essentials of true motion pictures. The first was a mechanism to enable sequence photographs to be taken within a single camera at regular, rapid intervals, and the second was a medium capable of storing images for more than the second or so of movement possible from drums, wheels, or disks.

A motion-picture camera must be able to advance the medium rapidly enough to permit at least 16 separate exposures per second as well as bring each frame to a full stop to record a sharp image. The principal technology

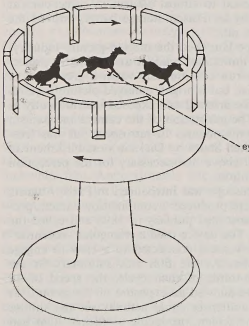


Figure 1: Zoetrope.

that creates this intermittent movement is the Geneva watch movement, in which a four-slotted star wheel, or "Maltese cross," converts the tension of the mainspring to the ticking of toothed gears. In 1882 Étienne-Jules Marey employed a similar "clockwork train" intermittent movement in a photographic "gun" used to "shoot" birds in flight. Twelve shots per second could be recorded onto a circular glass plate. Marey subsequently increased the frame rate, although for no more than about 30 images, and employed strips of sensitized paper (1887) and paper-backed celluloid (1889) instead of the fragile, bulky glass. The transparent material trade-named celluloid was first manufactured commercially in 1872. It was derived from collodion, that is, nitrocellulose (gun cotton) dissolved in alcohol and dried. John Carbutt manufactured the first commercially successful celluloid photographic film in 1888, but it was too stiff for convenient use. By 1889 the George Eastman company had developed a roll film of celluloid coated with photographic emulsion for use in its Kodak still camera. This sturdy, flexible medium could transport a rapid succession of numerous images and was eventually adapted for motion pictures.

Étienne-Jules Marey

Thomas Edison is often credited with the invention of the motion picture in 1889. The claim is disputable, however, specifically because Edison's motion-picture operations were entrusted to an assistant, W.K.L. Dickson, and generally because there are several plausible pre-Edison claimants in England and France. Indeed, a U.S. Supreme Court decision of 1902 concluded that Edison had not invented the motion picture but had only combined the discoveries of others. His systems are important, nevertheless, because they prevailed commercially. The heart of Edison's patent claim was the intermittent movement provided by a Maltese cross synchronized with a shutter. The October 1892 version of Edison's Kinetograph camera employed the format essentially still in use today. The film, made by Eastman according to Edison's specifications, was 35 millimetres (mm) in width. Two rows of sprocket holes, each with four holes per frame, ran the length of the film and were used to advance it. The image was 1 inch wide by ¾ inch high.

At first Edison's motion pictures were not projected. One viewer at a time could watch a film by looking through the eyepiece of a peep-show cabinet known as the Kinetoscope. This device was mechanically derived from the zoetrope in that the film was advanced by continuous movement, and action was "stopped" by a very brief exposure. In the zoetrope, a slit opposite the picture produced a stroboscopic effect; in the Kinetoscope the film traveled at the rate of 40 frames per second, and a slit in a 10-inch-diameter rotating shutter wheel afforded an exposure of $^1/_{6,000}$ second. Illumination was provided by an electric bulb positioned directly beneath the film. The film ran over spools. Its ends were spliced together to form a continuous loop, which was initially 25 to 30 feet long but later was lengthened to almost 50 feet. A direct-current motor powered by an Edison storage battery moved the film at a uniform rate.

The Kinetoscope

The Kinetoscope launched the motion-picture industry, but its technical limitations made it unsuitable for projection. Films may run continuously when a great deal of light is not crucial, but a bright, enlarged picture requires that each frame be arrested and exposed intermittently as in the camera. The adaptation of the camera mechanism to projection seems obvious in retrospect but was frustrated in the United States by Dickson's establishment of a frame rate well above that necessary for the perception of continuous motion.

After the Kinetoscope was introduced in Paris, Auguste and Louis Lumière produced a combination camera/projector, first demonstrated publicly in 1895 and called the *cinématographe.* The device used a triangular "eccentric" (intermittent) movement connected to a claw to engage the sprocket holes. As the film was stationary in the aperture for two-thirds of each cycle, the speed of 16 frames per second allowed an exposure of $^1/_{25}$ second. At this slower rate audiences could actually see the shutter blade crossing the screen, producing a "flicker" that had been absent from Edison's pictures. On the other hand, the hand-cranked *cinématographe* weighed less than 20 pounds (Edison's camera weighed 100 times as much). The Lumière units could therefore travel the world to shoot and screen their footage. The first American projectors employing intermittent movement were devised by Thomas Armat in 1895 with a Pitman arm or "beater" movement taken from a French camera of 1893. The following year Armat agreed to allow Edison to produce the projectors in quantity and to market them as Edison Vitascopes. In 1897 Armat patented the first projector with four-slot star and cam (as in the Edison camera).

The *cinématographe*

One limitation of early motion-picture filming was the tearing of sprocket holes. The eventual solution to this problem was the addition to the film path of a slack-forming loop that restrained the inertia of the take-up reel. When this so-called Latham loop was applied to cameras and projectors with intermittent movement, the growth and shrinkage of the loops on either side of the shutter adjusted for the disparity between the stop-and-go motion at the aperture and the continuous movement of the reels (see Figure 6).

The Latham loop

When the art of projection was established, the importance of a bright screen picture was appreciated. Illumination was provided by carbon arc lamps, although flasks of ether and sticks of unslaked calcium ("limelight") were used for brief runs.

Introduction of sound. The popularity of the motion picture inspired many inventors to seek a method of reproducing accompanying sound. Two processes were involved: recording and reproducing. Further, the sound reproduction had to be presented in an auditorium and had to be quite good. This could not be achieved without a good amplifier of electrical signals. In 1907 Lee De Forest invented the Audion, a three-element vacuum tube, which provided the basis in the early 1920s for a feasible amplifier that produced an undistorted sound of sufficient loudness.

Next came the problem of synchronization of the sound with the picture. A major difficulty turned out to be the securing of constant speed in both the recorder and reproducer. Many ingenious ideas were tried. In 1918 in Germany, the use of a modulated glow lamp in photographically recording sound and a photocell for reproduction were studied. In Denmark in 1923, an oscillograph light modulator and selenium-cell reproducer were developed. De Forest tried a gas-filled glow discharge operated by a telephone transmitter to record a synchronized sound track on the film. For loudspeakers he experimented with a variety of devices but finally chose the speaker with horn. The operating signal was obtained from a light shining through the film sound track and detected by a light-sensitive device (photocell). These were used in a system called Phonofilm, which was tried experimentally in a number of theatres. In 1927 the Fox Film Corporation utilized some of these principles in the showing of Fox Movietone News.

Meanwhile, the Western Electric Company laboratories in the United States had been making extensive studies on the nature of speech and other sounds and on techniques for recording and reproducing such sounds. They experimented with recording on a phonograph disc and developed a 16-inch (40.6-centimetre) disc rotated at 33⅓ revolutions per minute; they improved loudspeakers, introduced the moving-coil type of speaker, and generally improved the entire electronic amplification system. The Warner Bros. movie studio became interested in all these developments and formed the Vitaphone Corporation to market the complete system.

Vitaphone sound-on-disc recording

Warner Bros. premiered Vitaphone in 1926 with a program featuring short musical performances and a full-length picture, *Don Juan,* which had synchronized music and effects but no speech. In 1927 it brought out *The Jazz Singer,* which was essentially a silent picture with Vitaphone score and sporadic episodes of synchronized singing and speech. Warners presented the first "100-percent talkie," *The Lights of New York,* in 1928.

Although the Vitaphone system offered fidelity superior to sound-on-film systems at this stage, it became clear that recording on film would be much more convenient.

Among other disadvantages, it was extremely difficult with the wax discs to shoot outdoors or to edit sound. By 1931 Warner Bros. ceased production of sound-on-disc and adopted the sound-on-film option preferred by the other studios.

Sound-on-film, a system that in various guises had enjoyed several periods of popularity, underwent constant improvements in the 1910s and 1920s. Although a sound track on the picture negative was used for Movietone News, Fox's dramatic productions used a separate sound film on fine-grain print stock that could be edited apart from the picture yet in synchronism with it. One serious problem of sound-on-film systems had been the distortion of the signal introduced by the glow lamp when recording the sound track on film. The Western Electric Company devised a "double-string" light valve. A wire was looped around a post and parallel to itself. When speech current was applied to the wire in a magnetic field, the wire vibrated toward and away from itself according to the applied electrical waveform. A steady beam of white light shining through the loop was modulated in intensity by the varying gap between the wires; the modulated beam was photographed while masked by a slit perpendicular to the edge of the film. The resulting sound track appeared as darker or fainter parallel lines on the edge of the film. Known as the variable density system, this method of optically recording sound was originally used by all but one of the major Hollywood studios.

Variable area sound-on-film recording

The Radio-Keith-Orpheum Corporation (RKO) was created in 1928 to showcase the Radio Corporation of America (RCA) Photophone system of variable area recording. With this system, the sound recording was modulated by a rotating mirror and the slit was parallel to the edge of the film; reproduction employed the perpendicular slit of the variable density sound track. Minor problems of incompatibility between recording and reproduction were solved in late 1928 when the track was narrowed down to stay safely within the area scanned by the beam. Identical side-by-side tracks were employed to compensate for lateral misalignment. Initially inferior in quality, the variable area system gradually drew even with the quality of the density system and supplanted it altogether in the 1950s.

Whereas there was wide variation in the speed at which silent films were photographed and projected, sound necessitated standardization of the frame rate. In 1927 the speed was standardized at 24 frames per second, or 90 feet per minute for 35-mm film.

The development of sound technology in the first years of talking pictures focused on two areas. One involved the development of blimped cameras, directional microphones, microphone booms, and quieter lights, so that sound could be recorded more cleanly at the time of shooting. The other technologies involved the ability to add, edit, and mix sound separately from the time the picture was recorded. (P.Me./E.We./S.G.H.)

Introduction of colour. From their earliest days, silent films could be coloured using nonphotographic methods. One means was to hand-colour frames individually. Another method made it possible to use monochrome sections for mood (*e.g.*, blue for night scenes or red for passionate sequences). Monochrome stock was created by "tinting" the film base or "toning" the emulsion (by bathing the film in chemical salts).

The photography of colour was theorized decades before it was developed for motion pictures. In 1855 the British physicist James Clerk Maxwell argued that a full-colour photographic record of a scene could be made by filming three separate black-and-white negatives through filters coloured, respectively, red, green, and blue, the three primary colours. When converted to positives, the transparent exposed areas of the three films could pass light through the appropriate filter to produce three images, one red, one green, and one blue. Superimposing the three images would "rebuild" the image in its original colours.

Additive and subtractive systems of colour

In 1868 Louis Ducos du Hauron identified the additive and subtractive systems of colour. Both systems originate as red, green, and blue negative records. The difference occurs in the positive image, which may be composited from either the additive or subtractive primaries. The subtractive primaries—cyan, magenta, and yellow—are the complements of the additive primaries and can be obtained by subtracting, respectively, red, green, and blue from white. (Subtracting all three additive primaries yields black; adding all three yields white.)

In motion-picture prints, overlapping dye layers in the three subtractive primaries are simultaneously present on a clear, transparent base, and the image is projected with an exposure of white light. The dark areas of the cyan layer subtract all red colour, permitting only cyan (the mixture of blue and green) to pass through; the transparent areas pass all the white light. The magenta and yellow layers act similarly, and the original colour image is reproduced. The fineness of resolution is limited only by the structure of photographic grain or dye globules.

The first film colour systems were additive, but they were confronted by insurmountable limitations. In an additive system, the three colour records remain discrete and meet only as light rays on the screen. The best picture results when a separate film is made for each colour; however, each colour can occupy alternating frames or small, alternating portions of each frame of a single film. (A contemporary example of additive colour can be seen in projection television, in which red, green, and blue lenses converge to produce an image so enlarged that the separate colour areas, or dots, become discernible.)

The best known of the early additive processes was Kinemacolor (1906), which, for manageability, reduced the three colour records to two: red-orange and blue-green. A single black-and-white film was photographed and projected at 32 frames per second (twice the normal silent speed) through a rotating colour filter. The two colour records occupied alternate frames and were integrated by the retention characteristic of the human eye. As there were no separate red-orange and blue-green records for each image, displacement from frame to frame was visible during rapid movement, so that a horse might appear to have two tails. Inventors tried to increase the film speed, reduce the frame size, or combine two films with mirrored prisms, but additive systems continued to be plagued by excessive film consumption, poor resolution, loss of light, and registration problems.

The first subtractive process employing a single film strip in an ordinary projector without filters was Prizma Color in 1919. (Prizma Color had been introduced as an additive process but was soon revised.) The basis was an ingenious "duplitized" film with emulsion on both sides. One side was toned red-orange and the other blue-green. The stock long outlasted the Prizma company and was in use as late as the early 1950s in such low-cost systems as Cinecolor.

Similar enough to provoke litigation was an early (1922) process by Technicolor in which separate red and green films were cemented back-to-back, resulting in a thick and stiff print that scratched easily. Although only four two-colour Technicolor features were produced by the end of the silent era, Technicolor sequences were a highlight of several big-budget pictures in the mid-to-late 1920s, including *The Phantom of the Opera* (1923–25) and *Ben Hur* (1925). Technicolor devised the first of its dye-transfer, or imbibition, processes in 1928. Red and green dye images were printed onto the same side of clear film containing a black silver sound track.

Three-strip Technicolor

When Technicolor's appeal seemed on the wane, it devised a greatly improved three-register process (1932). The perfected Technicolor system used a prism/mirror beam-splitter behind a single lens to record the red, green, and blue components of each image on three strips of black-and-white film. Approximately one-third of the light was transmitted to the film behind a green filter in direct path of the lens; the film was sensitized to green light by special dyes. A partially silvered mirror (initially flecked with gold) directed the remainder of the light through a magenta (red plus blue) filter to a bi-pack of orthochromatic and panchromatic films with their emulsion surfaces in contact. The orthochromatic film became the blue record. As it was insensitive to red light, the orthochromatic film passed the red rays to the panchromatic film. A 1938 improvement added red-orange dye to the orthochromatic film so that only red light reached the panchromatic layer.

In 1941 Monopack Technicolor was introduced. This was a three-layer film from which separation negatives were made for the Technicolor dye-transfer printing process.

Using the dye-transfer method, it was necessary to make gelatin positives that contained the image in relief. Dye filled the recesses while the higher areas remained dry. Each gelatin matrix thus imprinted its complement onto the film base. As in the two-colour process, a black silver sound track was printed first on clear film. When magnetic sound became popular, the oxide strips were embossed after printing. Technicolor gave excellent results but was very expensive.

In 1936 Germany produced Agfacolor, a single-strip, three-layer negative film and accompanying print stock. After World War II Agfacolor appeared as Sovcolor in the Eastern bloc and as Anscocolor in the United States, where it was initially used for amateur filmmaking. The first serious rival to Technicolor was the single-strip Eastmancolor negative, which was introduced in 1952 by the Eastman Kodak Company but was often credited under a studio trademark (*e.g.,* Warnercolor). Eastmancolor did not require special camera or processing equipment and was cheaper than Technicolor. Producers naturally preferred the less expensive Eastmancolor, especially since they had, in response to the perceived threat of television, increased production of colour films. (After the 1960s black-and-white films were so rare that they cost more to print than colour films.) The 1950s vogue for CinemaScope and three-dimensional productions, both incompatible with the Technicolor camera, also hastened the demise of Technicolor photography.

Eastmancolor

Dye-transfer printing remained cost-effective somewhat longer, but Technicolor was forced to abandon the process in the 1970s. This has created a significant problem for film preservationists because only Technicolor film permanently retains its original colours. Other colour prints fade to magenta within seven years, yet the hard gelatin dyes of a Technicolor print remain undimmed even after the film's nitrate base has begun to decompose.

In the 1980s computerized versions of the hand-stenciled colour films of the silent era were developed to rejuvenate old black-and-white films for video. (E.We./S.G.H.)

Wide-screen and stereoscopic pictures. Until the early 1950s, the screen shape, or aspect ratio (expressed as the ratio of frame width to frame height), was generally 1.33 to 1, or 4 to 3. In the mid-1950s the ratio became standardized at 1.85 to 1 in the United States and 1.66 or 1.75 to 1 in Europe. These slightly wider images were accomplished by using the same film but smaller aperture plates in the projector and by using shorter-focal-length lenses.

Many people have felt that, while vision at the extreme sides of the vision field does not usually contribute much information to the eyes, it does add substantially to the illusion of reality when it is present. Hence, there have been periods when film producers have attempted to introduce extremely wide formats. As early as 1929, Grandeur films were presented using 70-mm instead of the standard 35-mm film to give a wider field of view.

In 1952 a radical attack was made on wide-screen projection in the form of the Cinerama, which used three projectors and a curved screen. The expanded field of view gave a remarkable increase in the illusion of reality, especially with such exciting and spectacular subjects as a ride down a toboggan slide. There were technical problems, including the necessity of carrying three cameras bolted together at the correct angles on the toboggan or other carrier, synchronization of the three separate films, and matching of the image structure and brightness at the joining edges on the screen. After 1963 Cinerama replaced its three-film process with a 70-mm anamorphic system with an aspect ratio of 2.75 to 1.

Heightening the illusion of reality

The use of anamorphic lenses for wide-screen projection was introduced by CinemaScope in 1953. An anamorphic optical system photographs with a different magnification horizontally than it does vertically. The lens seems to squeeze the image so that on the film itself figures appear tall and thin. A lens on the projector reverses the effect, so that the images on the screen reacquire normal proportions.

In 1955 Todd-AO introduced a wider film (photographed on a 65-mm negative and printed on a 70-mm positive for projection), with several sound tracks added. Like anamorphic systems, the wider format could be achieved with a single projector. The first two Todd-AO productions, *Oklahoma!* (1955) and *Around the World in 80 Days* (1956), were made at 30 frames per second for a nearly flicker-free image; 70-mm films are now photographed and projected at 24 frames per second.

Amusement parks and world's fairs have often featured 360-degree projection. The first system was presented at the Disneyland amusement park in 1955. At first, the projection involved 11 16-mm projectors and screens and, later, nine 35-mm projectors. The audience stood on a low platform in the middle. The result was extremely realistic. In one scene, showing the view from a cable car in San Francisco, the viewers were seen involuntarily to lean over on the curves, as if they were actually on the cable car. The format, however, has limited uses for general storytelling.

In the 1980s, efforts to improve picture quality took two routes: increase in frame rate (Showscan operates at 60 frames per second) or increase in overall picture size—height as well as width (IMAX and Futurevision). In these formats the sound tracks are usually printed on a separate, magnetic strip of film.

Another project intended to improve the illusion of reality in motion pictures has been stereoscopic, or three-dimensional, cinematography. "3-D" films use two cameras or one camera with two lenses. The centres of the lenses are spaced 2½ to 2¾ inches apart to replicate the displacement between a viewer's left and right eyes. Each lens records a slightly different view corresponding to the different view each eye sees in normal vision.

Stereoscopic cinematography

Despite many efforts to create "3-D without glasses" (notably in the U.S.S.R., where a screen of vertical slats was used for many years), audience members have had to wear one of two types of special glasses to watch 3-D films. In the early anaglyph system, one lens of the glasses was red and the other green (later blue). The picture on the screen viewed without glasses appeared as two slightly displaced images, one with red lines, the other with green. Each lens of the glasses darkened its opposite colour so that each eye would see only the image intended for it.

The Polaroid system, used for commercial 3-D movies since the early 1950s, is based on a light-polarizing material developed by the American inventor Edwin H. Land in 1932. In this method, known as Natural Vision, two films are recorded with lenses that polarize light at different angles. The lenses on the glasses worn by spectators are similarly polarized so that each admits its corresponding view and blocks the other. Early versions of Polaroid 3-D used two interlocked projectors to synchronize the two pictures. A later system, revived in the 1970s and 1980s, stacked the left and right components vertically on half-frames two sprocket holes high. The images were converged by means of a mirror and/or prism.

PROFESSIONAL MOTION-PICTURE PRODUCTION

Cameras. The principles of operation of modern professional motion-picture cameras are much the same as those of earlier times, although the mechanisms have been refined. A film is exposed behind a lens and is moved intermittently, with a shutter to stop the light while the film is moving. In the process, the film is unrolled from a supply reel, through the intermittent to the gate where the exposure takes place, and then on to the take-up reel.

Principal parts. Lenses have gone through a continuous evolution in the last half century, for both still and motion-picture photography. The two major objectives have been to focus properly all the colours of the image at the film plane (*i.e.,* to make the lens achromatic) and to focus portions of a beam coming from different portions of the lens, the centre or the edges, at the same point on the film (*i.e.,* anastigmatic). Both objectives require solution for as large a lens opening as possible, in order to capture maximum light for the exposure, and for as wide a field of view as will be needed in the use of the lens. In order to solve these problems, lenses have been

Achromatic and anastigmatic lenses

made with more and more components. Also, more types of glass have been discovered and developed, to give better achromatic performance. It was found, about 1939, that a special coating of the glass-to-air surface of a lens component could greatly diminish reflections from this surface without affecting other properties of the lens. The use of such coatings improved image contrast by reducing the stray rays that were produced by reflections in a multiple-component lens. Coatings also reduce loss of light by reflection in the desired rays. Coating developments have permitted the manufacture of lenses with many more components than had previously been possible.

Long experience with both motion-picture and still cameras has shown the need for a variety of focal lengths (ranging from ultrawide angle to telephoto) to photograph scenes under the best conditions. To make changing focal lengths more convenient, the lenses have sometimes been mounted on a turret, so that one out of a set of three lenses may be quickly selected. For motion pictures this would mean an interruption in the action depicted. A continuous change would be more desirable.

When two lenses are used in a tandem combination, the focal length of the combination varies according to the separation between the two components. For example, when two thin converging lenses are mounted close together, the combined focal length is shorter than when they are separated a certain distance. Thus, the focal length of the combination can be continuously varied over a range merely by changing the separation.

This observation led to the conception of camera lenses of variable focal length in which the variation is obtained by moving one or more elements. One simple design consists of two fixed convex (converging) lenses of unequal power with a movable concave (diverging) lens between them. When the central concave lens is located close to the front convex element, the combination focal length can be shorter (and the image therefore smaller) than when it is located close to the rear convex element. The design can be made such that, with the two convex elements remaining fixed, a distant view can remain almost in focus on the film as the middle element is moved. Exact focus for this arrangement, however, could not be attained. Thus, for lenses of this design, a cam device has in the past been provided to move the front convex element a short distance as the middle element is moved over its range, to keep the focus exact. This kind of lens has come to be called a zoom lens.

The zoom lens

By increasing the number of elements, the focus can be kept exact without the need of a correcting cam. Other improvements include increasing the range of focal lengths covered, increasing the effective lens aperture, increasing the angular field of view seen by the film, and improving the colour correction with radically new glass materials.

For a long time the change in focal lengths was carried out manually. More recently, the use of an electric motor drive has allowed a smoother change, with less distraction to the cameraman.

The general principles utilized in the film transport system have remained much the same over recent years, at least for the 35-mm film. The films are usually preloaded in lighttight reel cases (called magazines), with an exposed loop between the supply and take-up reels. This loop is quickly fitted into the camera mechanism when loading.

The intermittent is usually a claw-type mechanism, sometimes a "dual-fork" claw that pulls down four sprocket holes at a time. The fork protrudes and recedes to engage the sprocket holes. Some cameras are equipped with pin-registering mechanisms, which hold the film firmly in place in the exposure gate, with the pins engaging sprocket holes.

In the early days of sound films, the noise made by the intermittent and other moving parts in the camera was loud enough to interfere with the sound picked up by the microphone. Cameras were sheathed ("blimped") with outer, separate sound-absorbing materials. The sound insulation is now usually self-contained in the camera.

The film drive

Before the introduction of sound, the film and intermittent were driven by a crank operated by the cameraman. With sound, considerably more uniformity in the speed of the film drive became necessary. For this and other reasons, the film drive in modern cameras is provided by an accurately controlled electric motor, which maintains the standardized sound speed of 24 frames per second.

The shutter keeps light from striking the film while it is moving from one frame to the next. A variable shutter opening can also be used to reduce exposure when it is necessary or desirable to do this without reducing the lens aperture. The shutter is in most cases rotary and is synchronized with the intermittent.

Viewfinding for motion pictures is especially critical: whereas still photographs can be cropped during enlargement or printing, the film image must be framed as it will appear on the screen. Older cameras employed a mechanical "rack-over" that enabled the camera operator to sight directly through the aperture with the film transport out of the way. When an external viewfinder is used, the image seen through it is not exactly the same as that photographed. The viewfinder must be angled so that it and the taking lens both point at the centre of the subject. A system of cams in the focus mechanism of the camera keeps the viewfinder image free of parallax (viewpoint difference) by adjustment from infinity to the near-point of the lens with a separate cam for each focal length.

Most cameras used today are of the reflex type. A partially reflecting mirror (beam splitter) is positioned in the door of the camera body or built into the lens itself with a parallel viewing tube. The mirror diverts to the viewfinder some of the light rays coming through the lens. This method's major drawback is that it takes away part of the light that would otherwise be used for the exposure. A much-admired viewing system that allows the full amount of light to reach the film is the rotating mirror shutter employed in the Arriflex camera. Light is reflected into the viewfinder only when the shutter blade covers the film as it advances to the next frame. This arrangement, however, is not wholly free from objections. Chief among these is that the arrangement opens a return path for light from the viewer's eyepiece to reach the film. The eyepiece must fit snugly around the eye while the viewfinder is in use, and the finder must be closed completely while it is not in use. In addition, since the camera shutter is closed only once per frame, the image will be subject to a distinct flicker, to which the cameraman must adjust himself. Some cameras incorporate a "video assist" or "video tap" wherein the viewfinder image is electronically fed to a video monitor or video recorder, thus allowing evaluation of the take by videotape replay.

Focusing has also been a perennial problem for the motion-picture camera. On the camera the position of the lens is precisely indicated on a calibrated scale. The actor's location on the set was formerly marked on the floor and the exact distance to the camera measured with a tape. The actor moved to previously marked places, and an assistant to the cameraman, called a focus puller, or follow-focus assistant, kept the lens in adjustment. Various electrical devices have now been introduced for remote adjustment by the assistant. Where a through-the-lens finder is used, focusing can be done directly, using the viewfinder image. Also, experienced cameramen can estimate distances quite closely.

It is usual to generate some kind of signal in synchronism with the intermittent when an auxiliary, magnetic-tape sound recorder is used, so that the sound record can later be synchronized exactly with the picture. The sync-generator provides a record of the speed of the camera motor; each frame of picture causes 2.5 cycles of a 60-hertz pulse to be recorded on the sync-track of the sound tape. A newer system is based on the "time code" originally developed for videotape. A separate generator uses a digital audio signal to provide each frame of film with its own number. For each take the time code generator is set to zero; when the camera and film are running, the generator starts to emit numbers that represent "real-time" in hours, minutes, seconds, and frames. In one system, a light-emitting diode next to the camera aperture records the information as ordinary numbers that can be read by the eye; in others, the binary numbers are contained in a control surface of magnetic particles on the base side of the

Time-code numbers

film. One hundred feet of 35-mm film would be rendered in time code as 00:01:07:08, or one minute, seven seconds, eight frames. Corresponding information is recorded on the "address" track of the audio tape. The time code's last two digits, which represent frames, go up to either 24 or 30. Material intended for theatres is photographed at the international sound projection speed of 24 frames per second. Material filmed for American television is often shot at 30 frames per second (in countries with 50 hertz AC power, the rate is 25 frames per second).

The camera is often supplied with electric motors to perform miscellaneous functions, such as to provide smooth rotation (panning) of the camera or to change the magnification in a zoom lens (or change lenses in a turret). The camera is normally provided with footage indicators to indicate the amount of film left unexposed and with frame counters used when it is desired to superimpose a second exposure. There can also be an "inching knob" to reposition the film to a given frame for multiple exposures. When the camera is used at a speed different from standard, a tachometer may be provided to indicate the actual speed.

The cameras that have so far been described are for the standard 35-mm film. Cameras for 65-mm film are generally quite similar, though heavier. The 16-mm professional camera may differ from the 35-mm in the form of its case, in its use of a spring-operated film drive, and in its method of film loading, as a result of its development from a former amateur camera. On the other hand it may be a smaller version and have the same features as the 35-mm model by the same manufacturer.

Camera supports. The camera must be mounted on a substantial support to avoid extraneous movements while film is being exposed. In its simplest form this is a heavy tripod structure, with sturdy but smooth-moving adjustments and casters, so that the exact desired position can be quickly reached. Often a heavy dolly, holding both the camera and a seated cameraman, is used. This can be pushed or driven around the set. When shots from elevated positions are to be used, both camera and cameraman are carried on the end of a crane, also on a dolly. In some cases the assemblage is smoothly driven to follow the action being pictured, such as movement along a street. If the surface being traversed is not smooth, rails, resembling train tracks, must be laid on the floor or ground for the dolly. The camera may be freed from the tripod or dolly and carried by the operator by means of a body brace and gyroscope stabilizer. One such support is the Steadicam, which eliminates the tell-tale motions of the hand-held camera.

Film formats

Film. Film types are usually described by their gauge, or approximate width. The 65-mm format is used chiefly for special effects and for special systems such as IMAX and Showscan. It was formerly used for original photography in conjunction with 70-mm release prints; now 70-mm theatrical films are generally shot in 35-mm and blown up in printing. With some exceptions the 35-mm format is for theatrical use, 16-mm for institutional applications, and 8-mm for home movies. The more frequently encountered film formats are illustrated in Figure 2. There are some minor differences in the shape of the sprocket holes in 35-mm film between negative and positive film. The first 8-mm film was made by using 16-mm film, punched with twice as many sprocket holes of the same size and shape. One side, to the middle line, was exposed in one direction. The supply and take-up reels were then interchanged in the camera, and the other side was exposed in the other direction. After processing, the film was split into two strips, which were spliced into one. An improved version of 8-mm stock, called Super-8 film, was designed with the idea of reducing the sprocket-hole size and employing the space thus made available for a larger picture area.

Originally, the film base was some form of celluloid or cellulose nitrate. This material is highly flammable, and extensive precautions were required in projection rooms to avoid film ignition because of the proximity of the projector arc lamp to the film. In 1923, when 16-mm amateur film was introduced, cellulose acetate (or safety film), much less flammable than the nitrate, was used. It

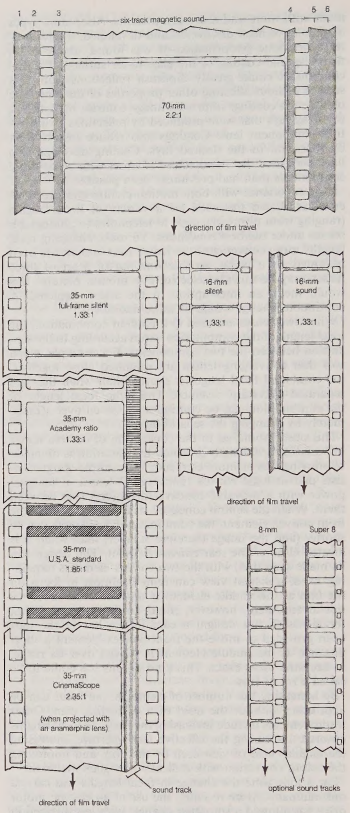


Figure 2: Film formats and usages (actual size).

was not considered desirable to adopt it for professional 35-mm film, largely because it was inferior in strength and dimensional stability. By the late 1930s an improved cellulose acetate safety film was introduced, and by the early 1950s it had generally replaced the nitrate film. Since 1956 acetate has lost ground to polyester- or mylar-based film, which is thinner, less brittle, and more resistant to tearing.

Emulsions. The film base is coated with a light-sensitive layer of silver halide emulsion; multiple layers are used for colour film. Emulsion manufacture is quite complicated and delicate. The earlier emulsions were most sensitive to violet and blue light, as shown schematically in Figure 3, curve *a*. Toward the cyan and green, sensitivity drops rapidly. Such an emulsion is called natural, or ordinary. The result of such a characteristic is that in a natural scene reds and yellows appear black in the positive, and green appears too dark. As early as 1873 it was found that dyes introduced into the emulsion could increase the sensitivity in the yellow and green (Figure 3, curve *b*). The change increased the natural appearance of the reproduced picture, and the emulsion was called orthochromatic. Later (1904) dyes were found to prolong the sensitivity into

Orthochromatic and panchromatic film

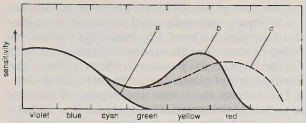


Figure 3: Sensitization of photographic emulsions (see text).

the red, and this emulsion is called panchromatic (Figure 3, curve *c*). The dates are fairly early for motion-picture application, but the development had importance in the general technology.

The overall sensitivity for picture taking has been increased greatly, from below about 10 ASA before 1930 to several hundred and even several thousand. The ASA (American Standards Association) scale is an arbitrary rating of film speed; that is, the sensitivity of the film to light. If everything else is kept constant, the required exposure time is inversely proportional to the ASA rating. Negative films designed for original picture exposure are usually faster (*i.e.,* have higher ASA ratings) than those for prints and are apt to be somewhat coarser grained.

Current technology has made use of a flatter crystal or "T-grain" that exposes more readily to light without an increase in the visible dimension of the grain. This enables use of very low light levels, especially when the film is "pushed" (given extended development) or "flashed" (prestruck with white light to accelerate exposure). When extreme sensitivity to light is not required, finer grain film may be used, particularly when it is intended to enlarge a 16-mm negative for 35-mm release or a 35-mm negative for 70-mm release.

The development of modern colour film

There are two major steps involved in making a dye image on motion-picture film. The first is to convert the negative silver image that is obtained from a normally exposed film into a positive dye image. The clue to how this can be done came from experience with a developer known as pyro (pyrogallol), once very popular with still photographers. A negative developed with pyro developer has not only a silver image but also a brown stain. Study of the process showed that the stain was caused by oxidation products given off locally by the developer in the development process. A substance in the developer reacts with these oxidation products to give an insoluble brown dye. The substance is called a dye coupler. Since the dye is not soluble, it does not wash off in the subsequent film treatment.

This suggested the possibility of bleaching to take away the silver image, leaving the dye image on the film. The first step was to find a developer and dye couplers that would produce the three dye colours that give a faithful three-colour picture rendering. The second step was to carry out the process in the film coating with three separate colours and keep them separate, all the way from exposure to the final three-colour image on the completed film.

The first portion of this second step is carried out by obtaining three emulsions that can be laid on top of one another and are sensitive, respectively, to the red, green, and blue of the exposing image without interfering with each other and that give corresponding silver layers that similarly do not interfere with each other.

It has been observed above that normal silver halide photographic emulsion is particularly sensitive to blue light and that one of the early problems was to obtain a more natural pictorial rendering by extending the sensitivity of the emulsion to green and finally to red light. The problem was solved by inserting appropriate dyes in the emulsion. The dye adds a peak of increased sensitivity, respectively, to green and red light, as in Figure 3. The triple-layer film then consists of, on the top, an ordinary blue-sensitive emulsion; below this, a yellow filter to cut off blue light; next below this, an emulsion with a sensitivity peak in the green, with the yellow filter cutting off blue sensitivity; and, finally, an emulsion with a peak sensitivity in the red, a valley in the green, and blue sensitivity cut off by the yellow filter. The sensitization can be chosen to locate and enhance the sensitivity peaks.

Thus, the blue layer responds to the blue light in the original, the green layer to the green light, and the red layer to the red light. These can be given a first development together, so that the individual responses will be indicated as silver deposits in the respective layers. The developer used is one which leaves no dye-coupler stains.

The non-substantive process

In what is called the nonsubstantive subsequent process, the dye couplers are introduced in a second development. Each colour layer is treated separately. Uniform red light is applied (from the bottom up) to expose the undeveloped silver halide in the red layer. It has no effect on the other layers because of their insensitivity to red. The film is processed with a developer containing a minus-red (or cyan) dye coupler. This leaves a silver and minus-red dye deposit wherever there was newly exposed silver halide in the red layer. Similarly, the blue layer, newly exposed with blue light from above and processed with a developer containing a minus-blue (or yellow) dye coupler, leaves a silver and minus-blue dye deposit wherever there was newly exposed silver halide in the blue layer. In the remaining green layer, a white-light exposure and development with a minus-green (or magenta) dye coupler converts the residual silver halide into a silver and minus-green dye deposit.

All the silver deposits and the yellow filter are finally bleached out. The remaining dye deposits serve to subtract from white light, in the manner that was described earlier, the correct part of the spectrum to leave the colour of the initial exposing light. For example, where this light was red, the final dyes absorb blue and green. Of the spectrum, this therefore leaves red light to go through the film.

The substantive process

In a modification called the substantive process, the appropriate dye couplers are suitably embedded in the emulsion in the appropriate colour layers to prevent their moving about during processing and contaminating the colours (an important problem). It is then possible to carry out the second exposure and development on all three layers in a single step with white light and with only one developer.

Nonsubstantive film is essentially an amateur medium that enables the camera original to be processed as a projection print. Commercial theatrical motion pictures are photographed on a colour negative stock containing dye couplers (*i.e.,* substantive type) from which prints can be made.

Lighting. The art of cinematography is, above all, the art of lighting, and the British term for the chief of the camera crew, lighting cameraman, comes closer to the matter than the Hollywood director of photography. In motion-picture photography, decisions about exposure are governed by the overall style of film, and light levels are set to expose the particular film stock at the desired f-stop.

Light sources. The earliest effective motion-picture lighting source was natural daylight, which meant that films at first had to be photographed outdoors, on open-roof stages, or in glass-enclosed studios. After 1903, artificial light was introduced in the form of mercury vapour tubes that produced a rather flat lighting. Ordinary tungsten (incandescent) lamps could not be used because the light rays they produced came predominantly from the red end of the spectrum, to which the orthochromatic film of the era was relatively insensitive. After about 1912, white flame carbon arc instruments, such as the Klieg light (made by Kliegl Brothers and used for stage shows) were adapted for motion pictures. After the industry converted to sound in 1927, however, the sputtering created by carbon arcs caused them to be replaced by incandescent lighting. Fresnel-lens spotlights then became the standard. Fresnel lenses concentrate the light beam somewhat and prevent excessive light loss around the sides. They can also, when suitably focused, give a relatively sharp beam. In the studio there are racks above and stands on the floor on which lamps can be mounted so that they direct the light where it is wanted. The advent of Technicolor led to a partial reversion to the carbon arc because incandescent light affected the colours recorded on the film. Around 1950, however, economic pressures caused Technicolor film to be rebalanced for incandescent light.

The modern era in lighting began in the late 1960s when

Tungsten-halogen lamps

tungsten-halogen lamps with quartz envelopes came into wide use. The halogen compound is included inside the envelope, and its purpose is to combine with the tungsten evaporated from the hot filament. This forms a compound that is electrically attracted back to the tungsten filament. It thus prevents the evaporated tungsten from condensing on the envelope and darkening it, an effect that reduces the light output of ordinary gas-filled tungsten lamps. The return of the tungsten to the filament means that the incandescent lamp can be run with a long life at a higher filament temperature and, more important, remain at precisely the same colour temperature. These lamps are now sometimes provided with a special multilayered filter to give a bluish light that approaches the colour of daylight. Halogen lamps give brilliant light from a compact unit and are particularly well-suited to location filming.

The principal light on a scene is called the key light. The position of the key light has often been conventionalized (*e.g.*, aimed at the actors at an angle 45 degrees off the camera-to-subject axis). Another school of cinematographers prefers source lighting, in the tradition of Renaissance and Old Master paintings; that is, a window or lamp in the scene governs the angle and intensity of light. A fill light is used to provide detail in the shadow areas created by the key light. The difference in lighting level between the key plus the fill light versus the fill light alone yields the lighting contrast ratio. The "latitude" of the film, or the spread between the greatest and least exposure that will produce an acceptable image, governs the lighting contrast ratio. For many years, the latitude of colour films was so restricted that it was thought necessary to have numerically low lighting ratios, typically 2 to 1 (a very flat lighting) and never more than 3 to 1. The introduction of Eastman 5254 colour negative in 1968 and the even more sophisticated 5247 in 1974 opened a new era in which colour film was exposed with higher ratios approaching the previous subtleties of black-and-white.

Light measurement. Precise control of exposure throughout filming is necessary to maintain consistent tones from shot to shot and to give an overall tenor of lighting that suits the pictorial style. To determine light levels in the studio and on interior locations, an incident light meter is primarily used. This type of meter is recognizable by a white plastic dome that collects light in a 180-degree pattern (the dome is an approximation of the shape of the human face). Because it measures the overall light (calibrated in footcandles) falling on the scene, it may be used without the actors present.

Reflected light readings measure the average light coming toward the camera from the scene being photographed. This works well for average subjects but gives wrong exposures if the background contains either many bright areas, as in a beach scene, or very dark areas, as in front of a dark building. In such cases the photocell must be held not at the camera but very close to the subject of interest, to eliminate the effect of the background. This is also the case when the scene contains a good deal of backlight. These shortcomings eventually led to the development of the spot meter.

Spot measurement readings measure the light coming toward the camera from selected spots in the subject being photographed. The meter for this purpose has an optical system that covers measurement of a spot of about one degree, making it extremely useful on exterior locations.

Colour temperature

Light is also measurable in terms of colour temperature. Light rich in red rays has a low reading in kelvins. Ordinary household light bulbs produce light of about 2,800 kelvins, while daylight, which is rich in rays from the blue end of the spectrum, may have readings from 5,000 to more than 20,000 K. The colour temperature meter uses a rotating filter to indicate a bias toward either red or blue; when red and blue rays are in balance, the needle does not move. Some meters also use red/blue and blue/green filters for fuller measurement.

The general practice has been to shoot the entire picture on stock balanced for artificial light at 3,200 K. Lights for filmmaking generally range between 3,200 K and 3,400 K. For daylight shooting, an orange filter is employed to counter the film's sensitivity to blue light. Although colour-correcting filters are produced in a great many gradations, the No. 85 filter is generally used to shoot tungsten-balanced colour film outdoors. For mixed-light situations where daylight enters through windows but tungsten light is used for the interior, the practice has been to cover the windows with sheets of plastic similar in colour to the No. 85 filter. This reduces the colour temperature of the natural light to that of the artificial light. When the windows are very large, blue filters are sometimes placed on the lights and the No. 85 orange filter is used on the lens, as if filming in exterior daylight. Yet another approach is to supplement natural daylight with metal halide (daylight-balanced) lights. With the increase in location shooting, daylight-balanced high-speed films have been introduced to allow shooting in mixed-light situations without light loss due to filters.

Film processing and printing. In the early days of motion pictures, films were processed by winding on flat racks and then dipping in tanks of solution. As films became longer, such methods proved to be too cumbersome. It was recognized that the processing system should have the following characteristics: it must run continuously; it must be lighttight and yet capable of being loaded in daylight; and it must be as compact as possible to provide a minimum air surface for the processing solutions. A general form evolved that is still in use.

Continuous method of film processing

For continuous operation the film must be passed continuously through the solutions and folded back over rollers that do not touch the emulsion surface. It must be handled very carefully, as the impregnation with solution weakens the support, and the sprocket holes should not be engaged. Drive should, therefore, be accomplished by a light friction force at the edges.

Splicing on a fresh film without affecting the motion of the part of the film being processed is handled by using a storage unit or reservoir. This reservoir has a variable capacity so that the output end can be giving out film while the input end is stationary as the new film is spliced. Lighttight gates prevent all but a short length of film being light-struck at the very beginning or end of the film (and leaders may be used). The take-up-reel case is fastened in a lighttight way to the storage unit so that after splicing, the film is unreeled into the storage and processing units until the other end is reached, ready for splicing to the next film after changing cases.

Many tank shapes have been tried. Long vertical tanks provide for several passes of the film through each tank. The spools are designed so as to hold the film at the edges by friction. There are a number of types of drive, but all function gently to avoid strain. Sometimes the spools have multistepped edges to accommodate various film widths. The lower spools (or "diabolos") are more or less free but guided in a loose fashion so that they will not jam or tangle. The long vertical tanks give a minimum of air surface to the solution. The motion of the film through the liquid can be sufficient for proper contact of the film with the solutions, but sometimes submerged sprays with small jets of fine nitrogen bubbles are provided to increase the agitation.

The last receptacle in the processing sequence is a drying oven. There are several designs, some of which generally resemble the tank but without solution and are provided with heating elements. This receptacle does not need to be lighttight.

The processing steps for the many different types of film are similar in principle, though there are variations in specific solutions and treatments. One variation is known as reversal processing. After partial development, the camera original is bleached and given a second exposure of uniform white light. This yields a positive rather than a negative image and thus saves the cost of an additional generation.

In laboratory parlance, the major functions are divided into "front end" and "release print" work and may be performed at different facilities. Front end work begins even before shooting with tests by the cinematographer on the same film stocks that will be used for the production. These will be used as a guide when takes from the camera negative that come in from each day's shooting

are printed. A colour video analyzer reads the red, blue, and green records of the tests over a range of six f-stops to establish "printer lights." As desired, the work print may be "one light" (given uniform exposure) or "timed" (exposure corrected for scene-to-scene variations).

The original negative is stored until postproduction is finished. Positive work print is furnished in 1,000-foot rolls for editing. When all editing, including the insertion of optical effects and titles, is completed, the negative cutter matches the original camera film frame by frame at each editing point. The edited camera negative is combined with the synchronized sound track negative into a composite print called the answer print. (The first answer print is rarely the same as the final release print.) After all colour-correction and timing takes place, the information is recorded on perforated paper tape that serves to control both the exposure for each shot and the louvered filters that add red, green, and blue values.

The answer print

For theatrical distribution, exhibition release prints are not normally struck from the original camera negative. The original negative is used to make a master positive, sometimes known as the protection positive, from which a printing negative is then made to run off the release prints. Alternatively, a "dupe" negative can be made by copying the original camera negative through the reversal process. This yields a colour reversal intermediate (CRI) from which prints can be struck.

Printing takes a number of different forms. In contact printing, the master film (or negative) is pressed against the raw stock; this combination is exposed to light on the master film side. In optical printing, the master film is projected through a lens to expose the raw stock. In continuous printing, the master film and the raw stock both run continuously. Continuous printing is usually contact printing but can be optical, through a projected slit. In intermittent, or step-by-step, printing, each frame of the master film is exposed as a whole to a corresponding frame space on the raw film.

It is possible to print from one size master film to another size raw stock, such as 35-mm to 16-mm, or vice versa. In such cases the printing must, of course, be optical, and in the examples cited must be intermittent if there is a sound track. This is because 35-mm sound film has a spacing between frames and 16-mm does not. The sound track must be printed separately. The preferred method for making 16-mm versions of 35-mm films is to make a 16-mm negative by reduction from the 35-mm negative. Sometimes a 35-mm release print is reduced and printed by reversal, but this yields a coarser image. When 16-mm film is "blown up," the 16-mm negative is immersed in a solution that conceals scratches and grain as it is being rephotographed; this process is called wet-gate printing.

Film prints to be used for projection are given a coat of wax over the sprocket-hole areas. This eases the film passage between the pressure plates at the projection aperture.

Sound-recording techniques. The art of sound recording for motion pictures has developed dramatically. Most of the improvements fall into three areas: fidelity of recording; separation and then resynchronization of sound to picture; and ability to manipulate sound during the postproduction stage.

Optical recording. Until the early 1950s the normal recording medium was film. Sound waves were converted into light and recorded onto 35-mm film stock. Today the principal use of optical recording is to make a master optical negative for final exhibition prints after all editing and rerecording have been completed.

Magnetic recording. Magnetic recording offers better fidelity than optical sound, can be copied with less quality loss, and can be played back immediately without development. Magnetic tracks were first used by filmmakers in the late 1940s for recording music. The physical principles are the same as those of the standard tape recorder: the microphone output is fed to a magnet past which a tape coated with iron oxide runs at a constant speed. The changes in magnetic flux are recorded onto the tape as an invisible magnetic "picture" of the sound.

At first the sound was recorded onto 35-mm film that had a magnetic coating. Today sprocketed 35-mm magnetic tape is used during the editing stages. For onset recording, however, the film industry converted gradually to the same unperforated quarter-inch tape format widely used in broadcasting, the record industry, and even the home. Documentary and independent filmmakers were the first to develop and use the portable, more compact apparatus. Improvements in magnetic recording have paralleled those in the recording industry and include the development of multiple-track recording and Dolby noise reduction.

Double-system recording. Although it is possible to reproduce sound, either optically or magnetically, in the same camera that is photographing a scene (a procedure known as single-system recording), there is greater flexibility if the sound track is recorded by a different person and on a separate unit. The main professional use for single-system recording is in filming news, where there is little time to strive for optimal sound or image quality. Motion-picture sound recording customarily uses a double system in which the sound track remains physically separate from the image until the very last stages of postproduction.

Double-system shooting requires a means of rematching corresponding sounds and images. The traditional solution is to mark the beginning of each take with a "clapper," or "clapstick," a set of wooden jaws about a foot long, snapped together in the picture field. The instant of clacking then is registered on both picture and sound tracks. Each new take number is identified visually by a number on the clapper board and aurally by voice. A newer version of the clapper is a digital slate that uses light-emitting diodes and an audio link to synchronize film and tape.

Synchronizing sound and image recording

Precise synchronism must be maintained between camera and recorder so that sound can be kept perfectly matched to the visuals. (Lack of perfect synchronism is most conspicuous in close-up shots in which a speaker's lips do not match his voice.) On some occasions several cameras shoot a scene simultaneously from different points of view while only one sound recording is made, or several sound records may be taken of a single shot. Thus, to maintain synchronism, all sound and picture versions of a particular scene must be recorded at the same speed; the camera and the recorder cannot fluctuate in speed. One way to achieve this is to drive all cameras and recorders from a common power supply. Alternatively, synchronization may be achieved through the automatic, continual transmission from cameras to recorders of a sync-pulse signal sent by cable or wireless radio. More convenient yet is crystal sync, whereby the speed of both cameras and recorders is controlled through the use of the oscillation of crystals installed in each piece of equipment. The most advanced system uses a time-code generator to emit numbers in "real-time" on both film and tape.

The sound recordist. The main task of the recordist during live recording is to get "clean" dialogue that eliminates background noise and seems to correspond to the space between speaker and camera. Most of the nonsynchronous dialogue, sound effects, and music can be added and adjusted later. During shooting the sound recordist adjusts the sound by setting levels, altering microphone placement, and mixing (combining signals if there is more than one microphone). Major technical and aesthetic reshaping is left for the postproduction phase when overhead is lower, the facilities are more sophisticated, and alternative versions can be created. It is also the job of the sound personnel to record wild sound (important sound effects and nonsynchronous dialogue) and ambient sound (the inherent sound of the location). Ambient sound is added to the sound track during postproduction to maintain continuity between takes. Usually, wild sound and music are also adjusted and added then.

Microphones. Microphones of many different types have been used for sound recording. These may differ in sound quality, in directional characteristics, and in convenience of use. Conditions that may dictate the choice of a particular microphone include the presence of minor echoes from objects in the set or reproduction of speech in a small room, as distinct from that in a large hall. Painstaking adjustments are made by careful attention to the choice of microphones, by the arrangement and sound absorbency of walls and furniture on the set, and by the

Choice of microphones

exact positioning of the actors. For recording a conversation indoors, the preferred microphone is sensitive in a particular direction in order to reduce extraneous noises from the side and rear. It is usually suspended from a polelike "boom" just beyond camera range in front of and above the actors so that it can be pivoted toward each actor as he speaks. Microphones can also be mounted on a variety of other stands. A second way to cut down background noise is to use a chest (or lavaliere) microphone hidden under the actor's clothing. For longer shots, radio microphones eliminate the wires connecting actors to recorders by using a miniature transistor radio to send sound to the mixer and recorder. (P.Me./E.We./S.G.H.)

Editing. The postproduction stage of professional filmmaking is likely to last longer than the shooting itself. During this stage, the picture and the sound tracks are edited; special effects, titles, and other optical effects are created; nonsynchronous sounds, sound effects, and music are selected and devised; and all these elements are combined.

Picture editing. The developed footage comes back from the laboratory with one or more duplicate copies. Editors work from these copies, known as work prints, so that the original camera footage can remain undamaged and clean until the final negative cut. The work prints reproduce not only the footage shot but also the edge numbers that were photographically imprinted on the raw film stock. These latent edge numbers, which are imprinted successively once per foot on the film border, enable the negative matcher to conform the assembled work print to the original footage.

Work prints

Before a day's work, or rushes, are viewed it is usual to synchronize those takes that were shot with dialogue or other major sounds. Principal sound is transferred from quarter-inch to sprocketed magnetic tape of the same gauge as the film (*i.e.*, 16-mm or 35-mm) so that once the start of each shot is matched, sound and image will advance at the same rate, even though they are on separate strips. Once synchronism is established, the sound and image tracks can be marked with identical ink "rubber" numbers so that synchronism can be maintained or quickly reestablished by sight.

The editor first assembles a rough cut, choosing with the director one version of each shot and providing one possible arrangement that largely preserves continuity and the major dialogue. The work print goes through many stages from rough to fine cut, as the editor juggles such factors for each shot and scene as camera placement, relation between sound and image, performance quality, and cutting rhythm. While the work print is being refined, decisions are made about additions or adjustments to the image that could not be created in the camera. These "opticals" range from titles to elaborate computer-generated special effects and are created in special laboratories.

Editing equipment. Rushes are first viewed in a screening room. Once individual shots and takes have been separated and logged, editing requires such equipment as viewers, sound readers, synchronizers, and splicers to reattach the separate pieces of film. Most work is done on a console that combines several of the above functions and enables the editor to run sound and picture synchronously, separately at sound speed, or at variable speeds. For decades the Hollywood standard was the Moviola, originally a vertical device with one or more sound heads and a small viewplate that preserves much of the image brightness without damaging the film. Many European editors, from the 1930s on, worked with flatbed machines, which use a rotating prism rather than intermittent motion to yield an image. Starting in the 1960s flatbeds such as the KEM and Steenbeck versions became more popular in the United States and Great Britain. These horizontal editing systems are identified by how many plates they provide; each supply plate and its corresponding take-up plate transports one image or sound track. Flatbeds provide larger viewing monitors, much quieter operation, better sound quality, and faster speeds than the vertical Moviola.

Electronic editing. Despite the replacement of the optical sound track by sprocketed magnetic film and the introduction of the flatbed, the mechanics of editing did not change fundamentally from the 1930s until the 1980s. Each production generated hundreds of thousands of feet of work print and sound track on expensive 35-mm film, much of it hanging in bins around the editing room. Assistants manually entered scene numbers, take numbers, and roll numbers into notebooks; cuts were marked in grease pencil and spliced with cement or tape. The recent application of computer and video technology to editing equipment, however, has had dramatic results.

The present generation of "random access" editing controllers makes it likely that physical cutting and splicing will become obsolete. In these systems, material originated on film is transferred to laser videodiscs. Videotape players may also be used, but the interactive disc has the advantage of speed. It enables editors to locate any single frame from 30 minutes of program material in three seconds or less. The log that lists each take is stored in the computer memory; the editor can call up the desired frame simply by punching a location code. The image is displayed without any distracting or obstructing numbers on a high-resolution video monitor. The editor uses a keypad to assemble various versions of a scene. There is neither actual cutting of film nor copying onto another tape or disc; computer numbers are merely rearranged. The end product is computer output in which the "edit decision" list exists as time code numbers (see above *Cameras*).

Electronic editing also simplifies the last stage in editing. Instead of assembling the camera negative with as many as 2,000 or more splices, an editor can match the time code information on a computer program against the latent edge numbers on the film. Intact camera rolls can then be assembled in order without cutting or splicing. Electronic editing equipment has been used primarily with material photographed at the standard television rate of 30 frames per second. Material shot at the motion-picture rate of 24 frames per second can be adapted for electronic editing by assigning each film frame three video fields, of which only two are used.

Special effects. Special effects embrace a wide array of photographic, mechanical, pyrotechnic, and model-making skills.

The most important resource of the special effects department is the optical printer, essentially a camera and projector operating in tandem, which makes it possible to photograph a photograph. In simplest form this apparatus is little more than a contact printer with motorized controls to execute simple transitions such as fades, dissolves, and wipes. A 24-frame dissolve can be accomplished by copying the end of one film scene and the beginning of another onto a third film so that diminished exposure of the first overlaps increased exposure of the second. Slow motion can be created by reprinting each frame two or three times. Conversely, printing every other frame (skip printing) speeds up action to create a comic effect or to double the speed when filming action such as collisions. A freeze frame is made by copying one frame repeatedly.

The optical printer can also be used to replace part of an image. For example, a high-angle long shot in a western may reveal what looks like an entire frontier town surrounded by wilderness. Rather than take the time and trouble to actually build and film on location for a shot that may last less than a minute, filmmakers can make the shot using standing sets on the studio backlot, with skyscrapers and freeway traffic visible in the distance. One frame of the original scene is then enlarged so that a matte artist can trace the outline of the offending area on paper. When the copy negative is made, the offending area is masked and remains unexposed. The negative can then be rewound to film a matte painting of suitable location scenery. In addition to combining artwork with live action, optical printing can combine two or more live-action shots.

Optical printing

In the aerial image optical printer, the camera is aimed straight down at a ground glass easel on which an image is projected from below. The large image allows the artist to make a very precise alignment of the artwork and live action so that they can be filmed in one pass.

Optical printing can be combined with blue-screen photography to produce such effects as characters flying through the air. Ordinary superimposition cannot be used

Blue-screen photography

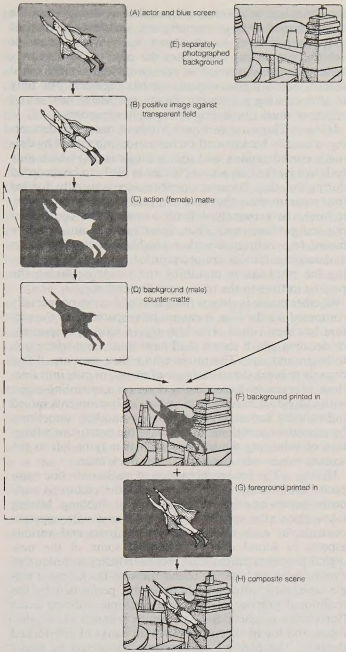


Figure 4: Steps in a blue-screen effect.

for this effect because the background will bleed through as the character moves. To create a traveling matte shot, it is necessary to obtain an opaque image of the foreground actors or objects against a transparent background. This is done by exploiting film's special sensitivity to blue light. In a traditional blue-screen process the actor is posed before a primary blue background, which, to avoid shadows, is illuminated from behind (see Figure 4A). Eastman No. 5247 colour negative is used to film the shot because its blue-sensitive layer yields a dense black-silver image in the area of the blue screen. On the positive print, the foreground action appears against a transparent field (see 4B). This image, printed with red light onto high-contrast panchromatic film, produces the action, or female, matte (see 4C). An additional generation yields a countermatte known as the background, or male, on which the action appears as an opaque silhouette (see 4D). This silhouette is placed with a separately photographed background (see 4E) in an optical printer. In the first pass through the optical printer, the background is "printed in" (see 4F). In the second pass, the actor and action matte are combined and the foreground is printed in (see 4G). All the elements are thus composited on one film (see 4H). There are many variations using more or fewer generations. In some systems the foreground is printed first. With a negative, or reverse, matte, the action matte is made from the camera negative and is opaque against a transparent background. The blue-screen process, in a form more complex than that described here, was used to create many spectacular effects in such films as *Star Wars* (1977) and *E.T.—The Extraterrestrial* (1982). The term blue-screen need not be taken literally. Blue-garbed Superman required a differentiated backing, and sodium vapour (yellow) light was used on the screen to yield a transparent background for the flight scenes in *Mary Poppins* (1964).

In the past two actors talking in a car were likely to be filmed in the studio using rear projection (process) shots; that is, the actors were photographed in front of a translucent screen through which previously filmed footage of passing scenery was projected. Location shooting and lightweight sound equipment have all but eliminated this formerly common practice in feature films, although it survives in television. When routine background replacement is still used in expensive productions, it is more likely to be done with blue-screen than with rear projection.

Front projection

The light loss and lack of sharpness (especially noticeable in colour) that made rear projection shots obvious has also inspired some interest in front projection. The camera is placed facing the screen, and the background projector is positioned in front of and to the side of the camera so that the beam it projects is perpendicular to the camera's line of sight. A semitransparent mirror is angled at 45 degrees between camera and projector; the camera photographs the scene through the glass while the mirror particles reflect the projection beam onto the screen. The screen is made of Scotchlite, the trade name for a material that was originally devised to make road signs that would reflect light from a car's headlight to the driver's eyes. Because camera and projector are in the same optical axis in the front projection process, the background illumination is reflected directly to the camera lens so brilliantly that it is not washed out by the lighting on the actors. The actors also mask their own shadows. Front projection was used to great effect in "The Dawn of Man" sequence in *2001* (1968) wherein a leopard's eyes lit up in facing the camera. Scotchlite screens have been used to reflect powerful lights that have been shone through tanks of dyed water to produce large-scale blue-screen effects.

To reduce the graininess that each generation of film adds to the original, concerns such as George Lucas' Industrial Light and Magic produce their effects on 65-mm film. Others, notably Albert Whitlock, have revived the old practice of making matte effects on the camera negative. In the silent film days, this was achieved using a glass shot in which the actors were photographed through a pane of glass on which the background had been painted. The Whitlock method employs a black matte in front of the camera. A hole is cut in the matte to expose the live action, which may account for only a small portion of the image. The partially exposed negative is rewound, and the background is photographed from a matte painting on glass on which the corresponding area of live action is absent.

Miniatures and models

Miniatures (scale models) are often used in special effects work because they are relatively inexpensive and easy to handle. Great care is needed to maintain smooth, proportionate movement to keep the miniatures from looking as small and insubstantial as they really are. Models may be filmed at speeds greater than 24 frames per second (*i.e.*, in slow motion) to achieve more realistic-looking changes in perspective and time scale. John Dykstra's Apogee, Inc., is a leader in the field of motion control, the use of computer-controlled motors to regulate the movement of models and camera in relation to one another, thereby improving the illusion of motion. The model aircraft or spacecraft can even be made to swoop and turn as they approach the camera.

Until recently it was difficult to introduce camera movement into special effects shots. Limited camera movement was achieved by moving the camera in the optical printer, thereby creating an optical zoom, but this method did not create a convincing illusion of three-dimensionality because the foreground and background elements, as well as the grain pattern in the film, were enlarged or reduced at the same rate. When a crane or dolly was used to shoot the live portion of the scene, the background had to be animated frame-by-frame, involving considerable expense in draftsmanship. Computer-enhanced animation has made it possible to store and recall the algorithms needed to model shapes and surfaces at varied perspectives.

The increased interface of film and video techniques has great implications in the effects area. The ease with which

colour components can be separated and reformed makes the electronic medium especially well suited to blue-screen and similar image replacement techniques. The creation of mattes through computer graphics rather than the laborious process of laboratory development is an obvious area of cost savings. Digital image storage on laser videodiscs, as in the Abekas system, enables images to be manipulated with ease.

Sound editing. Less than 25 percent of the sound track of a feature film may have been recorded at the time of photography. Much of the dialogue and almost all of the sound effects and music are adjusted and added during postproduction. Most sound effects and music are kept on separate magnetic tracks and not combined until the rerecording session.

Dialogue. Because of drastic changes in microphone placement from one shot to another, excessively "live" acoustics, background noise, and other difficulties, part or all of the dialogue in a scene may have to be added during postproduction. Production sound is used as a cue or guide track for replacing dialogue, a procedure commonly known as dubbing, or looping. Looping involves cutting loops out of identical lengths of picture, sound track, and blank magnetic film. The actor listens to the cue track while watching the scene over and over. The actor rehearses the line so that it matches the wording and lip movements and then a recording is made. The cutting of loops has largely been replaced by automatic dialogue replacement (ADR). Picture and sound are interlocked on machines that can run forward or backward. In the 1980s digitalized systems were developed that could, with imperceptible changes in pitch, stretch or shrink the replacement dialogue to match the waveforms in the original for perfect lip sync.

Dubbing

Dubbing also refers to the process of substituting one language for another throughout the entire picture. If this is to be done credibly, it is necessary to make the speech in the second language fit the character and cadence of the original. If the actor's face is visible in the picture it is also necessary to fit the words of the translation so that the lip movements are not too disparate. In the United States and England pictures intended for foreign distribution are prepared in a version with an M&E (music and effects) track separate from the dialogue to facilitate dubbing. In certain other countries, notably Italy, most dialogue recorded during production is meant merely to serve as a guide track, and nearly all sound is added during postproduction. One last form of speech recorded separately from photography is narration or commentary. Although images may be edited to fit the commentary, as in a documentary using primarily archival footage, most narration is added as a separate track and mixed like sound effects and music.

Sound effects. All sounds other than speech, music, and the natural sounds generated by the actors in synchronous filming are considered sound effects, whether or not they are intended to be noticed by the audience. Although some sounds may be gathered at the time of shooting, the big studios and large independent services maintain vast libraries of effects. Still other effects may be generated by re-creating conditions or by finding or creating substitute noises that sound convincing.

An expedient way of generating mundane effects is the "foley" technique, which involves matching sound effects to picture. For footsteps, a foley artist chooses or creates an appropriate surface in a studio and records the sound of someone moving in place on it in time to the projected image. Foleying is the effects equivalent of looping dialogue.

Background noise (room tone or presence) from the original location must be added to all shots that were not recorded live so that there is continuity between synchronous and postsynchronized shots. Continuous noises, such as wind or waves, may be put on separate tracks that are looped (the beginning of a track is spliced to follow its end), so that the sound can be run continuously.

Sound effects can be manipulated with the use of digital technology known as audio signal processing (ASP). The sound waveform is analyzed 44,000 times per second and converted into binary information. The pitch of a sound may be raised or lowered without altering the speed of the tape transport. Thus, engineers can simulate the changes in pitch perceived as an object, such as an arrow or vehicle, approaches and passes the camera. Sounds may be lengthened, shortened, or reversed without mechanical means. Some digital systems enable engineers not only to alter existing sounds but also to synthesize new sound effects or music, including full symphonic scores.

Music. There are two basic kinds of music; underscoring is usually background orchestration motivated by dramatic considerations, and source music is that which may be heard by the characters. Neither is likely to be recorded during shooting. Because a performance is usually divided into separate shots that take minutes or hours to prepare, it would be extremely difficult to produce a continuous musical performance. Thus, most musical numbers are filmed to synchronize with a playback track. The songs and accompaniment are prerecorded, so that during filming the musician is mouthing the words or faking the playing in time to the track recorded earlier.

Underscoring and source music

Whether music is chosen from music libraries or specially composed for the film, it cannot be prepared until the picture has been edited. The first step in scoring is spotting, or deciding which scenes shall have music and where it is to begin and end. The music editor then uses an editing console to break down each use of music, or cue, into fractions of seconds. Recording is done on a recording stage, with individual musicians or groups of instruments miked individually and separated from one another, sometimes by acoustical partitions. In this case the conductor's function of balancing the instrumentalists may be left to the scoring mixer, who can adjust each track later.

Mixing. The final combination of tracks onto one composite sound track synchronous with the picture is variously known as mixing, rerecording, or dubbing. Mixing takes place at a special console equipped with separate controls for each track to adjust loudness and various aspects of sound quality. Although some of the new digital processes employ the record-industry technique of overdubbing, or building sound track-by-track onto a single tape, most mixing in films is still performed by the traditional practice of threading multiple dubbing units (sprocketed magnetic film containing separate music, dialogue, and sound effects elements) on banks of interlocked dubbers. The playback dubbers are connected by selsyn motors to one another, as well as to the rerecorders that produce the master, or parallel music/dialogue/effects (M/D/E), track on full-coat magnetic stock. Also in interlock are a projector that allows the mixer to work from the actual image and a footage counter that allows the mixer to follow cue sheets, or logs, which indicate by footage number when each track should be brought in and out.

The mixer strives to strike the right dramatic balance between dialogue, music, and effects and to avoid monotony. Mixing procedures vary widely. Some studios use one mixer for each of the three main tracks, in which case the effects tracks have probably been mixed down earlier onto one combined track. In the early days of magnetic recording, stopping the rerecording equipment produced an audible click on the track; if a mistake were made, mixing would have to be redone from the beginning of the tape reel. The advent of back-up recording in the 1960s eliminated the click, making it possible for mixers to work on smaller segments and to correct mistakes without starting over. This enables the mix to be controlled by one person, who may be combining as many as 24 tracks. An even greater advance is the computerized console that enables the mixer to go back and correct any one track without having to remix the others.

Back-up recording

For monaural release, a composite music/dialogue/effects master on full-coat 35-mm magnetic film is converted to an optical sound negative. For stereo, four-track submasters for M/D/E are mixed down to a two-track magnetic matrix encoded to contain four channels of sound information. Optical sound negatives are copied from the magnetic master, and they are then composited with the picture internegative so that they are in projection sync (on 35-mm prints the sound is placed 21 frames in advance of its corresponding image; on 16-mm

prints the sound is 26 frames in advance of the picture).

Because of narrow track width, optical stereo sound tracks require a system of noise reduction such as Dolby Type A. The Dolby system works by responding to changing amplitudes in various regions of the frequency spectrum of an audio signal. The quieter passages are boosted to increase the spread between the signal (desired sound) and the unwanted ground noise. When played back, normal levels are restored, and the ground noise drops below the threshold of audibility.

Projection technology and theatre design. *Projectors.* The projector is the piece of motion-picture equipment that has changed the least. Manufacturers produce models virtually identical to those of the 1950s, and even the 1930 model Super Simplex is still in wide use. The essential mechanism is still the four-slot Maltese cross introduced in the 1890s. The Maltese cross provides the intermittent Geneva movement that stops each frame of the continuously moving film in front of the picture aperture, where it can be projected (or, in a camera, exposed). The movement starts with a continuously rotating gear and cam (see Figure 5, top). Each 360-degree rotation of the gear and cam causes a pin to engage one of the slots of the Maltese cross. The pin rotates the cross, which in turn rotates a shaft, one quarter turn. As the shaft rotates, four of the 16 teeth on the intermittent sprocket advance and engage the perforations (sprocket holes) on one frame of the film. The sprocket moves only when the pin is fully engaged in the Maltese cross slot (see Figure 5, bottom). This is the "pull-down" phase; in the other phases the curved surfaces of the cam and the cross are in contact and the movement is in the "dwell" position. The Geneva movement is also called a 3:1 movement because there are three quarter-cycles of dwell for every one quarter-cycle of pull-down.

Intermittent Geneva movement

Sound, unlike images, cannot be reproduced intermittently; sound must be continuous to be realistic. The optical-sound-reading equipment on a projector is therefore

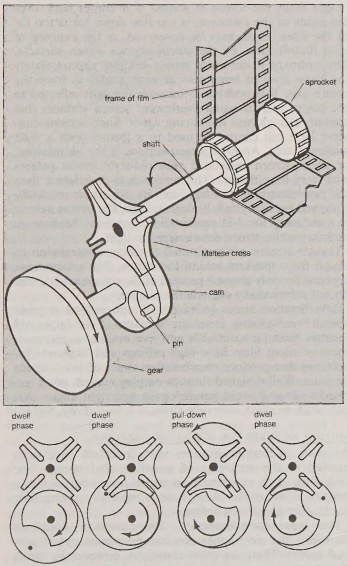


Figure 5: (Top) Intermittent Geneva movement. (Bottom) Successive positions of the Maltese cross.

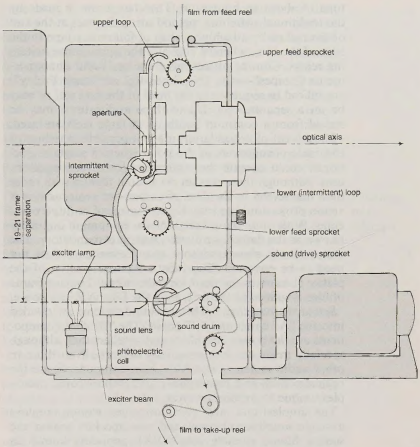


Figure 6: Film path in a typical 35-mm theatrical projector with optical sound reproducer (doors removed).

located below the picture aperture (see Figure 6), and the sound on an optical 35-mm print is located 21 frames ahead of its corresponding image. A light beam (supplied by a direct current for stability) is shone through a rectangular slit and focused by a lens to dimensions of .001 by .084 inch onto the sound track. The sound track's varying bands of light and dark then modulate the amount of light from the beam that is allowed to pass to the optical pickup. In older equipment this pickup was a photoelectric cell that changed electrical resistance under exposure to light. Newer designs employ a solar cell of photovoltaic material to convert light energy to electric energy.

An important element of picture quality on the screen is brightness. For decades the standard light source was the carbon-arc lamphouse, which used disposable electrodes (positive and negative carbon-clad rods) that would be moved together as they burned; the rods needed to be replaced every hour or so. Xenon lamps were introduced in West Germany in the 1950s, and carbon-arc projection is now found only in older theatres. Both carbon-arc and xenon lamps are run off a direct-current power supply in order to minimize brightness variations due to fluctuations in voltage. The xenon bulb replaces the positive and negative carbons with a tungsten anode and cathode in a quartz envelope filled with xenon gas under pressure. Light from xenon bulbs has a colour temperature closer to that of daylight than carbon-arc light does; that is, it is bluer and is therefore particularly well suited to colour films.

Carbon-arc and xenon lamps

Projection techniques. A 35-mm exhibition print is furnished to the theatre mounted on 2,000-foot (22-minute) reels. Thus, a typical feature film consists of five or six reels. For decades, the 2,000-foot reel was the basic unit of projection, and each screening required four or five changes of projector. Circular cue marks printed in the upper right corner of the picture indicated when each changeover should take place. Today the 2,000-foot reel is used primarily in single-screen theatres and in archival and repertory theatres that may present only a single screening of a film. Theatrical exhibition increasingly requires the film to be "made up"—that is, reels must be spliced together to enable the projectionist to make a single changeover between large reels or to use external transports that contain an entire feature without changeovers. For the former, a feature film of six 2,000-foot reels would be reassembled onto two 6,000-foot reels with a running

Changeovers

time of about an hour each. The changeover is made by the traditional switching method using the cues at the end of the reel or by attaching a strip of foil sensor tape to the edge of the film, where it activates the appropriate switching relays. Coming attractions ("trailers") and announcements ("snipes"—*e.g.,* "No Smoking" or "Starts Friday") are spliced in sequence at the head of the first reel or may be on a separate reel. Up to three auditoriums may be served from a common booth when large reels are used.

The advent of xenon lamps made it possible to reduce or eliminate changeovers to the point where a single projectionist could operate the equipment for several auditoriums. Although there was an occasional theatre with more than one screen in the days of carbon-arc projection, it is xenon projection that truly began the age of multiplex cinemas. With more than three screens, equipment popularly known as the flatbed, or platter, system is mandatory. The entire film is shown without changeovers and does not need to be rewound. The most advanced version of the platter eliminates the need for rethreading. The last frame of film is spliced to the first, as in the Edison Kinetoscope.

Sound reproduction. Theatre sound systems are divided into the "A" chain and "B" chain. The "B" chain components are the power amplifiers and speakers that, although specially made, are not essentially different from those in other audio systems. The "A" chain components are the optical pickup and preamplifier and employ some principles unique to motion pictures.

The simplest and most common sound system employs a single amplifier channel and one speaker behind the screen. Stereo variable area (SVA), popularly known as Dolby, though in fact made by several manufacturers, employs a split optical pickup for two sets of wires for the left and right channels. Three stage speakers (left, right, and centre) are mounted behind the screen, and an array of speakers is spread along the side and rear of the auditorium for "surround" sound. Most feature films are prepared so that dialogue issues from the centre speaker, music and on-screen sound effects from the left and right, and off-screen sounds from the surrounds. A processor decodes the four channels from dual variable area tracks; information appearing on the left track is sent to the left speaker, on the right track to the right speaker, while information on both tracks is combined in the centre channel. The surround channel is derived from inversion phase relationships between the left and right tracks.

In monaural systems, a treble cut is employed in accordance with the Standard Electrical Characteristic of 1938, or Academy Curve, so that frequencies above 8,000 hertz (Hz) are "rolled off." This practice dates from an era when sound tracks had a large degree of ground noise and vacuum tube amplifiers produced an audible hiss concentrated in the upper frequencies. A treble boost is added during rerecording so that monaural sound tracks sound shrill and sibilant when played without the Academy filter. The introduction of Dolby noise reduction in conjunction with optical tracks made it possible for frequencies to range up to about 12,000 Hz. With the replacement of tube power amplifiers by solid state ones, large wattages are easily obtainable, and theatre sound is generally louder than it was formerly. The normal level for dialogue in a monaural film is 80 decibels (dB) in the centre of the auditorium; the normal Dolby level is 85 dB, or nearly double that.

SVA is a direct replacement for the four-track magnetic sound introduced in 1953 in conjunction with CinemaScope. Today, magnetic sound is used only with 70-mm prints where six tracks are contained in four stripes of magnetic oxide embossed on the film. The magnetic reproducer, called a penthouse, is mounted above the projector. On a magnetic print, the sound displacement is behind the picture (28 frames in 35 mm and 23 frames in 70 mm).

Until recently, theatre speakers were not capable of reproducing sounds below 80 Hz. The standard theatre speaker was a two-way system with a high-frequency horn mounted atop a cabinet containing a wide, shallow paper cone woofer. The impetus given to 70-mm six-track sound by the great success of *Star Wars* led to the development of the THX system for exhibition. In the six-track system, five stage speakers are mounted in a flat baffle wall behind the screen; each has double 15-inch woofers for low-frequency reproduction down to 40 Hz. For frequencies down to 30 Hz, sub-woofers are connected to a bass extension module that augments signals below 100 Hz on the tracks. At this level, sound is not heard but felt as vibration in the viewer's diaphragm. The THX system delivers undistorted sound up to a level of 108 dB per channel.

THX system

Auditorium design. The most crucial consideration of theatre design is the relationship of picture size to the seating area. In the 1940s the Society of Motion Picture Engineers propounded the "two and six rule," which stated that the first row of seats should be at a distance from the screen equal to twice the picture width and the last row at six picture widths. This rule was based on the Academy picture ratio of 1.33 to 1, which is no longer used except for revival showings. The rule is still valid, however, because the wide-screen formats derive their impact from extension of the picture into the viewer's peripheral vision, and proper installation will maintain constant picture height through all formats.

Depending upon the seating capacity of the auditorium, the image may be made larger or smaller by changing the focal length of the lens. The lens size is calculated by multiplying the "throw" (distance from lens to screen) by the width of the aperture and dividing the total by the picture width. Thus, to produce a picture 18.5 feet wide in 1.85 format (aperture width .825 inch) in an auditorium having a 90-foot throw would require a 4-inch lens.

Screen brightness

The recommended level of screen brightness is 16 foot lamberts in the centre of the screen (with no film in the aperture), but a level of 12 to 14 foot lamberts is more typical for commercial cinemas. It is difficult to illuminate a large picture, because screen brightness decreases in proportion to the square of the increase in screen size; *i.e.,* the light source used to produce a 30-foot-wide picture will have to be not twice but four times as bright as that for a 15-foot image.

Light from the screen is wasted if it comes back over the heads of the audience, is too low down, or is too far to the sides. Light may be conserved, at the expense of even illumination, by the use of various screen surfaces. The ordinary matte-white screen exhibits approximately the same level of brightness at wide angles as from the centre axis. It is possible to increase the light reflected to the centre axis by using pearlescent screen surfaces that contain a brightness enhancing agent. Such screens conserve light but cannot be used in a theatre with a wide audience area. Another screen surface is the aluminized, or silver, screen associated with old-style movie palaces with very long throws. This screen is even brighter than the pearlescent version but loses its brightness markedly if viewed from beyond 20 degrees from the centre axis. It is mandatory for 3-D presentation, however, because an ordinary white screen depolarizes the light.

Theatre screens are perforated to allow transmission of sound from speakers behind the screen. The perforations account for only about 8 percent of the screen surface and do not substantially degrade the picture.

Reverberation times in excess of one second degrade speech intelligibility from the speakers. Very large, old theatres built for vaudeville and live musical accompaniment of silent films have high ceilings and large interior volumes that produce reverberation times of two seconds or more. Well-designed theatres employ curved, often serrated walls and avoid parallel walls and right angles that can produce short-path reflections. (E.We./S.G.H.)

MOTION PICTURES FOR SCIENTIFIC PURPOSES

As soon as motion pictures were invented, they were applied in the recording of scientific phenomena. The recording of an experiment in which a number of things happen at about the same time is especially appropriate for motion-picture recording.

Time-lapse cinematography. There are many occasions on which the cinematography can be carried out at normal speeds. There are other situations, however, in which the changes occur very slowly, so slowly that the eye does not discern the change. One example is the opening of

a flower blossom. In such a situation the technique used is to take successive pictures at intervals of, for example, an hour, taking great care not to move the camera or the plant and to project the resulting film at normal motion-picture speed. The projected picture will disclose many details in the development from the bud to the completed flower that are not apparent in ordinary visual observation. Other phenomena can be studied in this way.

These techniques require merely a standard camera that can take single exposures, plus a timed triggering device that can take the exposures at the desired intervals. The rest of the technique is mostly a matter of preventing undesired motions of camera and subject.

High-speed cinematography. Motion pictures have also been used to study phenomena that occur so fast that they cannot be recorded on normal cameras. An immense amount of ingenuity has been applied to the solution of many problems in this field.

Optical systems outside the camera. Shadowgraph film can show sharp shadows of fast-moving bodies, indicating their speed and any changes of attitude they undergo. With a rapid enough exposure this procedure can also show the sharp shadow of a wave front in air.

Schlieren optics show changes in the condition of a test area of space in the optical path, even when it remains fully transparent. A simplified outline of the arrangement is shown in Figure 7. A source sends out a beam of light through the apparatus to a film. Half the field is cut off by a knife-edged screen, K_1, which is imaged by a lens, L_1, to a position, K_1', in the same plane as a matching screen, K_2. The knife-edges of image and screen exactly coincide. A test position, T, is sharply focused on the film. Thus the light flow past K_1 to K_2 is all cut off from the film if the space at T is completely uniform. Any nonuniformity, such as caused by a wave front in the air at T, causes a scattered light beam to evade the screen, K_2 (path *a*), and reach the film.

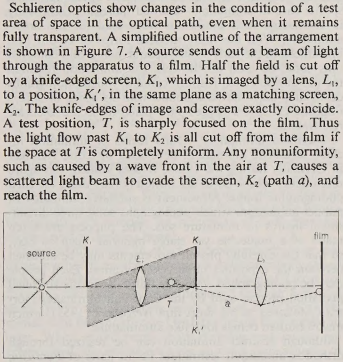


Figure 7: Schlieren optical system (see text).

The Schlieren interferometer is a modification of the system shown in Figure 7. An apparatus that polarizes the light beam—separating it into two slightly different paths and then reintegrating it into one path—is inserted before and after the area T to bring out details of the phase of the light as it progresses from left to right. These details appear in the form of light and dark phase bands, or fringes. They outline the disturbance of the wave by any nonuniformity existing at T. Counting the number of fringes displaced gives a measure of how great the nonuniformity is. The arrangement is especially adaptable to detecting and measuring irregular flow phenomena and wave fronts in the air (or another fluid) at T.

Spectrometric studies

A spectrum of a self-luminous subject is often obtained. Sometimes the spectrum varies quickly, as in an explosion, and it is desired to study the variation. The light output from the spectrometer is led into a motion-picture camera that can handle the speed needed, and a film record is taken. The film can then be studied at leisure.

Framing. The normal-speed camera records on the film a succession of frames, each showing a complete picture but taken at successive instants of time. Not all high-speed cameras record in this way, but some do, and the various methods of separating the frames and recording them represent key elements in the technology.

When a cube (or many-sided prism) is rotated in the optical path in a camera, it moves the image periodically past the picture aperture. If the film is moved in the same direction at the same speed, the image, while it is appearing, is fixed on the film. The problems are that, during its appearance, the image does not move with an exactly constant velocity, and the prism introduces some optical distortion of the image. These can be partially remedied by a variety of modifications, but there are still residual imperfections. The rotating prism device is used, however, up to about 10,000 frames per second. A variation, in which an internal mirror drum with many facets is used instead of a glass prism, is usable up to about 40,000 frames per second. In evaluating the performance of the system, the size of the frames and sharpness of the images must be considered, as well as the number of frames per second.

Rotating-mirror systems

Rotating-mirror systems take a number of forms, but Figure 8 shows a reasonably typical arrangement. The objective lens forms a primary image at the rotating-mirror position. The mirror reflects this image through an arc of fixed, individual relay lenses in succession on the stationary film. The relay lenses having the primary and final images both in focus keep the final image fixed at each place in succession on the film as the beam traverses each lens. With some rotating-mirror systems it is possible to go to some 5,000,000–10,000,000 frames per second (again keeping in mind that frame size and image sharpness are important as well). The arrangement wastes light, so that bright original subjects are necessary for a satisfactory exposure. The system has been used to study explosions and plasmas and to study subjects by reflected light with very high-intensity illuminants.

The central idea of the image dissector technique is to cut up a picture in the same way that a television picture is cut into horizontal scanning lines. The bright lines are made very narrow, with black or empty spaces between them, which permits superimposing other, similar pictures—also cut into fine lines separated by empty spaces. A number of pictures can be superimposed in this way without the lines interfering with each other. Lenticulations (embossed lenslike shapes) on the film form the scanning lines and concentrate the incoming light into fine lines on the film, according to where the light comes from on the objective lens.

The method will also work with two sets of lenticulations, one horizontal and the other vertical and superposed. This permits the storing of more pictures on the record film—in this case, as dots instead of thin lines. A number of devices based on these general ideas have been used. The frame speeds achievable vary with the specific arrangements but are generally lower than with the moving-mirror mechanisms.

The number of frames in Figure 8 may be increased to infinity by changing the optical system to put the primary image on the film and leaving out the relay lenses or, more simply, to replace the mirror with the film on a rotating drum. This requires compressing the individual frame from a two-dimensional into a one-dimensional image or slit. The equipment becomes a "streak camera." It is useful when there are one or more distinct demarcations in the one-dimensional view of the subject and it is desired to record their motion along a more or less straight line.

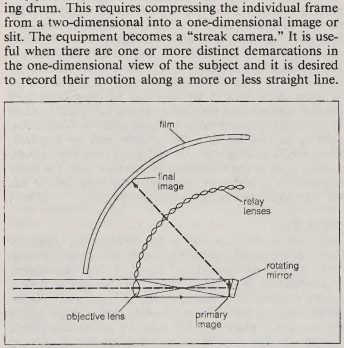


Figure 8: Arrangement of the principal parts of a rotating-mirror system (see text).

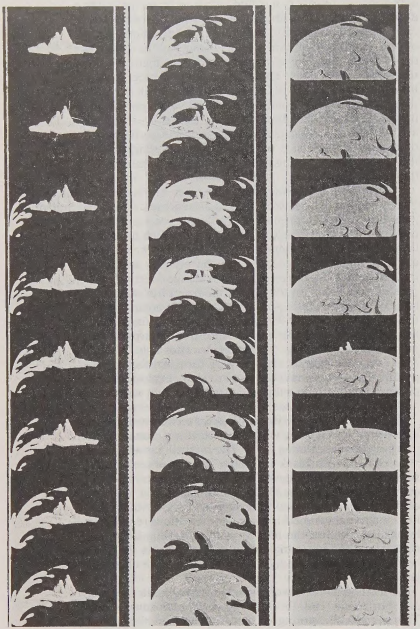


Figure 9: Twenty-four frames, the length of film projected each second, from *If You Could See the Earth*, an educational film. The jagged white line to the right of each frame is the sound track.
EB Inc

This is useful, for example, in recording the motion of the front of an explosion cloud or of a projectile. It leaves no unexplored areas of time, as does a framing record.

Illumination. The need for sufficient light is a most important requirement in high-speed cinematography. This need is so great that it is often undesirable to keep the light on longer than absolutely necessary, so that in many cases the light being turned on and off acts as a shutter. High-intensity, short-time sources have been studied extensively. Most sources consist of electrical discharges or, in some cases, arcs in air or a gas. In most cases they involve sophisticated electronic control methods. In cases in which the original subject is sufficiently self-luminous, such as in explosions, a fast shutter may be required. Since mechanical shutters do not go to very high speeds, various types of electro-optical shutters are used. On some occasions it is necessary to amplify the light after it has left the subject and before it reaches the film. (P.Me.)

ANIMATION

The basis of all animation is the building up, frame by frame, of the moving picture by exact timing and choreography of both movement and sound. All film movement is achieved by projecting during every second of time a certain number of frames, normally 24, each a still photograph minutely varied from its predecessor, which record the successive phases of the subject's movement before the camera. The same motion, or a stylized or caricatured version of it, can be achieved by "stop-motion" or "stop-action" cinematography, the frame-by-frame photographing of a similarly phased series of drawings (see Figure 9) or the phased movement of such objects as puppets, marionettes, or commercial products. And, as in live filming, the camera itself can create movement by tracking into a scene or panning across it. The great majority of animated films are short and have always been so for obvious reasons. When each second of action requires, for the fullest animation, 24 adjustments of the image, a minute's action may call for many hundreds of drawings.

The range of techniques in animation production is broad. The basic form is the simple, outlined figure, however, that moves against a simple, outlined background.

Figural basis of animation. The development of cel (or cell) animation permitted the phased movements of the figures to be traced onto a succession of transparent celluloid sheets and superimposed, in turn, onto a single static drawing representing the background. With this technique the background could be drawn in somewhat greater detail and tonal qualities introduced through shading, while the figure itself became a black silhouette, blotting out the background when the cels were superimposed. Multiple cel animation—the superimposition of several cel layers, each carrying different figures or parts of figures requiring special care in animation—allowed increased complexity in the image with minimum work load for the artist-animators. With the more modern forms of colour film introduced in the early 1930s, opaque paints and coloured inks could be used on the cels. Cel animation required the use of a so-called rostrum camera, which photographs downward onto the background with its series of superimposed cel layers pegged into place to secure accurate registration.

Cel animation

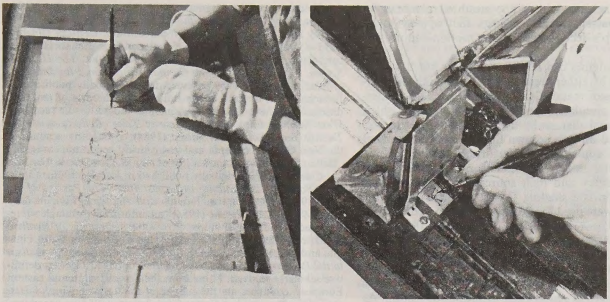
Noncellular animation. Other forms of animation include silhouette animation, developed by Lotte Reiniger in Germany during the 1920s. It uses jointed, flat-figure marionettes whose poses are minutely readjusted for each photographic frame. Movement is similarly simulated in puppet animation, which photographs solid three-dimensional figures in miniature sets. The puppets are often made of a malleable yet stable material, such as clay, so that the carefully phased movements may be adjusted between the exposures of successive frames. Even people may be photographed frame by frame, as in the so-called pixilation process used by the Canadian filmmaker Norman McLaren in his short film *Neighbors* (1952), which makes human beings look like automatons.

Although abstract animation can be realized through orthodox animation techniques (as in parts of *Fantasia*, 1940), it may also be inked or painted directly onto the film. This form of abstract animation was pioneered in the 1920s with the individual and collaborative work of the German Hans Richter and the Swede Viking Eggeling and continued in the 1930s with the films of Len Lye, a New Zealander also known for his abstract sculpture. McLaren, too, experimented with a wide range of techniques for animating directly on film; he even created many of his scores by stenciling directly onto the sound track rather than recording in the traditional manner. Since the 1970s, computers have often been used to generate abstract or stylized patterns, and means were developed to circumvent photography by transferring the results directly to 35 mm.

Abstract animation

Planning. The preparation of these films, whatever their length or form, follows a similar process. First comes the story, plot, action, or situational idea, which may be a written treatment with or without supporting sketches. It describes the continuity of what it is proposed should take place on the screen, the nature of the cartoon or puppet characters, the graphic stylization of the film as a whole, and similar considerations. Such a treatment, perhaps very brief, precedes any fuller scripting or other elaboration that may take place.

Since visual emphasis is the key to animation, and sound its close counterpart, the sooner ideas are translated into pictures the better. The "storyboard" provides the continuity of the action, which is worked out scene by scene simultaneously with the animation script. In the storyboard the story is told and to some extent graphically styled in a succession of key sketches with captions and fragments of dialogue, much like a cartoon strip but with much



Techniques of animation art.
(Left) Artist drawing onto a cel that is to be coloured and combined with background to be photographed as one frame; from Halas and Batchelor's *Animal Farm*. (Right) Animator drawing directly onto film.
By courtesy of (right) the National Film Board of Canada; photograph (left), Halas and Batchelor Animation, London

fuller treatment. A feature-length film could easily require a final continuity of several hundred such sketches.

Meanwhile, an animation director is also preparing modeling drawings for the principal characters and drawings establishing the backgrounds, or settings, for the film. These begin to indicate the general graphic style and, when colour is involved, the colour scheme and decor to be used. The modeling drawings must indicate the nature and temperament of the characters as well as their appearance when seen from a variety of angles and using a number of characteristic gestures. These will act as guides for the key animators, who with their assistants must bring the figures to dramatic life through the succession of final drawings created on the drawing board.

Animated films are, in effect, choreographed; since mobility involves time, the movements must be exactly timed and so deployed through the right number of successive drawings, like notes in music deployed through bars in a score. When the characters speak or sing, their lip movements must be synchronized with the words they appear to utter. When sound tracks, both dialogue and music, are prerecorded, the animators have an exact time scheme to follow; if the tracks are not prerecorded, then the "scoring" of the action will control the subsequent timing of the speech and music at recording stage. The timing in either case is predetermined on paper in a workbook, which grades the progression of the animators' drawings frame by frame with the same precision as a musical score. A similar control in the form of a time chart may be created by the director as a guide for the composer. A third control, the so-called dope sheet or camera exposure chart, guides the rostrum cameraman in the frame-by-frame setups and sequence of cels or backgrounds.

Sound synchronization

Execution. When the exacting labour of animation is under way, difficult moments in the choreography of the figures may be "line-tested"—that is, outlined in pencil, photographed, and tested out on the screen for rhythm and characterization. The key, or senior, animators draw, or "cartoon," the highlights, or salients, of the movement, perhaps the five or more drawings out of the 24 per second that will give the special edge of liveliness or characterization to the movements. Assistant animators, sometimes called in-betweeners, close the gaps by completing the intermediate drawings. The smaller the animation unit, the greater the burden each artist has to bear in the preparation of final drawings. These drawings, the backgrounds of which remain on drawing paper, are transferred to the cels by specialized artists, who trace the animators' work and paint over it with opaque colouring. The work of tracing and painting can be saved when the animators draw directly on the cels with coloured chinagraph pencils, which they can rub out or correct without harm. When the picture track and the sound track with speech, sound effects, and music dubbed together are completed under the control of the director and the editor, a "married print" can be made, with the track recorded optically. (R.M./E.We.)

Newer techniques. In the 1950s, animation studios such as Hanna-Barbera sought to lessen the extraordinary labour and costs of animation so that they could quickly produce cartoons for television. To do so, they employed the technique of limited animation, in which each drawing is repeated for two to five frames. The resultant movements are jerky, rather than smoothly gradated, and often only part of a body is animated and the remaining parts of the figure do not change at all. Another shortcut, cycling (reusing the same series of drawings over and over) is maximized in limited animation, especially when characters are walking or talking. Since the early 1980s, however, the use of computers has supplanted limited animation as a cost- and labour-saving method.

Today computers are used in virtually every step of sophisticated animation. Computers have been used, for example, to automate the movement of the rostrum camera or to supply the in-between drawings for full animation. They can also be used to modify or enhance a drawing that has been created by hand. If a three-dimensional figure is translated into computer terms (*i.e.*, digitized), the computer can move or rotate the object convincingly through space. Hence, computer animation can demonstrate highly complex movements for medical or other scientific researchers.

The various techniques used by computer animators range from simple graphics generation (for such effects as a waving flag or a "flying" television show title) to the sophisticated structure animation required for rendering humans or animals in action. The degree to which computers are employed in the making of an animated film depends on the nature of the task. The animator can use the computer to define each individual element of a film, or the computer can generate its own animated effects by assigning programmed behaviour to a given object or to a set of objects, such as a flock of birds in flight.

Computers can render two- or three-dimensional images based on either live-action models or line drawings. The most common method of creating animated images from live-action models is a motion-capture system, in which small reflective or magnetic sensors are attached to an actor's body at key positions (head, hands, feet, and most of the joints). The actor undergoes the series of movements to be performed by his computer-generated image in the finished film, and the markers feed a stream of data to a host computer, which in turn constructs a three-dimensional image based on the position and orientation of each marker. Such techniques were employed in the motion picture *Titanic* (1997) in order to obtain sweeping overhead shots of the title ship that would have been difficult or cost-

prohibitive to achieve with crane-mounted cameras. In these scenes, passengers and officers that appear to be strolling the ship's decks were actually motion-capture animations.

Computer animators can render characters not based on real-life models by either creating and employing an interconnected series of metaballs (software devices for rendering spherical or circular-shaped objects) and splines (which interconnect metaballs), or by using the computer to create images based on hand-drawn line art or mathematical models. In both approaches, the algorithm that creates the three-dimensional image also considers such matters as background scenery and light sources in order to determine the appropriate shading for the finished rendering. Such methods were used for the popular animated features *Toy Story* (1995), *A Bug's Life* (1998), *Antz* (1998), and *Toy Story 2* (1999).

Although traditional cel animation and keyframing were still being employed at the turn of the 21st century, they were increasingly replaced or aided by computer programs based on principles of physics and dynamic simulation. As the field expands to incorporate such innovations as synthetic actors capable of real-time interaction with humans, it would appear that computers offer animators heretofore unimaginable possibilities. (R.M./E.We./Ed.)

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Human Motivation

Motivation in human psychology is the term used to describe forces acting either on or within a person to initiate behaviour. The word motivation is derived from the Latin term *motivus* ("a moving cause"), which suggests the activating properties of the processes involved in psychological motivation. Psychologists study motivational forces to help explain observed changes in behaviour that occur in an individual. Thus, for example, the observation that a person is increasingly likely to open the refrigerator door to look for food as the number of hours since the last meal increases can be understood by invoking the concept of motivation. As the above example suggests, motivation is not typically measured directly but rather inferred as the result of behavioral changes in reaction to internal or external stimuli. It is also important to understand that motivation is primarily a performance variable. That is, the effects of changes in motivation are often temporary. An individual, highly motivated to perform a particular task because of a motivational change, may later show little interest for that task as a result of further change in motivation.

Motives are often categorized into primary, or basic, motives, which are unlearned and common to both animals and humans; and secondary, or learned, motives, which can differ from animal to animal and person to person. Primary motives are thought to include hunger, thirst, sex, avoidance of pain, and perhaps aggression and fear. Secondary motives typically studied in humans include achievement, power motivation, and numerous other specialized motives.

Unlearned and learned motives

Motives have also sometimes been classified into "pushes" and "pulls." Push motives concern internal changes that have the effect of triggering specific motive states. Pull motives represent external goals that influence one's behaviour toward them. Most motivational situations are in reality a combination of push and pull conditions. For example, hunger, in part, may be signaled by internal changes in blood glucose or fat stores, but motivation to eat is also heavily influenced by what foods are available. Some foods are more desirable than others and exert an influence on our behaviour toward them. Behaviour is, thus, often a complex blend of internal pushes and external pulls.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, section 433, and the *Index*.

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The study of motivation

PHYSIOLOGICAL, PSYCHOLOGICAL, AND PHILOSOPHICAL APPROACHES

Motivation has been studied in a variety of ways. For instance, it has been analyzed at the physiological level using electrical and chemical stimulation of the brain, the recording of electrical brain-wave activity with the electroencephalograph, and lesion techniques, where a portion of the brain (usually of a laboratory animal) is destroyed and subsequent changes in motivation are noted. Physiological studies performed primarily on animals other than humans have demonstrated the importance of certain brain structures in the control of basic motives such as hunger, thirst, sex, aggression, and fear.

Motivation may also be analyzed at the individual psychological level. Such analyses attempt to understand why people act in particular ways and seek to draw general conclusions from individual cases. Through studies of individuals, for example, it has been found that both men and women proceed through a series of identifiable stages of arousal during behaviours leading to and culminating in sexual intercourse. The finding may be applied to people in general.

Motivation of an individual is also influenced by the presence of other people. Social psychologists have been active in discovering how the presence of others in a given situation influences motivation. For example, students and teachers behave in predictable ways in the classroom. Those behaviours are often quite different, however, from the way students and teachers behave outside the classroom. Studies of conformity, obedience, and helping behaviours (which benefit others without reward) are three areas in this field that have received considerable attention.

Finally, motivation is sometimes also approached from a more philosophical direction. That is, analyses of motivation are understood, at least in part, by examining the particular philosophical point of view espoused by the theorist. For example, some motivational theorists conceive motivation to be an aversive state: one to be avoided. Sigmund Freud's view of motivational processes could be applied within this framework; his contention that blocked sexual energy could be displaced into acceptable behaviours implies that accumulation of sexual energy (motivation) is aversive. Other theorists see motivation as a much more positive experience. That is, motivation can produce behaviours that lead to increases in future motivation. The American psychologist Abraham H. Maslow's concept of self-actualization could be applied within this framework (see below).

Aversive and positive views

DEBATES IN MOTIVATIONAL STUDY

The nomothetic versus ideographic approach. However motivation is studied, certain fundamental debates have typified the positions taken by researchers. One such debate concerns the question of whether it is better to study groups of individuals and attempt to draw general conclusions (termed the nomothetic approach) or to study the behaviours that make individuals unique (termed the ideographic approach). Although both approaches have added to the understanding of motivational processes, the nomothetic approach has dominated motivational research.

Innate versus acquired processes. A second debate among theorists concerns the degree to which motivational processes are innate (genetically programmed) versus acquired (learned). Since the 1890s this debate has swung from one extreme to the other and then back toward the middle. Early approaches viewed motivation as largely or entirely instinctive. When the instinctive approach fell into disfavour during the 1920s, the idea that all behaviours were learned largely replaced the instinctive approach. By the 1960s, and continuing to the present, research indicated that the answer to the debate is that both positions are correct. Some motives, in some species, do appear to be largely innate, as, for example, in the courting behaviour of the three-spined stickleback, a small fish of the Northern Hemisphere (see below). Other motives, such as achievement motivation, seem more closely associated with learning. Some motive states, such as extreme shyness, seem to result from an innate predisposition coupled with a particular environment where learning interacts with the predisposition.

Internal needs versus external goals. Another dimension along which debates concerning motivational processes have flourished is the question of whether motivation is primarily the result of internal needs or external goals. As noted earlier, this dimension describes differences between push and pull motives. Research suggests that some motive states are best classified as internal (push motives) while other motive states develop from goals external to the individual (pull motives). Many real-life situations are undoubtedly a combination of both internal and external motives.

Mechanistic versus cognitive processes. Finally, researchers have tended to view motivational processes as either mechanistic or cognitive. The first of these assumes that motivational processes are automatic; that is, the organism, human or otherwise, need not understand what it is doing in order for the processes to work. This point of view has achieved considerable popularity. Neither conscious awareness nor intent is assumed to be operative in the mechanistic approach. Researchers taking the mechanistic point of view are often interested in studying internal need states and genetically programmed behaviours. The second and newer approach, promoted by researchers more often interested in external and acquired motives, has emphasized the importance of cognition in motivational processes. The cognitive approach assumes that the way in which one interprets information influences motives. Cognitive motivational approaches assume that the active processing of information has important influences on future motivation. Given the complexity of motivational processes, most theorists feel safe in assuming that some motive states are relatively mechanistic while others are more cognitive.

The mechanistic approach

Historical overview

PHILOSOPHERS' CONTRIBUTIONS

The history of motivational thought reflects the considerable influence of philosophers and physiologists. For example, the concept of free will as proposed by Aristotle and others was a widely accepted philosophical position until it was generally rejected in favour of determinism. Determinism, as the term is used by psychologists, holds that every behaviour has some antecedent cause. One antecedent to which particular behaviours are often attributed is motivation. Thus, if one sees a woman hurriedly eating a sandwich while continually glancing at her watch, one might infer that she is late for an appointment rather than that she is ravenously hungry. Regardless of the eventual explanation that would allow us to understand her behaviour, we do not assume that she is behaving randomly. Rather, we assume some motive is causing her to behave as she does.

Descartes's mind-body dualism

Aristotle's belief that the mind is at birth a blank slate upon which experience writes was the basis for studying the effects of learning on behaviour. The 17th-century philosopher René Descartes proposed the concept of mind-body dualism, which implied that human behaviour could be understood as resulting from both a free, rational soul and from automatic, nonrational processes of the body. His proposition that nonrational, mechanistic processes of the body could motivate behaviour under some circumstances led to the development of the concept of instinct and provided a counterpoint to Aristotle's emphasis on learning as the most important concept in the control of behaviour. Today, the mechanistic component of Descartes's dualism can be seen as the distant forerunner of the study of genetic components of motivation, while his other view of rational choices can be regarded as a precursor of modern cognitive approaches to motivation.

British empiricist philosophers, as exemplified by John Locke, also contributed to the development of modern motivational theory. Locke's emphasis on the importance of sensory experience can be understood as underlying the modern focus on external stimulation as motivating. Many psychologists believe that goals become valuable to us because of the sensory experience associated with these goals. Thus, for example, the motivating properties that cause a person to drive across the city to eat a particular food are thought to result from the desirable taste, smell, and perhaps texture of the food itself. If the food tasted and smelled like cardboard, it would not motivate future trips across the city to obtain it. Locke also provided the important concept of association. As proposed by Locke, one idea can become associated, or linked, to another to produce a new, more complex idea. The concept of association provides an explanation for how nonmotivating experiences can become motivating. If one pairs a nonmotivating stimulus with a highly motivating object several times, the formerly neutral stimulus begins to motivate behaviour in a fashion similar to the original object. Research has shown that, under some circumstances, phobias and other motives may be acquired through such association. The associative mechanism can serve as an example of Pavlovian classical conditioning. (Ivan P. Pavlov was a Russian scientist who taught dogs to associate food with the sound of a bell; the dogs learned to salivate at the sound of a bell, demonstrating what has been termed a conditioned response.) Perhaps the most commonly associated stimulus in Western society that is recognized for its strong motivational properties is money. Because money is paired with many strong motivators, it often becomes strongly motivating itself.

PHYSIOLOGISTS' CONTRIBUTIONS

Motivational research has also progressed through discoveries made in the field of physiology. The discovery of separate nerve fibers for sensory and motor information first suspected by the Greek physician Galen and separately confirmed by the English anatomist Sir Charles Bell in 1811 and the French physiologist François Magendie in 1822 led naturally to the development of the stimulus-response approach to motivation, which has become fundamental to the field.

Galvani's and Du Bois-Reymond's experiments

The discovery of the electrical nature of the nerve impulse, first suggested by the Italian physician and physicist Luigi Galvani's experiments in the 1770s and '80s with frogs and later directly measured by the German physiologist Emil Du Bois-Reymond in 1848–49 using a galvanometer, showed that nerves are not canals by which animal spirits flow through the body, as had been commonly thought, but are rather the conveyors of signals sent from one area of the body to another. The German psychologist Georg E. Müller added the concept of specific nerve energies, which proposed that the electrical signals passing along the nerves were specific, coded messages, while the German scientist Hermann von Helmholtz measured the speed of

the nerve impulse and found it to be about 100 miles (160 kilometres) per hour. These discoveries made it clear that the nervous system could be studied and paved the way for examination of its role in the motivation of behaviour.

Studies of the localization of function within the nervous system, especially the brain, derived at least in part from the phrenology of the German physician Franz Josef Gall during the early 1800s. Although phrenology has been thoroughly discredited, it indirectly contributed to the localization of motivational systems within such brain areas as the hypothalamus.

BEHAVIOURISM

The contributions from philosophical and physiological sources have generated several stages of evolution in motivational theory since the late 19th century. In the 1800s Descartes' dualism was often used to distinguish between animal and human motivation. By the end of the 19th century, behavioral theorists such as the American psychologists William James and William McDougall had begun to emphasize the instinctive component of human behaviour and to de-emphasize, and in some cases eliminate from discussion, the more mentalistic concept of will. Other behaviourists, as exemplified by the American psychologist John B. Watson, rejected theories of both instinct and will and emphasized the importance of learning in behaviour. This group conceived behaviour to be a reaction or response (R) to changes in environmental stimulation (S); their S-R psychology subsequently gained popularity, becoming the basis for the school of behaviourism. By the 1920s, the concept of instinct as proposed by theorists such as James and McDougall had been roundly criticized and fell into disrepute. Behaviourism dominated the thinking of motivational theorists and a new motivational concept, drive, congenial to behaviourism's S-R approach, was born. Drive, initially proposed by the American psychologist Robert S. Woodworth, was developed most fully by Clark Hull, an American psychologist who conceived motivation to result from changed internal bodily needs, which were in turn satisfied by obtaining specific items from the environment. Thus, hunger motivation was thought to occur as a result of a changed internal need for energy that motivated food-seeking behaviour in the environment.

Decline of the instinct concept

Behaviourism dominated motivational research until the 1960s, but even in the 1920s and '30s dissenting voices were heard. Researchers such as the American psychologist Edward C. Tolman and the German psychologist Wolfgang Köhler argued for the existence of a more active processing of information in both humans and animals and rejected the mechanistic S-R psychology. These early cognitive psychologists opened the way for other researchers to examine motivation resulting from the expectation of future events, choices among alternatives, and attributions concerning outcomes. In other words, with the advent of cognitive explanations of motivated behaviour, it became possible to argue that behaviours were sometimes purposive. The cognitive approach has proved useful in the analysis of several types of motivation, among them achievement behaviour, dissonance motivation, and self-actualization (see below).

Changing perspectives and research on motivation have led away from large, all-encompassing theories of motivation to smaller, discrete theories that explain specific motives or specific aspects of motivation under particular conditions. These microtheories of motivation are conveniently categorized as falling within three major areas: biological, behavioristic, and cognitive explanations.

Biological approaches to motivation

The biological microtheories of motivation can be divided into three categories: genetic contributions to motivated behaviour, arousal mechanisms, and biological monitoring systems.

GENETIC CONTRIBUTIONS

As indicated above, the idea that some motivated behaviours are the result of innate programs manifested in the nervous system had been proposed by James and McDougall in the late 1800s and early 1900s. These early instinct approaches fell into disfavour during the 1920s because of their proponents' inability to discriminate between instinctive and learned behaviours and because of the realization that labeling an observed behaviour as instinctive did not explain why the behaviour occurred. In Europe, however, a group of biologists interested in the evolutionary significance of animal behaviours kept the concept alive and continued to study the genetic basis of behaviour. Three of these researchers (the Austrians Karl von Frisch and Konrad Lorenz and the Netherlander Nikolaas Tinbergen) were awarded a Nobel Prize in 1973 for their work on the subject. They were early entrants in the field of study known as ethology, which studies the behaviour patterns of animals in their natural habitat. Ethologists argue that the evolutionary significance of a particular behaviour can best be understood after a taxonomy of behaviours for that species has been developed as a result of observation in nature. They propose further that the significance of a behaviour is often clearer when observed in the context of other behaviours of that animal. Ethologists use naturalistic observation and field studies as their most common techniques.

Ethology

The research conducted by the ethologists showed that some behaviours of some animal species were released in an automatic and mechanical fashion when conditions were appropriate. These behaviours, known as fixed-action patterns, have several salient characteristics: they are specific to the species under study, occur in a highly similar fashion from one occurrence to the next, and do not appear to be appreciably altered by experience. Furthermore, the stimulus that releases these genetically programmed behaviours is usually highly specific, such as a particular colour, shape, or sound. Such stimuli are termed key stimuli or sign stimuli and when provided by a conspecific organism (a member of the same species) are known as social releasers.

One thoroughly researched example of this type of genetically programmed behaviour is the courtship behaviour of the three-spined stickleback, a small fish. During the reproductive season, male sticklebacks become territorial and defend a portion of the streambed against other intruding stickleback males. Ethological analysis of this aggressive behaviour reveals that it is a series of fixed-action patterns released by the reddish coloration of the ventral (under) surface of the intruding males. A female stickleback entering the territory is not attacked because she does not possess the red coloration. Instead she is courted through a complex series of movements termed the zigzag dance. This behaviour pattern performed by the male stickleback is released by the shape of the ventral surface of the female, which is distended as a result of the eggs she carries. (See BEHAVIOUR, ANIMAL: *Nature and patterns of animal behaviour: Components of behaviour: Movement*).

Although the largest number of studies conducted by ethologists has been on nonhuman animals, some ethological researchers have applied the same kinds of analyses to human behaviour. Prominent among these is the Austrian ethologist Irenäus Eibl-Eibesfeldt. In a book entitled *Love and Hate: The Natural History of Behavior Patterns,* he summarized many years of cross-cultural research on human genetic behaviour patterns. Interestingly, research on the facial expressions associated with emotion has provided some support for the existence of innate motivations in humans.

MOTIVATION AS AROUSAL

The James-Lange theory. A second biological approach to the study of human motivation has been the study of mechanisms that change the arousal level of the organism. Early research on this topic emphasized the essential equivalency of changes in arousal, changes in emotion, and changes in motivation. It was proposed that emotional expressions and the motivation of behaviour are the observable manifestations of changes in arousal level. One of the earliest arousal theories suggested that one's perception of emotion depends upon the bodily responses

Study of the arousal level

the individual makes to a specific, arousing situation. This theory became known as the James-Lange theory of emotion after the two researchers, William James and the Danish physician Carl Lange, who independently proposed it in 1884 and 1885 respectively. The theory argued, for example, that experiencing a dangerous event such as an automobile accident leads to bodily changes such as increased breathing and heart rate, increased adrenaline output, and so forth. These changes are detected by the brain and the emotion appropriate to the situation is experienced. In the example of the automobile accident, fear might be experienced as a result of these bodily changes.

The Cannon-Bard theory. Walter B. Cannon, a Harvard physiologist, questioned the James-Lange theory on the basis of a number of observations; he noted that the feedback from bodily changes can be eliminated without eliminating emotion; that the bodily changes associated with many quite different emotional states are similar, making it unlikely that these changes serve to produce particular emotions; that the organs supposedly providing the feedback to the brain concerning these bodily changes are not very sensitive; and that these bodily changes occur too slowly to account for experienced emotions.

Cannon and a colleague, Philip Bard, proposed an alternative arousal theory, subsequently known as the Cannon-Bard theory. According to this approach, the experience of an event, such as the automobile accident mentioned earlier, leads to the simultaneous determination of emotion and changes to the body. The brain, upon receiving information from the senses, interprets an event as emotional while at the same time preparing the body to deal with the new situation. Thus, emotional responses and changes in the body are proposed to be preparations for dealing with a potentially dangerous emergency situation.

The cognitive-physiological theory

The Schachter-Singer model. In 1962 the American psychologists Stanley Schachter and Jerome Singer performed an experiment that suggested to them that elements of both the James-Lange and Cannon-Bard theories are factors in the experience of emotion. Their cognitive-physiological theory of emotion proposed that both bodily changes and a cognitive label are needed to experience emotion completely. The bodily changes are assumed to occur as a result of situations that are experienced, while the cognitive label is considered to be the interpretation the brain makes about those experiences. According to this view, one experiences anger as a result of perceiving the bodily changes (increased heart rate and breathing, adrenaline production, and so forth) and interpreting the situation as one in which anger is appropriate or would be expected. The Schachter-Singer model of emotional arousal has proved to be popular although the evidence for it remains modest. Other researchers have suggested that bodily changes are unnecessary for the experience of emotional arousal and that the cognitive label alone is sufficient.

The inverted-U function. The relationship between changes in arousal and motivation is often expressed as an inverted-U function (also known as the Yerkes-Dodson law). The basic concept is that, as arousal level increases, performance improves, but only to a point, beyond which increases in arousal lead to a deterioration in performance. Thus some arousal is thought to be necessary for efficient performance, but too much arousal leads to anxiety or stress, which degrades performance.

The search for a biological mechanism capable of altering the arousal level of an individual led to the discovery of a group of neurons (nerve cells) in the brain stem named the reticular activating system, or reticular formation. These cells, which are found along the center of the brain stem, run from the medulla to the thalamus and are responsible for changes in arousal that move a person from sleeping to waking. They are also believed to function in relation to an individual's attention factor.

Sleep processes and stress reactions. Research on arousal mechanisms of motivation has furthered understanding of both sleep processes and stress reactions. In the case of sleep, arousal levels generally seem lower than during waking; however, during one stage of sleep arousal levels appear highly similar to those in the waking state. Sleep itself may be considered a motivational state. The biological motivation to sleep can become so overpowering that individuals can fall asleep while driving an automobile or while engaged in dangerous tasks.

Five stages of sleep have been defined using the electroencephalograph (EEG). The EEG records the electrical activity of neurons in the outermost portion of the brain known as the cerebral cortex.

The five stages of sleep

According to EEG-based findings, everyone cycles through five stages during sleep. A complete cycle averages approximately 90 minutes. The two most interesting stages of sleep from a motivational point of view are stages 4 and 5. Stage 4 represents the deepest sleep in that the brain-wave activity as measured by the EEG is farthest from the activity seen when a person is awake. The brain-wave pattern is characterized by delta waves, which are large, irregular, and slow; breathing, heart rate, and blood pressure are also reduced. Because the overall activity of the individual in stage 4 is greatly reduced, it has been suggested by some researchers that stage 4 (and perhaps also stage 3) sleep serves a restorative function. However, a potential problem with such an explanation is that stage 4 sleep drops dramatically after age 30 and may be entirely absent in some people aged 50 or over who nevertheless appear to be perfectly healthy. Additionally, studies have shown that in the typical individual physical exhaustion does not lead to increases in stage 4 sleep as might be expected if it were serving a restorative function. The purpose of stage 4 sleep remains unknown.

Stage 5 sleep is also known as rapid eye movement (REM) sleep because during this stage the eyes begin to move rapidly under the eyelids. Interest in stage 5 sleep has been considerable since it was discovered that most, if not all, dreaming occurs during this stage. During stage 5 sleep the EEG pattern of brain-wave activity appears very similar to the brain-wave activity of an awake, alert person. Breathing, heart rate, and blood pressure rise from the low levels observed during stage 4 and can fluctuate rapidly. In addition to eye movements, fast, small, and irregular brain waves, and autonomic changes indicative of an aroused state, individuals in stage 5 sleep display a large loss in skeletal muscle tone that amounts to a temporary paralysis. Researchers have suggested that the muscle paralysis prevents the "acting out" of our dreams.

Another aspect of arousal processes concerns the high levels of arousal leading to a triggering of the stress reaction. The stress reaction can be triggered by a challenge to the physical integrity of the body, or it can occur as a result of some psychological challenge. Furthermore, the body appears to react in a similar fashion regardless of whether the demands made upon it are physical or psychological. Hans Selye, a Viennese-born Canadian medical researcher, showed that stressors trigger a chain of processes that begins with what is called the alarm reaction, may proceed to a second stage called the stage of resistance, and, if the stressor has still not been removed, may lead to a final stage called exhaustion.

The three stages of stress reaction

The alarm reaction occurs when a stressor is first detected and activates a brain structure called the hypothalamus. The hypothalamus, in turn, stimulates the sympathetic nervous system and also produces a substance called corticotropin-releasing hormone that activates the pituitary to produce adrenocorticotropic hormone (ACTH). Both ACTH and activation of the sympathetic nervous system stimulate the adrenal glands. ACTH stimulates the adrenals to produce hydrocortisone, or cortisol, an anti-inflammatory substance, while the sympathetic nervous system stimulates the centre portion of the adrenals to produce epinephrine and norepinephrine (adrenaline and noradrenaline). All these hormones are secreted into the bloodstream and have the effect of mobilizing the body to deal with the stressor. This initial mobilization is a whole-body response and leads to increases in heart rate, blood pressure, and respiration and other responses associated with high arousal. The person so aroused is, in effect, in a high state of readiness. The alarm reaction often succeeds in changing the situation so that the stressor is no longer present, as would be the case, for example, if one were to run away from a physical threat.

In the second stage, the stage of resistance, localized responses within appropriate areas of the body replace the whole-body response of the alarm reaction, and blood levels of hydrocortisone, epinephrine, and norepinephrine return to just slightly above normal levels. During this stage the ability to fight off the stressor is high and may remain so for considerable periods of time.

If these localized responses to a stressor prove to be inadequate, eventually the third stage of stress, that of exhaustion, will be triggered, during which hormonal levels rise once more and the whole body becomes mobilized again. Selye proposed that if the stressor is not quickly defeated during this last stage, the individual can become withdrawn, maladjusted, and even die.

This three-part mechanism for coping with a stressor is called the general adaptation syndrome and appears to have evolved primarily to deal with systemic stressors. As noted earlier, however, this same set of processes is also triggered by psychological stressors and is often inappropriate to the situation. For example, the stress of an important upcoming test can trigger the alarm reaction, yet it is not apparent how increased levels of hydrocortisone, epinephrine, and norepinephrine would facilitate removing the stress-provoking test. It has been suggested that overstimulation of the stress response, in which psychological stressors produce physical changes in the body, can lead to psychosomatic illness. When the stress response, especially the alarm reaction, is triggered too often, it can lead to physical deterioration.

The relationship between stress and illness has been investigated most thoroughly in regard to the effect life changes have on the likelihood of subsequent illness. The pioneer in the field was Adolph Meyer, a Swiss-born American psychiatrist. Several life-change scales have been developed that measure the number and severity of various life changes, such as the death of a spouse, divorce, retirement, change in living conditions, and so forth. High scores on these scales have been found to be consistently associated with an increased probability of future illness, although the relationship is not especially strong. Presumably the life changes lead to increased stress, which in turn promotes an increased likelihood of illness.

The Meyer scale of life-change stress

Some research has also been conducted on the ways in which the negative effects of stressors can be reduced. A personality characteristic called hardiness has been associated with the ability to better withstand the effects of stress. People who score high in hardiness appear to have high levels of commitment toward the things they do, a strong need to control the events around them, and a willingness to accept challenges. These characteristics may serve to protect individuals from the effects of stress related to major life changes. Exercise, especially in conjunction with hardiness, was reported to relieve stress stemming from physiological and psychological causes. Other factors unrelated to hardiness, such as social support from others, optimism, and humour in the face of difficulty, also have been reported to reduce the stressful effects of life changes.

BIOLOGICAL MONITORING SYSTEMS

For some basic motives such as hunger, thirst, and sex, a biological approach emphasizing regulatory mechanisms has dominated the thinking of researchers. The fundamental premise has been that such basic motives are homeostatically regulated—that is, the nervous system monitors levels of energy, fluid balance, and hormone production (in the case of sex) and alters motivation when these levels deviate too far from some optimum level.

Hunger. The question of why we eat when we do appears to involve two separate mechanisms. The first mechanism, typically called short-term regulation, attempts to take in sufficient energy to balance what is being expended. It is usually assumed that time between meals and meal size are determined by this short-term mechanism. A second mechanism, called long-term regulation, is directed toward storing away sufficient energy for possible later use should the short-term mechanism fail to adequately replenish energy expended. Energy for long-term use is stored in the form of fat within the fat cells of the body. Short-term regulation processes have generally been assumed to monitor the blood glucose (blood sugar) level and to initiate eating when this level falls below some predetermined optimum. Long-term regulation processes appear to monitor fat levels and to initiate eating when fat stores fall below some optimal level.

Explanations of short-term regulation of hunger motivation have revolved around two basic ideas. The earlier of these two, known as the local theory of hunger, suggested that the hunger signals that initiate eating originate in the gastrointestinal tract, specifically the stomach. Hunger pangs were thought to be the result of stomach contractions. Considerable research has shown that such an analysis is inadequate to explain hunger motivation. For example, it is known that much of the stomach can be removed without the loss of hunger motivation. Similarly, it is known that severing the vagus nerve, which causes stomach contractions to cease, does not eliminate the experience of hunger.

The local theory of hunger

When it became apparent that the local theory of hunger was incomplete, researchers began to look for the hunger-initiating mechanism in the brain. It was quickly discovered that the hypothalamus, a small structure lying below the thalamus of the brain, is involved in the regulation of eating. Damage to the ventromedial (lower, middle) area of the hypothalamus produces a condition known as hyperphagia, in which animals overeat and gain enormous amounts of weight. Damage to a different area known as the lateral hypothalamus (located on the sides of the hypothalamus) produces a total lack of eating known as aphagia, as well as a lack of drinking, or adipsia. It was assumed that these two areas share in the control of hunger motivation by activating and deactivating hunger as glucose levels within the blood change. It was further assumed that the specialized cells (glucoreceptors) monitoring the levels of blood glucose reside in these two hypothalamic areas. This belief was weakened, however, when these glucoreceptors could not definitely be located in the brain. Additional research suggests that such glucoreceptors may reside in the liver, where new arrivals of glucose are first received and whence signals about glucose content are sent to these hypothalamic areas.

Less is known about the long-term regulation of hunger motivation, but one suggestion has been that there exists in each individual a genetically programmed body-weight set point that determines how much energy is stored away as fat within the fat cells. According to this theory, hunger motivation would serve to keep individuals close to this set point, even though the fat level maintained may not be what the individual desires nor what society dictates as beautiful or healthy. Such a system would help to explain why weight loss is so hard to maintain in many persons.

Theory of long-term hunger regulation

Thirst. Processes similar to the physiological control mechanisms of hunger are thought to regulate thirst motivation and sexual behaviour. In the case of thirst, the desire to drink appears to be initiated by fluid loss from within specialized brain cells known as osmoreceptors and also from fluid loss from the area outside of cells, such as from bleeding. Thirst, therefore, would seem to be triggered by mechanisms controlling the fluid integrity both within and around the cells of the body. Cells within the hypothalamus also seem to be involved in the control of thirst motivation.

Sexual motivation. In most animals sexual motivation is under stricter hormonal control than is the case in humans. The female of most species is not interested in sexual behaviour until cyclic hormonal changes produce estrus. The male, however, is usually sexually ready but is prevented from engaging in sexual behaviour by the female until estrus occurs. Research indicates that the anterior (front) portion of the hypothalamus is involved with the estrous cycle of female mammals; it has been demonstrated that destruction of these hypothalamus cells eliminates estrus. Similarly, destruction of the anterior region of the hypothalamus reduces or eliminates sexual behaviour in male rats. Since hormone replacement therapy in both males and females is ineffective in reestablishing sexual behaviours reduced by anterior hypothalamic damage, it has been suggested that this region contains receptors sensitive to changes in the levels of circulating

sex hormones. Damage to the ventromedial hypothalamus (VMH) also arrests estrus in females and sexual behaviour in males, but hormone replacement therapy successfully restores these functions, suggesting that VMH is involved with the expression of sexual behaviour when hormonal conditions are appropriate.

Behavioristic approaches to motivation

The behavioristic approach examines how motives are learned and how internal drives and external goals interact with learning to produce behaviour. Learning theorists have taken a somewhat more global perspective when studying motivation than researchers using the biological approach. These researchers have regarded motivation as one component out of several that combine to cause behaviour. Thus, for example, one major theory regards learning and motivation as combining multiplicatively to determine behaviour. Among the behavioristic approaches, three concepts are especially prominent: drive, learned motives, and incentives.

DRIVE

Although in many respects Freud's psychoanalytic theory of behaviour was a drive theory, the term drive was first used by Robert S. Woodworth, an American psychologist, in 1918. The concept of drive is closely tied to the concept of homeostasis. It was assumed that drive would be triggered when internal conditions changed enough to be detected and to initiate the motivational changes that amounted to drive. Thus it was assumed that some tissue need within the body would instigate drive, which would, in turn, instigate behaviours aimed at reducing the drive. According to this sort of analysis, energy depletion would lead to a hunger drive, which would in turn lead to food-seeking behaviours. Drive, then, would serve to energize appropriate behaviours, either innate or learned, which would effect a lowering of the need state of the individual.

Woodworth's early concept of drive theory

The most extensive theoretical model of drive was developed by Clark Hull in the 1940s. Hull argued that drive is general in nature and that various motives such as hunger, thirst, or sex may add to the overall drive level of an individual. Since drive was regarded as the instigator of behaviour, increases in drive level were expected to lead to increases in activity. According to Hull's model, drive is directed by what he termed drive stimuli. These internal stimuli were thought to be different for different motives and to direct the activity of an individual in ways appropriate for the particular motive state present. Thus, for example, a hungry person might go to the refrigerator seeking food because drive stimuli linked with hunger had been associated with responses of obtaining food from the refrigerator in the past.

Finally, Hull suggested that learning itself depends upon adequate drive. Responses were thought to be strengthened when followed by drive or drive-stimulus reduction. If drive or drive stimuli were not reduced, then learning would not occur.

Assessment of Hull's drive theory

Hull's drive theory generated a tremendous body of research, but the model of motivation he evolved was not more effective than others in explaining behaviour. For example, studies showed that increases in activity that occur when subjects are deprived depend largely on the species of the subject and the manner in which the activity is tested. Some species do not become more active when deprived, and changes in activity that are apparent when one type of apparatus is used (*e.g.*, a running wheel) are not seen when other types of apparatus (*e.g.*, a stabilimeter cage—for measuring caged animal activity) are used. Furthermore, drive stimuli, the proposed directional mechanism in Hull's model, have proved to be very elusive, and it is not clear that under normal circumstances their presence, if they exist, is crucial to the direction of behaviour. Finally, several studies have shown that learning can occur under circumstances that would seem to preclude any reduction in drive or drive stimuli. Since Hull's model tied learning to a reduction in drive, these studies pose a problem. Although explicit theoretical models of drive have not proved to be any better at explaining motivation than other approaches, the drive concept, in general, would seem to have some validity if only because people often express their subjective feelings of motivation in terms that suggest they are driven. In particular, the drive concept would often seem to apply to feelings associated with human sexual motivation. The drive theory no longer has wide acceptance in the motivational field.

LEARNED MOTIVES

One of the most significant contributions that the learning approach has made to the study of motivation is its emphasis on the ability of individuals to learn new motives. It has been demonstrated that new motives may be acquired as a result of three learning techniques: classical, instrumental, and observational learning.

Classical conditioning. In classical conditioning, also called Pavlovian conditioning, a neutral stimulus gains the ability to elicit a response as a result of being paired with another stimulus that already causes that response. Such learning situations can then lead to changes in motivated behaviour. Pavlov, for example, showed that dogs would develop what appeared to be neurotic behaviour if they were required to make finer and finer discriminations between stimuli in a classical conditioning discrimination experiment. The dogs became motivated to avoid the experiment room, were restless during the experimental session, and sometimes bit the apparatus. The neurosis developed when the dogs were no longer able to discriminate between the two stimuli presented to them. Later researchers have noted that this motivational change may have resulted from a lack of predictability or control on the part of the animal rather than from the classical conditioning process per se.

In 1920 the American psychologists John B. Watson and Rosalie Rayner demonstrated the development of an emotional response in a young boy using classical conditioning techniques. The presentation of a white rat was paired with the striking of a steel bar, which induced fear in the little boy. After only a few pairings, the white rat became capable of inducing fear responses similar to those produced by striking the bar. This early demonstration of learned emotional responses has suggested to psychologists that many human motives may result from the accidental pairing of events. It has been proposed that some fears, phobias, taste aversions, and even eating problems can result from classical conditioning.

Inducement of a fear response through conditioning

Instrumental learning. The second type of learning technique is instrumental learning, or conditioning, also called operant conditioning. In this type of conditioning a response is followed by some consequence which then changes the future probability of that response. For example, instrumental conditioning appears to be one way in which aggressive motivation can be changed. If an aggressive response by one child toward another child is followed by some positive event such as the aggressor getting to play with a desired toy, then the motivation to behave aggressively can be expected to increase in the future. Furthermore, through a process called conditioned reinforcement, neutral stimuli associated with a reinforcer can become reinforcers in their own right. These stimuli can then be used to motivate behaviour. Perhaps the most common example of a conditioned reinforcer is money. A piece of paper with numbers and intricate drawings on it can motivate all sorts of behaviour if that paper has previously been associated with important reinforcers such as food, clothing, sex, and so forth. Money is in effect a token of the things it can buy. Psychologists have used different types of tokens as rewards to implement reinforcement, and token economies, involving the principles of conditioned reinforcement, have been successfully used to alter behaviour in schools, institutions, and hospitals (see below).

Observational learning. In the third type of learning technique, observational learning, or modeling, a new behaviour is learned simply by watching someone else behave. In a very real sense, such learning is the ability to profit from another's successes or mistakes. This type of learning is important because the learning can occur without an individual ever having to perform the behaviour.

Thus, watching another child put a finger in an electrical outlet and get shocked is often enough to keep the observing child from behaving the same way. Similarly, noticing that friends do well in school because they study hard may be a sufficient stimulus to motivate students. Albert Bandura, a Canadian psychologist, has proposed, and provided a wealth of support for, the observational learning of aggression in humans. He has shown that young children will mimic the aggressive responses they see performed by adults. Such aggressive responses can potentially be learned by observation of violent acts on television or in movies or by reading or hearing about violent behaviour. If the observed violent acts are further perceived to lead to desired goals, then the observed aggressive behaviours may be utilized at some future date by the observer.

Learned aggressive responses in children

Research indicates that persons also learn their society's rules of sexual conduct through observation. These sexual values are taught in part by parents, clergy, political leaders, books, movies, and television. Although the learning is often indirect, people nevertheless learn how to express their sexuality. The rules for sexual behaviour in a given culture appear to be learned during adolescence. In monkeys, social isolation impairs sexual functioning. Although isolated monkeys seem to have adequate sexual motivation, the lack of appropriate social skills results in inappropriate behaviours. Thus, learning would appear to be a significant factor in normal sexual behaviour. It is generally thought that certain sexual preferences are also learned, by one technique or another. In one experiment a boot fetish was established in three males by pairing pictures of boots with pictures of nude women (at the conclusion of the experiment the fetish was extinguished). Such a demonstration would seem to indicate that some sexual preferences are learned.

INCENTIVE MOTIVATION

One area within the study of human motivation that has proved fruitful is research on incentives. Incentive motivation is concerned with the way goals influence behaviour. For example, a person might be willing to travel across the city to dine at a special restaurant that served a favourite dish. On the other hand, that same person might not be willing to travel the same distance to eat an ordinary frankfurter. The two meals have different incentive values and motivate behaviour to differing degrees.

It is often assumed that the stimulus characteristics of the goal are what produce the goal's motivating properties. Thus, the taste, smell, and texture of one food would motivate behaviour better than these qualities in another food. Unlike drives, which were thought to be innate, incentives are usually considered to be learned. An individual is not born preferring one goal over another, but rather these preferences develop as new goals are experienced. Incentive motivation is not restricted to goals associated with the primary motives of hunger, thirst, sex, or avoidance of pain. Indeed, one of the most important aspects of this type of motivation is that any goal one seeks can motivate behaviour. For example, the goal of obtaining a high-paying job could serve as a strong motivator for studying hard in school. Goals serving as incentive motivators do not even need to physically exist at the time they activate behaviour, such as might be the case for someone who is motivated to get high grades now in order to eventually get into medical school.

Effect of goal-seeking on behaviour

Theoretical explanations of incentive motivation have ranged from mechanical stimulus-response approaches based on classical conditioning to cognitive approaches emphasizing the learning of expectancies, as discussed in the section below. Several theories have emphasized the role of predictive cues in the development of incentive motivation. Researchers concerned primarily with human motivation have suggested that much of human behaviour can be understood as being directed toward specific goals.

Cognitive motivation

Cognitive theories of motivation assume that behaviour is directed as a result of the active processing and interpretation of information. Motivation is not seen as a mechanical or innate set of processes but as a purposive and persistent set of behaviours based on the information available. Expectations, based on past experiences, serve to direct behaviour toward particular goals.

Important concepts of cognitive motivation theory include expectancy-value theory, attribution theory, cognitive dissonance, self-perception, and self-actualization.

EXPECTANCY-VALUE THEORY

According to expectancy-value theory, behaviour is a function of the expectancies one has and the value of the goal toward which one is working [expressed as $B = f(E \times V)$]. Such an approach predicts that, when more than one behaviour is possible, the behaviour chosen will be the one with the largest combination of expected success and value. Expectancy-value theory has proved useful in the explanation of social behaviours, achievement motivation, and work motivation. Examination of its use in achievement motivation can serve to represent the various types of expectancy-value motivations.

Achievement was initially recognized as an important source of human motivation by the American psychologist Henry Murray in the late 1930s. Although Murray identified achievement motivation as important to the behaviour of many people, it was the American psychologists David McClelland and John Atkinson who devised a way of measuring differences in achievement motivation. These researchers used Murray's Thematic Apperception Test (TAT), a series of ambiguous pictures about which people were asked to write stories (as a determination of personality traits), to measure differences in achievement motivation. Using a technique known as content analysis, the stories were scored for achievement imagery. Based on a substantial body of research, a theoretical model was developed that rested upon the fundamental concepts of expectancy and goal value.

The expectancy-value model of achievement motivation proposes that the overall tendency to achieve in a particular situation depends upon two stable motives—a motive for success and a motive to avoid failure—and the subjective evaluation of the probability of success in the situation. The motive for success is regarded as a relatively stable personality characteristic by the time adulthood is reached. One's motive for success is believed to result from learning in prior achievement situations where the individual has performed successfully. Thus, someone who has, for the most part, had successful experiences in the past is thought to be highly achievement-oriented. The motive to avoid failure is also assumed to be relatively stable by adulthood and represents the compilation of those prior instances where achievement behaviours were unsuccessful. It is argued that someone who has made many unsuccessful attempts in achievement situations will develop a strong motive to avoid failure.

The motive for success

Since almost everyone has experienced both successes and failures during development, the theory assumes that each person has differing degrees of both motivation for success and motivation to avoid failure. These two motivations are opposing tendencies, and as a result the difference in strength between the two will determine whether a given individual is an "achiever" or not. People with high motivation for success and low motivation to avoid failure will be achievement-oriented, while people with strong motivation to avoid failure and weak motivation for success will try to avoid most achievement situations if possible.

The expected probability of success in a particular achievement situation is also important in this achievement theory. The theory predicts that persons highly motivated for success will tend to choose to participate in achievement situations that they judge to be moderately difficult, while the theory also predicts that people highly motivated to avoid failure will tend to choose tasks that they judge to be either very easy or extremely difficult. The choices made by people either highly motivated to achieve success or to avoid failure differ because of the differing value of easy, moderate, and difficult goals for these two types of people. The model mathematically predicts that goals that require moderate effort to achieve will have the greatest value for persons highly motivated

for success. Stated another way, high achievers want to obtain goals that are difficult enough to have some value but not so difficult as to be impossible or so easy as to be worthless. Persons with strong motivation to avoid failure believe they are likely to be unsuccessful. For this reason, the theory predicts that they would prefer easy tasks where success is likely or tasks so difficult that little embarrassment would ensue if they fail.

Attempts to test these predictions have met with mixed results. Some studies have found that people scoring high in motivation for success do often choose tasks that they consider moderately difficult, while other studies have failed to find such results. Also, persons scoring high in motivation to avoid failure do sometimes choose very easy tasks, as the theory predicts, but often do not choose very difficult tasks as also predicted. Clearly much research remains to be done before the model's accuracy in predicting achievement behaviour can be judged.

ATTRIBUTION THEORY

Rejection of the expectancy-value concept

A second major approach to achievement motivation rejects the expectancy-value formulation and analyzes instead the attributions that people make about achievement situations. In general, attribution theory concerns how people make judgments about someone's (or their own) behaviour—that is, the causes to which they attribute behaviour. Considerable research has found that people typically attribute behaviour either to stable personality characteristics, termed dispositions, or to the situations that were present at the time the behaviour occurred.

In regard to achievement behaviour, the attributions of ability, effort, task difficulty, and luck are argued to be especially important in determining future achievement motivation. For example, when a person is successful at a task and attributes that success to ability, that person is likely to approach new achievement situations in the future. Similarly, if the success was attributed to an intense effort, future achievement behaviour would depend upon a willingness to expend such effort in the future. Task difficulty appears to be judged from social norms. If most people are unsuccessful at a task, it is judged to be difficult, and, if most people are successful, the task is judged to be easy. The attribution of success to task difficulty therefore, would be expected to modify future achievement behaviour. If success was judged to be due to the fact that the task was very easy, future achievement behaviour would not be expected to change much; however, success in a task judged to be very difficult might prompt a person to expand the range of tasks he or she is willing to attempt. Ascriptions of luck in an achievement task would also influence future achievement behaviour. Basically, luck is assumed when a person expects to have no control over the outcome in the task. Success attributed to luck is not expected to increase future achievement behaviour much, nor would failure attributed to bad luck be expected to decrease it much.

Locus, stability, and controllability

Research on the attributions people make in achievement-related situations suggests that the four causal ascriptions mentioned above and perhaps other ascriptions as well can best be understood as falling along three dimensions: locus, stability, and controllability. Locus refers to the location, internal or external, of the perceived cause of a success or failure. Ability and effort, for example, are seen as internal dispositions of a person, while task difficulty and luck are situational factors external to the person. Stability refers to how much a given reason for success or failure could be expected to change. Ability and task difficulty are stable and therefore not expected to change much, while effort and luck are unstable and could therefore change dramatically over time. Controllability refers to how much control the individual has over the events of the situation. Causes such as effort are considered to be controllable, whereas luck is uncontrollable.

COGNITIVE DISSONANCE

One of the most popular cognitive approaches to the study of motivation has been the theory of cognitive dissonance, first systematically studied by the American psychologist Leon Festinger. This theory proposed that people attempt to maintain consistency among their beliefs, attitudes, and behaviours. According to this theory, a motivational state termed cognitive dissonance is produced whenever beliefs, attitudes, and behaviours are inconsistent. Cognitive dissonance is considered to be an aversive state that triggers mechanisms to bring cognitions back into a consistent relationship with one another. Much of the research on cognitive dissonance has centred around what happens when attitudes and behaviours are inconsistent. This research suggests that behavior inconsistent with one's beliefs—if there is insufficient justification for the behaviour—will often bring about modification of those beliefs. Suppose, for example, that a person is required to undergo a stressful initiation in order to join a select group. After undergoing this initiation the person discovers that becoming a member of the group does not provide the satisfaction originally expected. Such an outcome should produce cognitive dissonance because the behaviours required and the current belief about the group are inconsistent. As a result, the theory suggests that motivation will be triggered to bring the dissonant elements back into a consistent relationship. The behaviour cannot be changed because it has already occurred; the belief, on the other hand can be changed. Under these conditions dissonance theory predicts that the person's attitude will change and that he will actually come to believe that he likes the group more. Several studies have supported this prediction.

SELF-PERCEPTION THEORY

Cognitive dissonance approaches have not gone unchallenged. An alternative approach, known as self-perception theory, suggests that all individuals analyze their own behaviour much as an outside observer might and, as a result of these observations, make judgments about why they are motivated to do what they do. Thus, in the example above, self-perception theory would argue that the person, in observing his own behaviour, assesses the effort involved and decides that the initiation was endured because he really wanted to be a member of this group. Dissonance theory and self-perception theory are not necessarily mutually exclusive; several studies suggest that both processes can and do occur but under different conditions.

SELF-ACTUALIZATION

Cognitive motivational approaches have also explored the idea that human motivation is heavily influenced by a need for competence or control. Although there are several varieties of these theories, most have in common the idea that human behaviour is at least partially motivated by a need to become as much as one can possibly become. One example of this approach is the self-actualization theory of Abraham Maslow previously mentioned.

Maslow's hierarchy of needs

Maslow has proposed that human motivation can be understood as resulting from a hierarchy of needs. These needs, starting with the most basic physiological demands, progress upward through safety needs, belonging needs, and esteem needs and culminate in self-actualization. Each level directs behaviour toward the need level that is not being adequately met. As lower-level needs are met, the motivation to meet the higher-level needs becomes active. Furthermore, as an individual progresses upward, it becomes progressively more difficult to successfully fulfill the needs of each higher level. For this reason Maslow believed that very few people actually reach the level of self-actualization, and it is a lifelong process for the few who do.

Based on his observations of individuals he believed to be self-actualized, including historical figures such as the U.S. presidents Abraham Lincoln and Thomas Jefferson, Maslow outlined a cluster of 14 characteristics that distinguish self-actualized individuals. Summarized, these characteristics define individuals who are accepting of themselves and others, are relatively independent of the culture or society in which they live, are somewhat detached but with very close personal ties to a few other people, and are deeply committed to solving problems that they deem important. Additionally, self-actualized individuals intensely appreciate simple or natural events, such as a sunrise, and they sometimes experience profound changes

that Maslow termed peak experiences. Although difficult to describe, peak experiences often involve a momentary loss of self and feelings of transcendence. Reports of peak experiences also include the feeling of limitless horizons opening up and of being simultaneously very powerful, yet weak. Peak experiences are extremely positive in nature and often cause an individual to change the direction of his or her future behaviour. Maslow believed that everyone is capable of having peak experiences, but he believed that self-actualized persons have these experiences more often. (H.L.P.)

Applications in society

Attempts have been made in society to use motivational methods to achieve certain goals. In the control of animal behaviour, for example, it is clear that depriving an organism of food is a powerful means for accomplishing reinforcement. Appropriate use of food under these circumstances is an effective procedure for shaping an animal's behaviour, maintaining it, and controlling the rate of its occurrence. Likewise, it is clear that animals have preferences (within, for example, the range of foodstuffs) and that their behaviour can be controlled with relatively greater effectiveness by the proper selection of preferred substances for use in training.

Behavioral control through motivational reinforcement

In many cultures, deprivation cannot be used so readily with human beings as it can be with other animals, although there are many human examples. Thus, some success has been reported in effecting desired behaviour in the classroom by depriving children of some of their recess time when they behave in ways deemed undesirable by the school authorities. Economies based on the use of tokens (*e.g.,* poker chips) have been set up in schools, psychiatric hospitals, and institutions for retarded people. The result typically has been an improvement in the subjects' behaviour and personal care and in the ease with which they may be managed. In such economies, tokens can be exchanged for privileges and commodities (*e.g.,* candy and toys). The individual's ability to obtain tokens is made contingent on socially desirable acts, such as making beds, being personally clean, being cooperative, and being generally acceptable to others. There have been reports of marked improvement in scholastic achievement among institutionalized juvenile delinquents who have been placed in such token economies.

The effectiveness of these and similar procedures has been most easily demonstrated in institutions, in which the situation permits a great deal of control over the subjects' conditions of life and over their activities. In society at large, of course, this degree of control is effectively not feasible. There also are widely endorsed moral or ethical concerns about the desirability of instituting such control even if it were possible. The use of particular kinds of motivational devices in the control of human behaviour seems to many to be incompatible with the ethical idea of personal freedom and fraught with potential for immoral misuse in the hands of those who seek to manipulate others for ends that are politically or socially conformist.

On the other hand, it often is observed that many of society's problems are motivational. This observation usually means that the goals and values of economically affluent groups in the Americas, Europe, and Asia are not shared by members of deprived urban populations or by millions of poor people in industrially less-developed countries. Or, it may mean that the goals of those who own or control profit-seeking enterprises (to make a product or deliver a service for the investors' profit) are not shared by workers below the level of middle management. Many techniques have been tried in business and industry to effect so-called motivational involvement with production on the part of ordinary employees. Some of them have had success. Incentive systems, employee participation in company planning and decisions, and human-relations training exemplify the procedures used. A substantial corps of specialists throughout the world provides programs to industry designed to improve the motivation, morale, and satisfaction of workers at all levels. Although these programs have wide acceptance, most of them have received very little objective evaluation. (C.N.C.)

Motivational techniques in business and industry

Summary

Motivation is a complex topic that spans virtually all areas of psychology. No one theory is capable of explaining all that we know about motivational processes. Some motives such as hunger, thirst, and sexual activity seem best understood from a biological viewpoint. Other motives appear to be learned, and such motives help to account for the diversity and complexity of human activities. Still other motives are influenced by the cognitive processes in which we engage. Our interpretation of the events around us influences our future motivation.

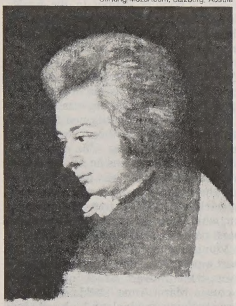
A complicating factor in human motivation is the fact that even basic motives are influenced by a variety of elements. For example, we may eat because of energy needs, but some people also eat when stressed or anxious, when depressed or alone, or because of social influences such as other people eating. The taste qualities of certain foods may also cause us to eat when not hungry. This interaction of many factors in determining the motivation of behaviour seriously hinders our ability to understand even basic motivational processes; the contribution of various motivational components must be carefully separated and analyzed. When the study of more subtle motives is attempted, these complicating factors hinder understanding even more. In spite of the large amount of information we have on motivation, much yet remains to be understood. (H.L.P.)

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Mozart

Wolfgang Amadeus Mozart is widely recognized as one of the greatest composers in the history of Western music. With Haydn and Beethoven he brought to its height the achievement of the Viennese Classical school. Unlike any other composer in musical history, he wrote in all the musical genres of his day and excelled in every one. His taste, his command of form, and his range of expression entitle him to be considered the most universal of all composers.

By courtesy of the Internationale Stiftung Mozarteum, Salzburg, Austria



Mozart, unfinished oil portrait by Joseph Lange, 1789. In the Internationale Stiftung Mozarteum, Salzburg, Austria.

Early life and works. Mozart was born in Salzburg, now in Austria, then in church lands, on Jan. 27, 1756. Although baptized Joannes Chrysostomus Wolfgangus Theophilus, he most commonly called himself Wolfgang Amadè or Wolfgang Gottlieb. His father, Leopold, came from a family of good standing, which included architects and bookbinders, and was the author of a famous violin-playing manual; his mother, Anna Maria Pertl, was born of a middle-class family active in local administration. Mozart and his sister Maria Anna ("Nannerl") were the only two of their seven children to survive.

The boy's early talent for music was remarkable. At three he was picking out chords on the harpsichord, at four playing short pieces, at five composing. There are anecdotes about his precise memory of pitch, about his scribbling a concerto at the age of five, and about his gentleness and sensitivity (he was afraid of the trumpet). Just before he was six, his father took him and Nannerl, also highly talented, to Munich to play at the Bavarian court, and a few months later they went to Vienna and were heard at the imperial court and in noble houses.

"The miracle which God let be born in Salzburg" was Leopold's description of his son, and he was keenly conscious of his duty to God, as he saw it, to draw the miracle to the notice of the world (and incidentally to profit from doing so). In mid-1763 he obtained a leave of absence from his position as deputy Kapellmeister at the prince-archbishop's court at Salzburg, and the family set out on a prolonged tour. They went to what were all the main musical centres of western Europe—Munich, Augsburg, Stuttgart, Mannheim, Mainz, Frankfurt, Brussels, and Paris (where they remained for the winter), then London (where they spent 15 months), returning through The Hague, Amsterdam, Paris, Lyon, and Switzerland, and arriving back in Salzburg in November 1766. In most of these cities Mozart, and often his sister, played and improvised, sometimes at court, sometimes in public or in a church. Leopold's surviving letters to friends in Salzburg tell of the universal admiration that his son's achievements aroused. In Paris they met several German composers, and Mozart's first music was published (sonatas for keyboard and violin, dedicated to a royal princess); in London they met, among others, Johann Christian Bach, Johann Sebastian Bach's youngest son and a leading figure in the city's musical life, and under his influence Mozart composed his first symphonies—three survive (K 16, K 19, and K 19a—K signifying the work's place in the catalog of Ludwig von Köchel). Two more followed during a stay in The Hague on the return journey (K 22 and K 45a).

First European tour

After little more than nine months in Salzburg the Mozarts set out for Vienna in September 1767, where (apart from a 10-week break during a smallpox epidemic) they spent 15 months. Mozart wrote a one-act German singspiel, *Bastien und Bastienne,* which was given privately. Greater hopes were attached to his prospect of having an Italian opera buffa, *La finta semplice* ("The Feigned Simpleton"), done at the court theatre—hopes that were, however, frustrated, much to Leopold's indignation. But a substantial, festal mass setting (probably K 139/47a) was successfully given before the court at the dedication of the Orphanage Church. *La finta semplice* was given the following year, 1769, in the archbishop's palace in Salzburg. In October Mozart was appointed an honorary Konzertmeister at the Salzburg court.

La finta semplice

Still only 13, Mozart had by now acquired considerable fluency in the musical language of his time. The early Paris and London sonatas, the autographs of which include Leopold's helping hand, show a childlike pleasure in patterns of notes and textures. But the London and The Hague symphonies attest to his quick and inventive response to the music he had encountered, as, with their enrichment of texture and fuller development, do those he produced in Vienna (such as K 43 and, especially, K 48). And his first Italian opera shows a ready grasp of the buffo style.

The Italian tours. Mastery of the Italian operatic style was a prerequisite for a successful international composing career, and the Austrian political dominion over northern Italy ensured that doors would be open there to Mozart. This time Mozart's mother and sister remained at home, and the family correspondence provides a full account of events. The first tour, begun on Dec. 13, 1769, and lasting 15 months, took them to all the main musical centres, but as usual they paused at any town where a concert could be given or a nobleman might want to hear Mozart play. In Verona Mozart was put through stringent tests at the Accademia Filarmonica, and in Milan, after tests of his capacities in dramatic music, he was commissioned to write the first opera for the carnival season. After a stop in Bologna, where they met the esteemed theorist Giovanni Battista Martini, they proceeded to Florence and on to Rome for Holy Week. There Mozart heard the Sistine Choir in the famous *Miserere* of Gregorio Allegri (1582–1652), which was considered the choir's exclusive preserve but which Mozart copied out from memory. They spent six weeks in Naples; returning through Rome, Mozart had a papal audience and was made a knight of the order of the Golden Spur. The summer was passed near Bologna, where Mozart passed the tests for admission to the Accademia Filarmonica. In mid-October he reached Milan and began work on the new opera, *Mitridate, rè di Ponto* ("Mithradates, King of Pontus"). He had to rewrite several numbers to satisfy the singers, but, after a series of rehearsals (Leopold's letters provide fascinating insights as to theatre procedures), the premiere at the Regio Ducal

Rome

Teatro on December 26 was a notable success. Mozart, in the traditional way, directed the first three of the 22 performances. After a brief excursion to Venice he and his father returned to Salzburg.

Plans had already been laid for further journeys to Italy: for a theatrical serenata commissioned for a royal wedding in Milan in October 1771 and for a further opera, again for Milan, at carnival time in 1772–73. Mozart was also commissioned to write an oratorio for Padua; he composed *La Betulia liberata* during 1771, but there is no record of a performance. The second Italian visit, between August and December 1771, saw the premiere of his *Ascanio in Alba,* which, Leopold gleefully reported, "completely overshadowed" the other new work for the occasion, an opera (*Ruggiero*) by Johann Adolph Hasse, the most respected opera seria composer of the time. But hopes that Leopold had entertained of his son's securing an appointment in Milan were disappointed. Back in Salzburg, Mozart had a prolific spell: he wrote eight symphonies, four divertimentos, several substantial sacred works, and an allegorical serenata, *Il sogno di Scipione.* Probably intended as a tribute to the Salzburg prince-archbishop, Count Schrattenbach, this work may not have been given until the spring of 1772, and then for his successor Hieronymus, Count Colloredo; Schrattenbach, a tolerant employer generous in allowing leave, died at the end of 1771.

Third Italian journey

The third and last Italian journey lasted from October 1772 until March 1773. *Lucio Silla* ("Lucius Sulla"), the new opera, was given on Dec. 26, 1772, and after a difficult premiere (it began three hours late and lasted six) it proved even more successful than *Mitridate,* with 26 performances. This is the earliest indication of the dramatic composer Mozart was to become. He followed *Lucio Silla* with a solo motet written for its leading singer, the castrato and composer Venanzio Rauzzini, *Exsultate, jubilate* (K 165), an appealing three-movement piece culminating in a brilliant "Alleluia." The instrumental music of the period around the Italian journeys includes several symphonies; a few of them are done in a light, Italianate style (*e.g.,* K 95 and K 97), but others, notably the seven from 1772, tread new ground in form, orchestration, and scale (such as K 130, K 132, and the chamber musical K 134). There are also six string quartets (K 155–160) and three divertimentos (K 136–138), in a lively, extroverted vein.

Early maturity. More symphonies and divertimentos, as well as a mass, followed during the summer of 1773. Then Leopold, doubtless seeking again a better situation for his son than the Salzburg court (now under a much less sympathetic archbishop) was likely to offer, took him to Vienna. No position materialized, but Mozart's contact with the newest Viennese music seems to have had a considerable effect on him. He produced a set of six string quartets in the capital, showing in them his knowledge of Haydn's recent Opus 20 in his fuller textures and more intellectual approach to the medium. Soon after his return he wrote a group of symphonies, including two that represent a new level of achievement, the "Little" G Minor (K 183) and the A Major (K 201). Also dating from this time was Mozart's first true piano concerto (in D, K 175; earlier keyboard concertos were arrangements of movements by other composers).

The year 1774 saw the composition of more symphonies, concertos for bassoon and for two violins (in a style recalling J.C. Bach), serenades, and several sacred works. Mozart was now a salaried court Konzertmeister, and the sacred music in particular was intended for local use. Archbishop Colloredo, a progressive churchman, discouraged lavish music and set a severe time limit on mass settings, which Mozart objected to but was obliged to observe. At the end of the year he was commissioned to write an opera buffa, *La finta giardiniera* ("The Feigned Gardener Girl"), for the Munich carnival season, where it was duly successful. It shows Mozart, in his first comic opera since his childhood, finding ways of using the orchestra more expressively and of giving real personality to the pasteboard figures of Italian opera buffa.

La finta giardiniera

A period of two and a half years (from March 1775) began in which Mozart worked steadily in his Salzburg post. The work was for him undemanding and by no means compatible with his abilities. During this period he wrote only one dramatic work (the serenata-like *Il rè pastore,* "The Shepherd King," for an archducal visit), but he was productive in sacred and lighter instrumental music. His most impressive piece for the church was the *Litaniae de venerabili altaris sacramento* (K 243), which embraces a wide range of styles (fugues, choruses of considerable dramatic force, florid arias, and a plainchant setting). The instrumental works included divertimentos, concertos, and serenades, notably the *Haffner* (K 250), which in its use of instruments and its richness of working carried the serenade style into the symphonic without prejudicing its traditional warmth and high spirits. The five concertos for violin, all from this period (No. 1 may be slightly earlier), show a remarkable growth over a few months in confidence in handling the medium, with increasingly fanciful ideas and attractive and natural contexts for virtuoso display. The use of popular themes in the finales is typically south German. He also wrote a concerto for three pianos and three piano concertos, the last of them, K 271, showing a new level of maturity in technique and expressive range.

Mannheim and Paris. It must have been abundantly clear by this time to Mozart as well as his father that a small, provincial court like that at Salzburg was no place for a genius of his order. In 1777 he petitioned the archbishop for his release and, with his mother to watch over him, set out to find new opportunities. The correspondence with his father over the 16 months he was away not only gives information as to what he was doing but also casts a sharp light on their changing relationship; Mozart, now 21, increasingly felt the need to free himself from paternal domination, while Leopold's anxieties about their future assumed almost pathological dimensions.

They went first to Munich, where the elector politely declined to offer Mozart a post. Next they visited Augsburg, staying with relatives; there Mozart struck up a lively friendship with his cousin Maria Anna Thekla (they later had a correspondence involving much playful, obscene humour). At the end of October they arrived at Mannheim, where the court of the Elector Palatine was musically one of the most famous and progressive in Europe. Mozart stayed there for more than four months, although he soon learned that again no position was to be had. He became friendly with the Mannheim musicians, undertook some teaching and playing, accepted and partly fulfilled a commission for flute music from a German surgeon, and fell in love with Aloysia Weber, a soprano, the second of four daughters of a music copyist. He also composed several piano sonatas, some with violin. He put to his father a scheme for traveling to Italy with the Webers, which, naive and irresponsible, met with an angry response: "Off with you to Paris! and that soon, find your place among great people—aut Caesar aut nihil." The plan had been that he would go on alone, but now Leopold felt that he was not to be trusted and made the ill-fated decision that his mother should go too. They reached Paris late in March 1778, and Mozart soon found work. His most important achievement was the symphony (K 297) composed for the Concert Spirituel, a brilliant D Major work in which he met the taste of the Parisian public (and musicians) for orchestral display without sacrifice of integrity; indeed he exploited the devices they admired (such as the opening coup d'archet—a forceful, unanimous musical gesture) to new formal ends.

Mother's death

By the time of its premiere, on June 18, his mother was seriously ill, and on July 3 she died. Mozart handled the situation with consideration, first writing to his father of her grave illness, then asking an abbé friend in Salzburg to break the news. He went to stay with Friedrich Melchior, Baron von Grimm, a German friend. Soon after, Grimm wrote pessimistically to Leopold about his son's prospects in Paris, and Leopold negotiated a better post for him in Salzburg, where he would be court organist rather than violinist as before, though still nominally Konzertmeister. Summoned home, Mozart reluctantly obeyed, tarrying en route in Mannheim and in Munich—where the Mannheim musicians had now mostly moved and where

he was coolly received by Aloysia Weber. He reached Salzburg in mid-January 1780.

Salzburg and Munich. Back in Salzburg, Mozart seems to have been eager to display his command of international styles: of the three symphonies he wrote in 1779–80, K 318 in G Major has a Parisian premier coup d'archet and crescendos of the type favoured in Mannheim, and K 338 in C Major shows many features of the brilliant Parisian manner. His outstanding orchestral work of this period was, however, the sinfonia concertante for violin and viola K 364; the genre was popular in both cities, and there are many features of the Mannheim style in the orchestral writing, but the character of the work, its ingenious instrumental interplay, and its depth of feeling are unmistakably Mozartian. Also from this time came the cheerful two-piano concerto and the two-piano sonata, as well as a number of sacred works, including the best-known of his complete masses, the *Coronation Mass*.

But it was dramatic music that attracted Mozart above all. He had lately written incidental music to a play by Tobias Philipp von Gebler, and during 1779–80 he composed much of a singspiel, known as *Zaide*, although with no sure prospects of performance. So Mozart must have been delighted, in the summer of 1780, to receive a commission to compose a serious Italian opera for Munich. The subject was to be Idomeneus, king of Crete, and the librettist the local cleric Giambattista Varesco, who was to follow a French text of 1712. Mozart could start work in Salzburg as he already knew the capacities of several of the singers, but he went to Munich some 10 weeks before the date set for the premiere. Leopold remained at home until close to the time of the premiere and acted as a link between Mozart and Varesco; their correspondence is accordingly richly informative about the process of composition. Four matters dominate Mozart's letters home. First, he was anxious, as always, to assure his father of the enthusiasm with which the singers received his music. Second, he was concerned about cuts: the libretto was far too long, and Mozart had set it spaciously, so that much trimming—of the recitative, of the choral scenes, and even of two arias in the final acts—was needed. Third, he was always eager to make modifications that rendered the action more natural and plausible. And fourth, he was much occupied with accommodating the music and the action to the needs and the limitations of the singers.

Idomeneo

In *Idomeneo, rè di Creta* Mozart depicted serious, heroic emotion with a richness unparalleled elsewhere in his operas. Though influenced by Christoph Gluck and by Niccolò Piccinni and others, it is not a "reform opera": it includes plain recitative and bravura singing, but always to a dramatic purpose, and, though the texture is more continuous than in Mozart's earlier operas, its plan, because of its French source, is essentially traditional. Given on Jan. 29, 1781, just after Mozart's 25th birthday, it met with due success. Mozart and his father were still in Munich when, on March 12, he was summoned to join the archbishop's retinue in Vienna, where the accession of Joseph II was being celebrated.

Vienna: the early years. Fresh from his triumphs in Munich, where he had mixed freely with noblemen, Mozart now found himself placed, at table in the lodgings for the archbishop's entourage, below the valets if above the cooks. Furthermore, the archbishop refused him permission to play at concerts (including one attended by the emperor at which Mozart could have earned half a year's salary in an evening). He was resentful and insulted. Matters came to a head at an interview with Archbishop Colloredo, who, according to Mozart, used unecclesiastical language; Mozart requested his discharge, which was eventually granted at a stormy meeting with the court steward on June 9, 1781.

Mozart, who now went to live with his old friends the Webers (Aloysia was married to a court actor and painter), set about earning a living in Vienna. Although eager for a court appointment, he for the moment was concerned to take on some pupils, to write music for publication, and to play in concerts (which in Vienna were more often in noblemen's houses than in public). He also embarked on an opera, *Die Entführung aus dem Serail* (*The Abduction from the Seraglio*). (Joseph II currently required that German opera, rather than the traditional Italian, be given at the court theatre.) In the summer of 1781, rumours began to circulate, as far as Salzburg, that Mozart was contemplating marriage with the third of the Weber daughters, Constanze; but he hotly denied them in a letter to his father: "I have never thought less of getting married . . . besides, I am not in love with her." He moved lodgings to scotch the gossip. But by December he was asking for his father's blessing on a marriage with Constanze, with whom he was now in love and to whom, probably through the machinations of her mother and her guardian, he was in some degree committed. Because Constanze later destroyed Leopold's letters, for reasons that are easy to imagine, only one side of the correspondence exists; Leopold's reactions can, however, be readily inferred, and it would seem that this period marked a low point in the relationship between father and son.

Die Entführung aus dem Serail

Musically, Mozart's main preoccupation was with *Die Entführung* in the early part of 1782. The opera, after various delays, reached the Burgtheater stage on July 16. The story of the emperor's saying "very many notes, my dear Mozart" may not be literally true, but the tale is symptomatic: the work does have far more notes than any other then in the German repertory, with fuller textures, more elaboration, and longer arias. Mozart's letters to his father give insight into his approach to dramatic composition, explaining, for example, his use of accompanying figures and key relationships to embody meaning. He also had the original text substantially modified to strengthen its drama and allow better opportunities for music. Noteworthy features are the Turkish colouring, created by "exotic" turns of phrase and chromaticisms as well as janissary instruments; the extended Act 2 finale, along the lines of those in opera buffa but lacking the dramatic propulsion of the Italian type; the expressive and powerful arias for the heroine (coincidentally called Constanze); and what Mozart called concessions to Viennese taste in the comic music, such as the duet "Vivat Bacchus."

Die Entführung enjoyed immediate and continuing success; it was quickly taken up by traveling and provincial companies—as *La finta giardiniera* had been, to a lesser degree—and carried Mozart's reputation widely around the German-speaking countries. Later in the year he worked on a set of three piano concertos and began a set of six string quartets. He also started work on a mass setting, in C Minor, which he had vowed to write on his marriage but of which only the first two sections, "Kyrie" and "Gloria," were completed. Among the influences on this music, besides the Austrian ecclesiastical tradition, was that of the Baroque music (Bach, Handel, and others) that Mozart had become acquainted with, probably for the first time, at the house of his patron Baron Gottfried van Swieten, a music collector and antiquarian. The Baroque influence is noticeable especially in the spare textures and austere lines of certain of the solo numbers, though others are squarely in the decorative, south German late Rococo manner (this interest in "old-fashioned" counterpoint can also be seen in some of Mozart's piano music of the time and in his string arrangements of music from Bach's *The Well-Tempered Clavier*). Mozart and his wife visited Salzburg in the summer and autumn of 1783, when the completed movements were performed, with (as always intended) Constanze singing one of the solo soprano parts, at St. Peter's Abbey. On the way back to Vienna Mozart paused at Linz, where he hastily wrote the symphony known by that city's name for a concert he gave there.

The Baroque influence

The central Viennese period. Back in Vienna Mozart entered on what was to be the most fruitful and successful period of his life. He had once written to his father that Vienna was "the land of the piano," and his greatest triumphs there were as a pianist-composer. During one spell of little more than five weeks he appeared at 22 concerts, mainly at the Esterházy and Galitzin houses but including five concerts of his own. In February 1784 he began to keep a catalog of his own music, which suggests a new awareness of posterity and his place in it (in fact his entries are sometimes misdated). At concerts he would normally play the piano, both existing pieces and improvisations;

his fantasias—such as the fine C Minor one (K 475) of 1785—and his numerous sets of variations probably give some indication of the kind of music his audiences heard. He would also conduct performances of his symphonies (using earlier Salzburg works as well as the two written since he had settled in Vienna, the *Haffner* of 1782, composed for the Salzburg family, and the *Linz* [*Symphony No. 36 in C Major*]); but above all the piano concertos were the central products of his concert activity.

In 1782–83 Mozart wrote three piano concertos (K 413–415), which he published in 1785 with string and optional wind parts (so that they were suitable for domestic use) and described as "a happy medium between what is too easy and too difficult." Six more followed in 1784, three each in 1785 and 1786 and one each in 1788 and 1791. With the 1784 group he established a new level of piano concerto writing; these concertos are at once symphonic, melodically rich, and orchestrally ingenious, and they also blend the virtuoso element effectively into the musical and formal texture of the work. Much melodic material is assigned to the wind instruments, and a unique melodic style is developed that lends itself to patterns of dialogue and instrumental interplay. After the relatively homogeneous 1784 group (K 449, 450, 451, 453, 456, and 459), all of which begin with themes stated first by the orchestra and later taken up by the piano, Mozart moved on in the concertos of 1785 (K 466, 467, and 482) to make the piano solo a reinterpretation of the opening theme. These concertos are increasingly individual in character—one a stormy and romantic D Minor work, the next a closely argued concerto in C Major with a slow movement remarkable for its troubled beauty, and the third, in E-flat Major, notable for its military rhythms and wind colouring. The 1786 group begins with the refined but conservatively lyrical K 488, but then follow two concertos with a new level of symphonic unity and grandeur, that in C Minor (K 491), using the largest orchestra Mozart had yet called for in the concert hall, and the imperious concerto in C Major (K 503). The two final concertos (K 537 and 595) represent no new departures.

Mozart's other important contributions of this time come in the fields of chamber and piano music. The outpouring of 1784 included the fine piano sonata K 457 and the piano and violin sonata K 454 (written for a visiting violin virtuoso, it was produced in such haste that Mozart could not write out the piano part and played from blank paper at the premiere). He also wrote, in a style close to that of the concertos, a quintet for piano and wind instruments (K 452), which he considered his finest work to date; it was first heard at a concert in the house of his pupil Barbara Ployer, for whom two of the 1784 concertos had been written (K 449 and 453). The six string quartets on which he had embarked in 1782 were finished in the first days of 1785 and published later that year, dedicated to Haydn, now a friend of Mozart's. In 1785 Haydn said to Leopold Mozart, on a visit to his son in Vienna, "Your son is the greatest composer known to me in person or by name; he has taste, and what is more the greatest knowledge of composition."

Haydn's praise

From Figaro to Don Giovanni. In spite of his success as a pianist and composer, Mozart had serious financial worries, and they worsened as the famously fickle Viennese found other idols. One may calculate his likely income during his last five years, 1786–91, as being far larger than that of most musicians though much below that of the section of society with which he wanted to be associated; Leopold's early advice to be aloof ("like an Englishman") with his fellow musicians but friendly with the aristocracy had its price. His sense of being as good a man as any privileged nobleman led him and his wife into tastes that for his actual station in life, and his income, were extravagant. He saw a court appointment as a possible source of salvation but knew that the Italian musical influence at court, under the Kapellmeister Antonio Salieri, was powerful and exclusive—even if he and Salieri were never on less than friendly terms personally.

Success in the court opera house was all-important. Joseph II had now reverted to Italian opera, and since 1783 Mozart had been seeking suitable librettos (he had even started work on two but broke off when he came to realize their feebleness for his purpose). He had become acquainted with Lorenzo da Ponte, an Italian abbé-adventurer of Jewish descent who was a talented poet and librettist to the court theatre. At Mozart's suggestion he wrote a libretto, *Le nozze di Figaro,* based on Beaumarchais's revolutionary comedy, *Le Mariage de Figaro,* but with most of the political sting removed. Nonetheless, the music of *Figaro* makes the social distinctions clear. *Figaro,* as well as the later opera *Don Giovanni,* treats the traditional figure of the licentious nobleman, but the earlier work does so on a more directly comic plane even though the undercurrents of social tension run stronger. Perhaps the central achievement of *Figaro* lies in its ensembles with their close link between music and dramatic meaning. The Act 3 Letter Duet, for instance, has a realistic representation of dictation with the reading back as a condensed recapitulation. The act finales, above all, show a broad, symphonic organization with each section worked out as a unit; for example, in the B-flat section of the Act 2 finale the tension of the count's examination of Figaro is paralleled in the tonal scheme, with its return to the tonic only when the final question is resolved: a telling conjunction of music and drama. These features, coupled with the elaborate commentary on character and action that is embodied in the orchestral writing, add depth to the situations and seriousness to their resolution and set the work apart from the generality of Italian opere buffe.

Le nozze di Figaro

Figaro reached the stage on May 1, 1786, and was warmly received. There were nine performances in 1786 and a further 26 when it was revived in 1789–90—a success, but a modest one compared with certain operas of Martín y Soler and Giovanni Paisiello (to whose *Il barbiere di Siviglia* it was a sequel, and planned in direct competition). The opera did, however, enjoy outstanding popularity in Prague, and at the end of the year Mozart was invited to go to the Bohemian capital; he went in January 1787, giving a new symphony there and accepting a further operatic commission. He returned to Vienna in February 1787.

Mozart's concert activities in Vienna were now on a modest scale. No Viennese appearances at all are recorded for 1787. In April he heard that his father was gravely ill. Mozart wrote him a letter of consolation putting forward a view of death ("this best and truest friend of mankind") based on the teachings of Freemasonry, which he had embraced at the end of 1784. Leopold died in May 1787.

Mozart's music from this time includes the two string quintets K 515–516, arguably his supreme chamber works. Clearly this genre, with the opportunities it offered for richness of sonority and patterns of symmetry, had a particular appeal for him. The quintet in C Major (K 515) is the most expansive and most richly developed of all his chamber works, while the G Minor (K 516) has always been recognized for its depth of feeling, which in the circumstances it is tempting to regard as elegiac. From this period come a number of short but appealing lieder and three instrumental works of note: the *Musikalischer Spass* (*Musical Joke*), a good-humoured parody of bad music, in a vein Leopold would have liked (it was thought to have been provoked by his death until it was found that it was begun much earlier); *Eine kleine Nachtmusik,* the exquisite and much-loved serenade, probably intended for solo strings and written for a purpose that remains unknown; and a fine piano and violin sonata, K 526.

But Mozart's chief occupation during 1787 was the composition of *Don Giovanni,* commissioned for production in Prague; it was given on October 29 and warmly received. *Don Giovanni* was Mozart's second opera based on a libretto by da Ponte, who used as his model a libretto by Giovanni Bertati, set by Giuseppe Gazzaniga for Venice earlier in 1787. Da Ponte rewrote the libretto, inserting new episodes into the one-act original, which explains certain structural features. A difference in Mozart's approach to the work—a *dramma giocoso* in the tradition of Carlo Goldoni that, because of its more serious treatment of character, had a greater expressive potential than an opera buffa—is seen in the extended spans of the score, with set-piece numbers often running into one another.

Don Giovanni

As in *Figaro,* the two act finales are again remarkable: the first for the three stage bands that play dances for different social segments, the second for the supper scene in which the commendatore's statue consigns Giovanni to damnation, with trombones to suggest the supernatural and with hieratic dotted rhythms, extreme chromaticism, and wildly lurching harmony as Giovanni is overcome. But it remains a comic opera, as is made clear through the figure of Leporello, who from under a table offers the common man's wry or facetious observations; and at the end the surviving characters draw the moral in a cheerful sextet. The "demonic" character of the opera has caused it to exercise a special fascination for audiences, and it has given rise to a large critical, interpretative, and purely fanciful literature.

The last travels. On his return from Prague in mid-November 1787, Mozart was at last appointed to a court post, as *Kammermusicus,* in place of Gluck, who had died. It was largely a sinecure, the only requirement being that he should supply dance music for court balls, which he did, in abundance and with some distinction, over his remaining years. The salary of 800 gulden seems to have done little to relieve the Mozarts' chronic financial troubles. Their debts, however, were never large, and they were always able to continue employing servants and owning a carriage; their anxieties were more a matter of whether they could live as they wished than whether they would starve. In 1788 a series of letters begging loans from a fellow Freemason, Michael Puchberg, began; Puchberg usually obliged, and Mozart seems generally to have repaid him promptly. He was deeply depressed during the summer, writing of "black thoughts"; it has been suggested that he may have had a cyclothymic personality, linked with manic-depressive tendencies, which could explain not only his depression but also other aspects of his behaviour, including his spells of hectic creativity.

Financial difficulties

During the time of this depression Mozart was working on a series of three symphonies, in E-flat Major (K 543), G Minor (K 550), and C Major (the *Jupiter,* K 551), usually numbered 39, 40, and 41; these, with the work written for Prague (K 504), represent the summa of his orchestral output. It is not known why they were composed; possibly Mozart had a summer concert season in mind. The Prague work was a climax to his long series of brilliant D Major orchestral pieces, but the closely worked, even motivic form gives it a new power and unity. The E-flat Major work, scored with clarinets and more lyrical in temper, makes fewer departures, except in the intensity of its slow movement, where Mozart used a new palette of darker orchestral colours, and the epigrammatic wit of its finale. In the G Minor work the tone of passion and perhaps of pathos, in its constant falling figures, is still more pronounced. The *Jupiter* (the name dates from the early 19th century) summarized the series of C Major symphonies, with their atmosphere of military pomp and ceremony, but it went far beyond them in its assimilation of opera buffa style, profundity of expression (in its andante), and richness of working—especially in the finale, which incorporates fugal procedures and ends with a grand apotheosis in five-voice counterpoint.

Early in 1789 Mozart accepted an invitation to travel to Berlin with Prince Karl Lichnowsky; they paused in Prague, Dresden (where he played at court), and Leipzig (where he improvised on the Thomaskirche organ). He appeared at the Prussian court and probably was invited to compose piano sonatas for the princess and string quartets with a prominent cello part for King Friedrich Wilhelm II. He did in fact write three quartets, in parts of which he allowed the individual instruments (including the royal cello) special prominence, and there is one sonata (his last, K 576) that may have been intended for the Prussian princess. But it is unlikely that Mozart ever sent this music or was paid for it.

The summer saw the composition of the clarinet quintet, in which a true chamber style is warmly and gracefully reconciled with the solo writing. Thereafter Mozart concentrated on completing his next opera commission, the third of his da Ponte operas, *Così fan tutte,* which was given on Jan. 26, 1790; its run was interrupted after five performances when theatres closed because of the death of Joseph II, but a further five were given in the summer. This opera, the subtlest, most consistent, and most symmetrical of the three, was long reviled (from Beethoven onward) on account of its subject, female fickleness; but a more careful reading of it, especially in light of the emotional texture of the music, which gains complexity as the plot progresses, makes it clear that it is no frivolous piece but a penetrating essay on human feelings and their mature recognition. The music of Act 1 is essentially conventional in expression, and conventional feeling is tellingly parodied in certain of the arias; but the arias of Act 2 are on a deeper and more personal level. Features of the music of *Così fan tutte*—serenity, restraint, poise, irony—may be noted as markers of Mozart's late style, which had developed since 1787 and may be linked with his personal development and the circumstances of his life, including his Masonic associations, his professional and financial situation, and his marriage.

Così fan tutte

The year 1790 was difficult and unproductive: besides *Così fan tutte,* Mozart completed two of the "Prussian" quartets, arranged works by Handel for performance at van Swieten's house (he had similarly arranged *Messiah* in 1789), and wrote the first of his two fantasy-like pieces, in a variety of prelude-and-fugue form, for a mechanical organ (this imposing work, in F Minor [K 594], is now generally played on a normal organ). In the autumn, anxious to be noticed in court circles, he went to Frankfurt for the imperial coronation of Leopold II, but as an individual rather than a court musician. His concert, which included two piano concertos and possibly one of the new symphonies, was ill timed, poorly attended, and a financial failure. Anxieties about money were a recurrent theme in his letters home.

The last year. But 1791 promised to be a better year. Music was flowing again: for a concert in March Mozart completed a piano concerto (K 595) begun some years before, reeled off numerous dances for the Redoutensaal, and wrote two new string quintets, the one in D (K 593) being a work of particular refinement and subtlety. In April he applied successfully for the role of unpaid assistant to the elderly Kapellmeister of St. Stephen's Cathedral, Leopold Hofmann (with the expectation of being duly appointed his successor, but Hofmann was to live until 1793).

An old friend of Mozart's, Emanuel Schikaneder, had in 1789 set up a company to perform singspiels in a suburban theatre, and in 1791 he engaged Mozart to compose a score to his *Die Zauberflöte* (*The Magic Flute*); Mozart worked on it during the spring and early summer. Then he received another commission, anonymously delivered, for a requiem, to be composed under conditions of secrecy. In addition he was invited, probably in July, to write the opera to be given during Leopold II's coronation festivities in September. Constanze was away taking a cure at Baden during much of the summer and autumn; in July she gave birth to their sixth child, one of the two to survive (Carl Thomas, 1784–1858, and Franz Xaver Wolfgang, 1791–1844, a composer and pianist). Mozart's letters to her show that he worked first on *Die Zauberflöte,* although he must have written some of the Prague opera, *La clemenza di Tito* ("The Clemency of Titus"), before he left for the Bohemian capital near the end of August. Pressure of work, however, was such that he took with him to Prague, along with Constanze, his pupil Franz Xaver Süssmayr, who almost certainly composed the plain recitatives for the new opera. The work itself, to an old libretto by Pietro Metastasio, condensed and supplemented by the Dresden court poet Caterino Mazzolà, was long dismissed as a product of haste and a commission unwillingly undertaken; but in fact the spare scoring, the short arias, and the generally restrained style are better understood in terms of Mozart's reaction to the neoclassical thinking of the time and the known preferences of Leopold II. The opera was indifferently received by the court but quickly won over the Prague audiences and went on to become one of Mozart's most admired works over the ensuing decades.

Die Zauberflöte

Mozart was back in Vienna by the middle of September; his clarinet concerto was finished by September 29, and the next day *Die Zauberflöte* had its premiere. Again,

early reactions were cautious, but soon the opera became the most loved of all of Mozart's works for the stage. Schikaneder took its plot from a collection of fairy tales by Christoph Martin Wieland but drew too on other literary sources and on current thinking about Freemasonry—all viewed in the context of Viennese popular theatre. Musically it is distinguished from contemporary singspiels not merely by the quality of its music but also by the serious ideas that lie below what may seem to be merely childish pantomime or low comedy, welding together the stylistically diverse elements.

Mozart had been ill during the weeks in Prague, but to judge by his letters to Constanze in October he was in good spirits and, with some cause, more optimistic about the future. He wrote a Masonic cantata for his lodge and directed a performance of it on November 18. He was also working steadily on the commissioned requiem. Later in November he was ill and confined to bed; some apparent improvement on December 3 was not sustained, and on Dec. 5, 1791, he died. "Severe miliary fever" was the certified cause; later, "rheumatic inflammatory fever" was named. Other diagnoses, taking account of Mozart's medical history, have been put forward, including Schönlein–Henoch syndrome. There is no evidence to support the tale that he was poisoned by Salieri (a colleague and friend, hardly a real rival) or anyone else. He was buried in a multiple grave, standard at the time in Vienna for a person of his social and financial situation; a small group of friends attended the funeral.

Completion of the requiem

Constanze Mozart was anxious to have the requiem completed, as a fee was due; it had been commissioned, in memory of his wife, by Count von Walsegg-Stuppach to pass off as his own. She handed it first to Joseph Eybler, who supplied some orchestration but was reluctant to do more, and then to Süssmayr, who produced a complete version, writing several movements himself though possibly basing them on Mozart's sketches or instructions. Although subject to criticism for its technical weaknesses, which editors have sought to remedy, this must remain the standard version by dint of its position as the only one with a source close to Mozart. The sombre grandeur of the work, with its restrained instrumental colouring and its noble choral writing, hints at what might have been had Mozart lived to take on the Kapellmeistership of St. Stephen's.

Mozart's place. At the time of his death Mozart was widely regarded not only as the greatest composer of the time but also as a bold and "difficult" one; *Don Giovanni* especially was seen as complex and dissonant, and his chamber music as calling for outstanding skill in its interpreters. His surviving manuscripts, which included many unpublished works, were mostly sold by Constanze to the firm of André in Offenbach, which issued editions during the 19th century. But Mozart's reputation was such that even before the end of the 18th century two firms had embarked on substantial collected editions of his music. Important biographies appeared in 1798 and 1828, the latter by Constanze's second husband; the first scholarly biography, by Otto Jahn, was issued on Mozart's centenary in 1856. The first edition of the Köchel catalog followed six years later, and the first complete edition of his music began in 1877.

First edition of the Köchel catalog

The works most secure in the repertory during the 19th century were the three operas least susceptible to changes in public taste—*Le nozze di Figaro, Don Giovanni,* and *Die Zauberflöte*—and the orchestral works closest in spirit to the Romantic era—the minor-key piano concertos (Beethoven wrote a set of cadenzas for the one in D Minor) and the last three symphonies. It was only in the 20th century that Mozart's music began to be reexamined more broadly. Although up to the middle of the century Mozart was still widely regarded as having been surpassed in most respects by Beethoven, with the increased historical perspective of the later 20th century he came to be seen as an artist of a formidable, indeed perhaps unequaled, expressive range. The traditional image of the child prodigy turned refined drawing-room composer, who could miraculously conceive an entire work in his head before setting pen to paper (always a distortion of the truth), gave way to the image of the serious and painstaking creative artist with acute human insight, whose complex psychology demanded exploration by writers, historians, and scholars. But regardless of such shifting currents of interpretation, in public esteem and affection Mozart's place more than equals that of any other composer.

MAJOR WORKS

Mozart's works are listed in the catalog of LUDWIG RITTER VON KÖCHEL, *Chronologisch-thematisches Verzeichniss sämtlicher Tonwerke Wolfgang Amade Mozarts* (1862). It was twice significantly revised and enlarged, namely, for the 3rd ed., edited by ALFRED EINSTEIN (1937), with suppl. (1947), and the 6th ed., edited by FRANZ GIEGLING, ALEXANDER WEINMANN, and GERD SIEVERS (1964, reprinted 1983).

The following list excludes works that are lost, of doubtful authenticity, or substantially incomplete.

Vocal works

SACRED WORKS: 7 long masses (1 incomplete); 7 short masses; *Requiem,* K. 626, 1791 (incomplete); 4 litanies; 2 vespers; 22 motets and miscellaneous works (including *Exsultate, jubilate,* K. 165, 1773); 17 church sonatas.

ORATORIOS AND CANTATAS: 2 oratorios; 1 act of a sacred drama; Passion cantata; 4 Masonic cantatas.

DRAMATIC WORKS: 15 operas (including *Idomeneo, rè di Creta,* K. 366, 1781; *Die Entführung aus dem Serail,* K. 384, 1782; *Le nozze di Figaro,* K. 492, 1786; *Don Giovanni,* K. 527, 1787; *Così fan tutte,* K. 588, 1790; *Die Zauberflöte,* K. 620, 1791; *La clemenza di Tito,* K. 621, 1791); 2 serenatas; 1 ballet; 1 Latin intermezzo; incidental music.

MISCELLANEOUS VOCAL: 17 pieces for 2 to 4 voices with orchestra, ensemble, or piano; 48 songs and arias with orchestra (some for insertion into operas); 31 songs with piano; 15 vocal and 20 unspecified canons.

Instrumental works

SYMPHONIES: 56 symphonies, with some adapted from overtures and serenades (the traditional numbering up to 41 omits many and includes three not by Mozart), including *No. 38 in D Major (Prague),* K. 504, 1786; *No. 39 in E-flat Major,* K. 543, 1788; *No. 40 in G Minor,* K. 550, 1788; *No. 41 in C Major (Jupiter),* K. 551, 1788.

OTHER ORCHESTRAL AND ENSEMBLE MUSIC: 21 serenades (including *Serenata notturna,* K. 239, 1776; *Serenade in D Major [Haffner],* K. 250, 1776; *Serenade in D Major [Posthorn],* K. 320, 1779; *Eine kleine Nachtmusik,* K. 525, 1787), cassations, and divertimentos; 17 serenades and divertimentos for wind instruments; 13 marches, 105 minuets, 56 German dances, 47 contredanses.

CONCERTOS: For piano, 21, 7 arrangements of music by other composers, and 2 rondos (the traditional numbering includes 2 multiple concertos and 4 arrangements); 1 for 2 pianos; 1 for 3 pianos; 5 for violin; 1 *Concertone,* K. 190, 1774, for two violins; 1 *Sinfonia concertante,* K. 364, 1779, for violin and viola; 2 for flute; 1 for oboe; 1 for clarinet; 1 for bassoon; 3 and 1 incomplete for horn.

CHAMBER MUSIC: 6 string quintets; 26 string quartets and *Adagio and Fugue,* K. 546, 1788; 2 string trios; 2 string duos; 1 duo for bassoon and cello; 4 flute quartets; 1 oboe quartet; 1 clarinet quintet; 1 horn quintet; 1 quintet for piano and winds; 2 piano quartets; 7 piano trios (1 with clarinet); adagio and rondo for glass harmonica, wind, and strings; 32 sonatas and 2 sets of variations for piano and violin.

KEYBOARD MUSIC: 19 piano sonatas; 5 sonatas for piano duet; 1 two-piano sonata; 16 sets of variations for piano; 1 set of variations for piano duet; 27 pieces for piano; fugue for 2 pianos; 3 pieces for mechanical organ; adagio for glass harmonica.

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A comprehensive bibliography of secondary sources appeared as the *Mozart-Jahrbuch 1975* and in 1976 was published as *Mozart-Bibliographie (bis 1970),* RUDOLPH ANGERMÜLLER and OTTO SCHNEIDER (comps.). These compilers have continued the bibliography in *Mozart-Bibliographie, 1971–1975* (1978), *Mozart-Bibliographie, 1976–1980* (1982), and *Mozart-Bibliographie, 1981–1985* (1987). More selective bibliographies are included in many of the biographical works cited here.

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Muscles and Muscle Systems

Movement, the intricate cooperation of muscle and nerve fibres, is the means by which an organism interacts with its environment. The innervation of muscle cells, or fibres, permits an animal to carry out the normal activities of life. An organism must move to find food or, if it is sedentary, must have the means to bring food to itself. An animal must be able to move nutrients and fluids through its body, and it must be able to react to external or internal stimuli. Muscle cells fuel their actions by converting chemical energy in the form of adenosine triphosphate (ATP), which is derived from the metabolism of food, into mechanical energy.

Muscle is contractile tissue grouped into coordinated systems for greater efficiency. In humans, the muscle systems are classified by gross appearance and location of cells. The three types of muscles are striated (or skeletal), cardiac, and smooth (or nonstriated). Striated muscle is almost exclusively attached to the skeleton and constitutes the bulk of the body's muscle tissue. The multinucleated fibres are under the control of the somatic nervous system and elicit movement by forces exerted on the skeleton similar to levers and pulleys. The rhythmic contraction of cardiac muscle is regulated by the sinoatrial node, the heart's pacemaker. Although cardiac muscle is specialized striated muscle consisting of elongated cells with many centrally located nuclei, it is not under voluntary control. Smooth muscle lines the viscera, blood vessels, and dermis, and, like cardiac muscle, its movements are operated by the autonomic nervous system and thus are not under voluntary control. The nucleus of each short, tapering cell is located centrally.

Unicellular organisms, simple animals, and the motile cells of complex animals do not have vast muscle systems. Rather, movement in these organisms is elicited by hairlike extensions of the cell membrane called cilia and flagella or by cytoplasmic extensions called pseudopodia.

This article consists of a comparative study of the muscle systems of various animals, including an explanation of the process of muscle contraction and an account of the human muscle system as it relates to upright posture. A brief survey of the diseases that affect human muscle is also included.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, sections 421 and 423, and the *Index*. (W.F.W./R.McN.A./Ed.)

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General features of muscle and movement

Muscle powers the movements of multicellular animals and maintains posture. Its gross appearance is familiar as meat or as the flesh of fish. Muscle is the most plentiful tissue in many animals; for example, it comprises 50 to 60 percent of the body mass in many fishes, and 40 to 50 percent in antelopes. Some muscles are under conscious control and are called voluntary muscles. Other muscles, called involuntary muscles, are not consciously controlled by the organism; for example, in vertebrates, muscles in the walls of the heart contract rhythmically, pumping blood around the body; muscles in the walls of the intestines move food along by peristalsis; and muscles in the walls of small blood vessels constrict or relax, controlling the flow of blood to different parts of the body. (The effects of muscle changes in the blood vessels are apparent in blushing and paling due to increased or decreased blood flow, respectively, to the skin.)

Non-muscular movement

Muscles are not the only means of movement in animals. Many protists (unicellular organisms) move instead by using cilia or flagella (actively beating processes of the cell surface that propel the organism through water). Some unicellular organisms are capable of amoeboid movement, in which the cell contents flow into extensions (pseudopodia) from the cell body. Some of the ciliated protozoans move by means of rods called myonemes, which are capable of shortening rapidly.

Nonmuscular methods of movement are important for multicellular animals as well. Many microscopic animals

swim by means of beating cilia. Some small mollusks and flatworms crawl using cilia on the underside of the body. Some invertebrates that feed by filtering particles from water use cilia to create the necessary water currents. In higher animals, white cells use amoeboid movements, and cilia from cells lining the respiratory tract remove foreign particles from the delicate membranes.

Muscles consist of long, slender cells (fibres) each of which is a bundle of finer fibrils (Figure 1). Within each fibril are relatively thick filaments of the protein myosin and thin ones of actin and other proteins. When a muscle fibre lengthens or shortens, the filaments remain essentially constant in length but slide past each other as shown in Figure 2. Tension in active muscles is produced by cross bridges (*i.e.*, projections from the thick filaments that attach to the thin ones and exert forces on them). As the active muscle lengthens or shortens and the filaments slide past each other, the cross bridges repeatedly detach and reattach in new positions. Their action is similar to pulling a rope in hand over hand. Some muscle fibres are several centimetres long, but most other cells are only a fraction of a millimetre long. Because these long fibres cannot be served adequately by a single nucleus, numerous nuclei are distributed along their length.

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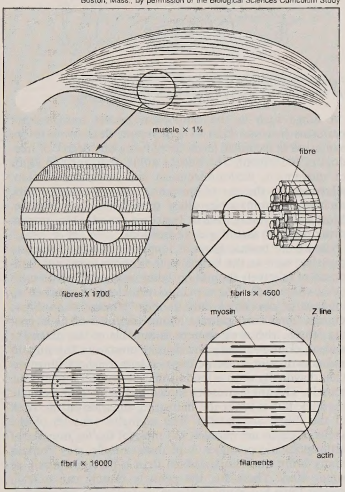


Figure 1: Striated muscle structure in increasingly magnified drawings.

Energy requirements

The work done by muscle requires chemical energy derived from the metabolism of food. When muscles shorten while exerting tension and performing mechanical work, some of the chemical energy is converted to work and some is lost as heat. When muscles lengthen while exerting tension (such as in slowly lowering a weight), the chemical energy that is used along with the mechanical energy absorbed by the action is converted to heat. Generation of heat is an important function of muscle in warm-blooded animals. Shivering is muscle activity that generates heat and warms the body. Similarly, some insects vibrate their wings for a while before flight, heating the muscles to the temperature at which they work best.

DIVERSITY OF MUSCLE

Muscle fibres differ from species to species of animal and between parts of the same animal. Apart from the distinction between voluntary and involuntary muscles, muscles differ in structure and activity.

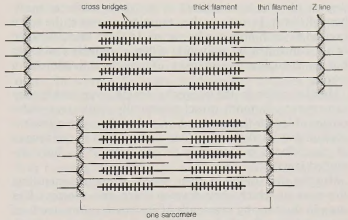


Figure 2: *The arrangement of the myofilaments in a striated muscle.*
The muscle is extended in the upper diagram and contracted in the lower one. The thick filaments are 1.6 micrometres (0.0016 millimetre) long in vertebrate striated muscle but up to six micrometres long in some arthropods.

Types of muscle fibres

Muscles differ in the arrangement of their myofilaments. The principal types of muscle are striated muscle, in which the filaments are organized in transverse bands as in Figure 2; obliquely striated muscle, in which the filaments are staggered, making the bands oblique (Figure 3); and smooth muscle, in which the filaments are arranged irregularly. In vertebrates, all voluntary muscles are striated and all involuntary muscles are smooth, except for cardiac muscle, which is involuntary but striated. Obliquely striated muscle is found only in some invertebrate groups (the nematodes, annelids, and mollusks) and has the protein paramyosin in the thick filaments as well as myosin.

Muscles differ in the stimuli required to activate them. In vertebrates, voluntary muscles require action potentials (electrical signals) in their nerves to initiate every contraction. Some involuntary muscles are spontaneously active, and the action potentials in their nerves only modify the natural rhythm of contraction. The leg muscles of all insects, and the wing muscles of many, require action potentials to initiate every contraction; however, the wing muscles of other insects consist of fibrillar muscle, which requires only occasional action potentials to maintain its rapid rhythmic contractions. The wings of these insects are attached to the body in such a way as to have a resonant frequency of vibration (like a guitar string that vibrates, when plucked, at its resonant frequency). When fibrillar muscles are active, they contract so as to maintain the vibrations of the resonant system.

Stress

Muscles differ in the ability to exert stress. Muscles that exert large stresses have long, thick filaments that carry larger numbers of cross bridges. The result is more cross bridges than in other muscles. This means that more force can be transmitted from each thick filament to the adjacent thin filaments, and larger stresses can be exerted. Less stress can be exerted when the fibres are shortening than when they are maintaining constant length, and more when they are being forcibly stretched.

Muscles differ in the manner in which their forces are controlled. Most of the fibres in the voluntary muscles of mammals can only be switched on or off, and different

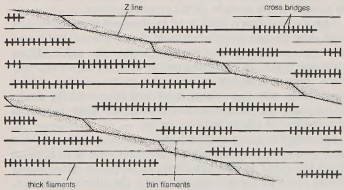


Figure 3: The arrangement of the myofilaments in obliquely striated muscle.

degrees of force are obtained by activating different numbers of fibres. In many other muscles, however, the force exerted by each fibre can be varied. In these muscles, force is not controlled by activating different numbers of fibres but by changing the intensity of muscle activation as a whole.

Muscles differ in the ranges of length over which they can operate. Smooth muscles generally work over wider ranges of length than striated ones, but there are a few exceptional striated muscles. One such muscle in the tongue of chameleons can shorten to one-sixth of its fully extended length.

Muscles also differ in their speed of action, including the rates at which they develop force and shorten. If a muscle shortens by one-tenth of its length in one-tenth of a second, its rate of shortening is one length per second. Maximum rates of shortening vary between species and between muscle fibres in a single animal. For example, two muscles in the limbs of mice have maximum shortening speeds (at 37° C) of 24 and 13 lengths per second.

Metabolism

Finally, muscles differ in their metabolism. The adenosine triphosphate (ATP) that they use as their immediate energy source may be produced either by oxidative reactions, in which food is oxidized to carbon dioxide and water, or by processes that do not require oxygen (anaerobic). Vertebrates and crabs use the anaerobic process of glycolysis, converting the carbohydrate glycogen to lactic acid, for short bursts of vigorous activity such as sprinting. The burst of activity is followed by a recovery period in which oxygen is used to oxidize some of the lactic acid, releasing the energy needed to convert the rest back to glycogen. The advantage of using anaerobic metabolism in this way is that the intensity of activity during the burst is not limited by the rate at which the blood can bring oxygen to the muscles.

In vertebrates, many muscle fibres perform only oxidative metabolism or only glycolysis, though some perform both. Oxidative fibres are commonly red, owing to the presence of the pigment myoglobin. Most fishes show an obvious distinction between the main bulk of white swimming muscle and a narrow strip of red muscle along the side of the body. Slow swimming is powered by the red (oxidative) muscle and bursts of fast swimming by the white (glycolytic) muscle. Red and white muscles are also easy to distinguish in the domestic chicken, in which the pale meat of the breast consists mainly of white fibres and the dark meat of the legs the red fibres. The breast muscles are the main muscles of the wings, which are used by chickens only for occasional short bursts of flight. Other birds that practice sustained flight (*e.g.*, hummingbirds) mainly have red breast muscles.

MUSCLES THAT WORK SKELETONS

Figure 4 shows a simple system, in which a skeleton is worked by muscles. The two rigid parts of the clam shell (Figure 4A) are hinged together. They can be closed to protect the animal within or allowed to open. A block of rubbery protein, the inner hinge ligament, lies just inside the hinge. When the adductor muscle contracts it closes the shell, but in so doing it compresses the inner hinge ligament. When it relaxes, the ligament recoils elastically, reopening the shell. This is an unusual system, in that it is worked by just one muscle. Most other skeletal systems need muscles in antagonistic pairs, in which each muscle is paired with a muscle of the opposite effect.

Human ankle joint

This antagonism is illustrated by the human ankle (Figure 4B). The tibialis anterior muscle flexes the ankle (raising the toes) and the soleus muscle extends the ankle. These muscles make up an antagonistic pair. In this particular case there is another muscle, the gastrocnemius, which cooperates with the soleus, helping it to extend the ankle. (The gastrocnemius, however, crosses the knee as well as the ankle and affects both joints.)

The ankle is not a simple hinge joint. As well as flexion and extension, it can exhibit inversion (the sole of the foot faces the other leg) or eversion (the opposite movement). These movements are controlled by the tibialis posterior, which inverts the ankle, and the peronaeus muscles, which are antagonistic and evert it (Figure 4B).

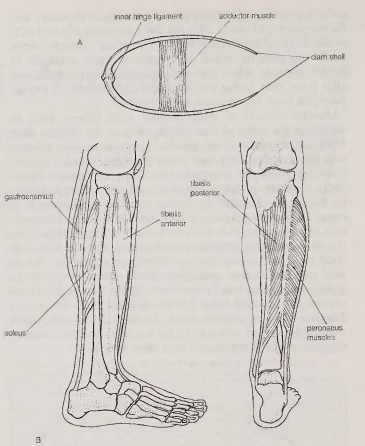


Figure 4: *Rigid skeletons worked by muscles.*
(A) Cross section of a clam shell. (B) Human lower leg.

A hinge such as the clam joint or the human knee performs just one kind of movement, flexion/extension, expressed in technical terms as allowing one degree of freedom of movement. The human ankle performs two kinds of movement, flexion/extension and inversion/eversion, allowing two degrees of freedom. Ball-and-socket joints, such as the human hip, allow three degrees of freedom. Most animal joints have at least two muscles (an antagonistic pair) for each degree of freedom.

Seldom are muscle fibres as long as a muscle, but many muscles, such as the biceps in the human arm, are composed of relatively long fibres lying nearly parallel to each other (Figure 5). These parallel muscles are attached to tendons or apodemes only at their extreme ends. Since muscle fibres can contract about one-third of their resting length, this arrangement is suitable to an extensive and quick movement. The deltoid muscle in the human shoulder is said to be pennate: relatively short fibres attach diagonally onto a tendon that penetrates far into the muscle. The ankle muscles shown in Figure 4 are pennate muscles, but most of the hamstring muscles (at the back of the thigh) are parallel. The adductor muscles of the shells of clams are parallel, but most of the leg muscles of arthropods are pennate. A pennate muscle may contain many more and shorter fibres than a parallel muscle of equal mass. Therefore, the pennate muscle can exert a greater force but cannot shorten a great deal; the parallel-fibred muscle can exert only a relatively small force but can shorten significantly. The presence of pennate muscle in a given structure may have the same effect as a longer lever arm. In the slender legs of arthropods, with insufficient space for bulky muscles or long lever arms, many of the muscles are pennate.

Pennate muscle

Tendons and apodemes (in arthropods, chitinous rods that serve as sites for muscle attachment) have elastic properties. Tendons in the legs of mammals serve as springs, reducing the energy cost of running: energy that is lost as the foot hits the ground and decelerates the body is stored as elastic strain energy in tendons and is subsequently returned in an elastic recoil. An apodeme in the hind legs of locusts is one of the important elastic elements in the catapult mechanism that powers jumping.

MUSCLE IN SOFT ANIMALS

Slugs, worms, and many other invertebrate animals have no skeleton, and thus movement is not produced by lever

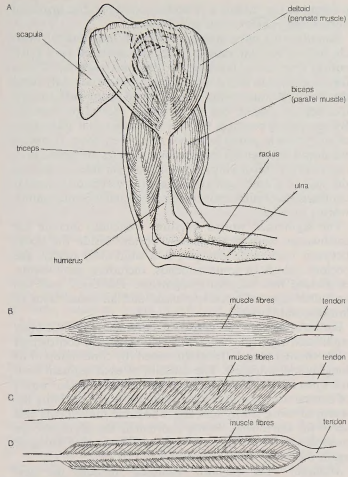


Figure 5: *Gross muscle structure.*
(A) Lateral view of some muscles in the human upper arm. (B) Parallel fibred muscle. (C,D) Two types of pennate muscles.
Adapted from *Mellon's Illustrated Medical Dictionary* (1978); reproduced by permission of Williams and Wilkins, Baltimore

action. Even vertebrates have parts of the body that have muscles but no skeletal component (for example, the tongue). Many soft-bodied animals have muscle systems based on the principle illustrated in Figure 6, which shows a simple wormlike animal. The longitudinal muscle fibres run lengthwise along the body and the circular fibres encircle it. The body contents are liquids or tissues that can be deformed into different shapes, but they maintain a constant volume. If longitudinal muscles contract and the body shortens, it must widen to accommodate its volume; if the circular muscles contract and the body thins, it must lengthen. Thus the longitudinal and circular muscles are antagonistic, and shortening of either extends the other.

Antagonism of muscles

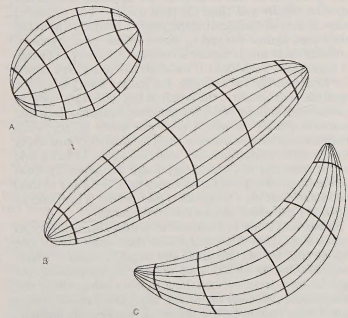


Figure 6: *Changes in body form in wormlike soft-bodied animals.*
(A) The longitudinal muscle contracting. (B) The circular muscle contracting. (C) The longitudinal muscle above contracting while the circular muscles maintain a constant length, stretching the longitudinal muscles below.

Further, if the length of a circular muscle remains constant while the longitudinal muscle of one side of the body shortens, the body bends and the longitudinal muscle of the other side is stretched. Thus the longitudinal muscles of the left and right sides can be antagonistic toward each other. In worms the body fluids render muscles antagonistic through hydrostatic forces. The principle involved is sometimes called the principle of the hydrostatic skeleton.

The principle of the hydrostatic skeleton can apply to individual muscles as well if their fibres run in several directions. For example, in a muscle that has some fibres running longitudinally and others running circularly and/or radially, when the longitudinal fibres shorten, the muscle becomes shorter and fatter; and when the circular and radial fibres shorten, it becomes longer and thinner. There are many examples of muscle structure like this in the mollusks. One such is the shell muscle of the abalone *Haliotis*, which connects the domed shell of the animal to its adhesive foot. When the muscle shortens, with the foot attached to a rock, the shell is pulled down over the animal to protect it. When the muscle lengthens (by contraction of circular and radial fibres) the shell is raised from the rock, allowing respiratory water currents to circulate.

Muscle systems

INVERTEBRATE MUSCLE SYSTEMS

Cnidarians. The phylum Cnidaria includes the hydras, jellyfishes, and sea anemones. Cnidarians have two main body forms, the cylindrical tentacled polyp exemplified by the hydra and the sea anemone, and the bell-shaped (or inverted saucer-shaped) medusa. Hydras are some of the simplest multicellular animals to have muscle. They are hollow, cylindrical, freshwater creatures about 10 millimetres long. One end attaches to a plant or some other support, and the other end is free and has a mouth surrounded by tentacles. The body wall consists of two layers of cells with a middle gelatinous layer (mesoglea). In hydras and other two-layered animals one kind of cell serves as both muscle and epithelial cells. The compact body of each cell is packed closely with the adjacent cells to form an epithelium, and the base of each cell, where it meets the mesoglea, is drawn out into a long muscle fibre. Hydras and medusae

In the hydra the musculoepithelial cells that cover the outer surface of the body have longitudinal muscle fibres; those that line the gut cavity (the gastrodermis) have circular muscle fibres. Sea anemones have all of the muscle fibres in the gastrodermis, though some of the fibres are longitudinal and some are circular. When the mouth of the sea anemone is closed, the water in the gut cavity acts as a hydrostatic skeleton, permitting the animal to grow longer and thinner or shorter and fatter, or to bend in any direction. These changes result from the interaction of the longitudinal and circular muscles through movements that are not as simple as those of the schematic worm of Figure 6. The hydra can reduce its volume by using its muscles to squeeze water out of the gut cavity through the open mouth. It can reinflate using cilia to circulate water into the gut cavity. Its movements are also influenced by the viscoelastic properties of the mesogleal jelly.

The largest and most familiar medusae are the jellyfishes of the class Scyphozoa, some of which grow to a diameter of two metres. Though large, the scyphozoan jellyfishes have only a single layer of cells on the outer surface of the body and a single layer lining the gut cavity; most of the volume of the animal is occupied by the gelatinous mesoglea. The epidermis of the undersurface of the bell includes the musculoepithelial cells responsible for the animal's weak swimming movements. The muscle fibres contract, reducing the diameter of the bell and forcing out a stream of water. The bell then returns to its original shape by elastic recoil of the mesoglea. These movements are performed in a regular rhythm with a period of a few seconds, propelling the animal through the water. Medusae are among the simplest animals that use muscles to make rhythmic movements. In at least some medusae the circular muscles, which do most of the work of swimming, are striated. In contrast, most of the other muscles of cnidarians are smooth. Jellyfishes

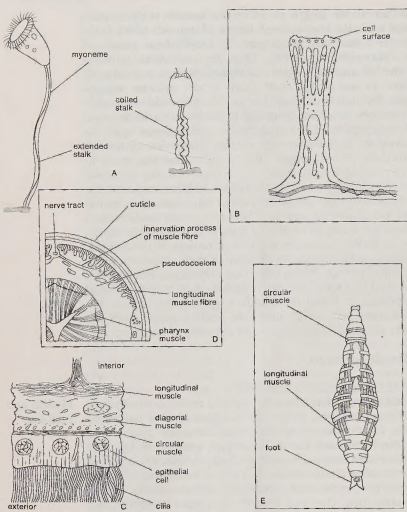


Figure 7: *Types of invertebrate contractile systems.* (A) Contractile stalk in protozoan *Vorticella.* (B) Epitheliomuscle cell of coelenterate *Hydra.* (C) Longitudinal section through ventral portion of body wall of freshwater flatworm. (D) Quadrant of cross section through a nematode (*Ascaris*) at level of pharynx. (E) Muscle bands in body wall of rotifer.

From (A) Parker and Haswell, *A Textbook of Zoology,* St Martin's Press, Inc., Macmillan & Co., Ltd., (B) W. Andrew, *Textbook of Comparative Histology* (1956), and (C,D,E) *Invertebrate Zoology* by Paul Meglitsch. Copyright © 1967 by Oxford University Press, Inc. Reprinted by permission

Multilayered animals. *Worms.* Although all worms have more than two layers of cells and most have long, slender bodies, the various groups of worms are different from each other in other respects.

The simplest worms are the flatworms (phylum Platyhelminthes), most of which have flattened shapes like leaves or ribbons. Although musculoepithelial cells have been found in some flatworms, the muscle cells in most are distinct from the epithelial cells. There is a layer of circular muscle fibres immediately under the epidermis, a layer of diagonal fibres, and a still deeper longitudinal layer (Figure 7C). There are also dorsoventral muscle fibres running from the upper to the lower epidermis of the flattened body. These sets of muscle fibres act in various combinations to make the body long and thin, short and fat, or bent to one side or the other. These muscles are also used by some of the larger flatworms to pass waves of muscular contraction along the body, enabling the worm to crawl in a snaillike fashion.

Many flatworms have a mouth opening connected to the pharynx, a muscular tube that conveys food from the mouth to the intestine. In some flatworms the pharynx is protruded and inserted into invertebrate prey, to digest and suck out the contents. The sucking is done by peristalsis, waves of muscular contraction that move along the tube from the mouth toward the gut. Although the muscle cells of flatworms are generally not musculoepithelial, their nuclei are found in large cell bodies. The muscle fibres of vertebrates and higher invertebrates, on the other hand, have no projecting cell body.

Roundworms

Roundworms (phylum Nematoda) also have large cell bodies on their muscle cells, but these muscle cells are unique in that nerve fibres do not travel to them as they do in the muscles of other animals. Instead, narrow projections of the muscle cell bodies extend to the principal nerves and contact nerve cells there.

Roundworms have obliquely striated, longitudinal muscle but no circular muscle. They are enclosed in a thick cuticle that allows bending but prevents swelling. Therefore, contraction of the longitudinal muscle can only bend the body. Roundworms do not bend from side to side like eels or snakes, but up or down (dorsal or ventral). By preventing swelling, the cuticle ensures that shortening of one muscle group stretches the other; thus, it makes the dorsal and ventral longitudinal muscles antagonistic to one another. Most crawl between soil particles or among the villi of a host's gut by undulating waves of muscular contraction. Similar movements also enable some roundworms to swim.

The segmented worms (phylum Annelida) include the earthworms and many marine worms. Inside the body, between body wall and gut, is a fluid-filled cavity, the coelom, which in some annelids, including earthworms, is divided into successive segments. The body wall has an outer layer of circular muscle and an inner layer of longitudinal muscle.

Earthworms crawl by peristaltic contractions of the body wall. Each segment is alternately elongated (by contraction of its circular muscles) and shortened (by contraction of its longitudinal muscles). The muscles of each segment contract just after those of the segment in front, so that waves of contraction pass backward along the body, enabling the worm to move slowly forward. The same movements also serve for burrowing. While shortened, the segments are pushed against the burrow wall, and when they elongate again the worm moves forward.

Mollusks. The phylum Mollusca includes the gastropods (snails, slugs, periwinkles), the bivalves (clams, oysters, mussels, and scallops), the cephalopods (octopods and squids), and other smaller classes. All mollusks, except the cephalopods, have a highly muscular organ called the foot, through which muscle fibres run in all directions. The foot of a gastropod is a flat structure used for crawling. Waves of muscular contraction travel along its length, moving the animal slowly over the ground. The foot of a bivalve mollusk is a bulbous or tonguelike organ that is used for burrowing in sand or mud. The foot pushes down into the substrate, then swells to anchor itself and pulls the rest of the animal down behind it.

In addition to the muscles of the foot, gastropod and bivalve mollusks have large muscles attached to their shells. The columellar (shell) muscles of gastropods pull the foot and other parts of the body into the shell. The adductor muscles of bivalves (Figure 4) shorten to close the shell or relax to allow the shell to spring open, enabling the mollusk to extend its foot or to feed. The adductor muscle can shorten rapidly and close the shell quickly. The muscle is also capable of maintaining the tension needed to hold the shell shut against the spring action of the hinge ligament without using much metabolic energy. Economy of energy is particularly important if the shell has to be kept closed for long periods; for example, for several hours while the mollusk is exposed on the beach at low tide. Fast muscles can shorten rapidly because their cross bridges detach and reattach quickly; however, they use much energy while maintaining tension because there is an energy cost every time a cross bridge detaches and reattaches. Muscles that are economical in their energy usage are generally slow. Accordingly, most bivalve mollusks have two parts to their adductor muscles, a translucent part, which is fast, and an opaque part, which is slow but economical.

Squids and cephalopods

Squids and other cephalopod mollusks also swim by jet propulsion. They draw water into the mantle cavity (the cavity that houses the gills) and expel it rapidly. Vigorous movements of this kind provide jet propulsion, but gentler ones serve for breathing by circulating water, and thus oxygen, through the mantle and gills. Fast-swimming squid have mantle cavities whose muscular walls make up as much as 35 percent of the mass of the body.

These walls mainly consist of circular muscle fibres that squeeze water out of the mantle cavity when they contract. Other fibres run radially through the thickness of the wall. These fibres make the wall thinner when they

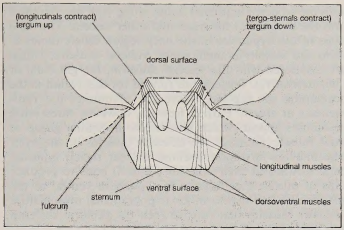


Figure 8: Muscles involved in insect flight (see text).
From C.A. Villee, W.F. Walker, and F.E. Smith, General Zoology (1963), W.B. Saunders Company

contract, stretching the circular muscle and enlarging the cavity again. Cephalopods do not have longitudinal muscle fibres; however, layers of collagen fibres on the outer and inner surfaces of the muscle prevent the animal from lengthening when the muscles contract. Thus the circular and radial muscle fibres are antagonistic. Enlargement of the cavity, however, is not solely due to the radial muscle fibres: the cavity tends to expand by elastic recoil of the tissues, when the circular muscles relax.

Though many mollusks have shells, most molluscan muscle systems depend on the principle of the hydrostatic skeleton. In some cases body fluids are involved, for example, in the feet of clams, which are extended and inflated by inflow of blood. In other cases the muscle itself serves as the incompressible element that must thicken as it shortens or become slender as it elongates, to maintain constant volume. Examples include the shell muscle of the abalone and the tentacles of squid, which are shortened by contraction of longitudinal muscle fibres and lengthened by circular and transverse ones.

Arthropods. Arthropoda is the largest phylum of invertebrate animals and comprises the crustaceans, insects, arachnids (spiders and scorpions), and other classes. Some arthropods have soft-bodied young stages in which the principle of the hydrostatic skeleton is important. Most adult arthropods are encased in a skeleton with jointed appendages formed from a stiff cuticle that is divided into separate plates to assist in movement. This skeleton, working as a system of levers, is largely responsible for making muscles antagonistic.

Insect wings

The wing muscles of dragonflies (Odonata) and those of some other insects are worked in simple, direct ways by pulling on the wing bases and making them pivot about their joints. More advanced insects, including flies (Diptera), work their wings indirectly by muscles that attach to other parts of the skeleton. Although the details of the mechanisms are complicated, the basic principle is simple. Each wing-bearing segment of the body is enclosed by two main plates of cuticle, a tergum above and a sternum below (Figure 8). These plates are flexible enough to be distorted by muscle action. Distortions of the tergum are particularly important in the wing mechanism.

The principal wing muscles are the dorsoventral muscles, which run vertically from the sternum to the tergum, and the longitudinal muscles, which run lengthwise along the segment. Contraction of the longitudinal muscles makes the tergum bow upward, and contraction of the dorsoventral muscles pulls it down again. The wings have joints connecting them to the tergum and to the sternum. Upward movement of the tergum (from contraction of the longitudinal muscles) lowers the wings and downward movement (from contraction of the dorsoventral muscles) raises them.

All arthropod muscles seem to be striated, not obliquely striated or smooth, and the sarcomeres are of varying lengths. In locusts the sarcomeres (the primary structural and functional unit responsible for contraction; see below *Striated muscle: The myofilament*) of wing muscles are 3.9 micrometres long, but the sarcomeres of leg muscles (which do not have to contract so quickly) are 8.5 micrometres long. Wing muscles in many other insects have shorter sarcomeres, often about the same length as those in mammalian muscle (about 2.5 micrometres).

The force exerted by the muscle is controlled by varying the frequency of action potentials in the axons (an extension of the nerve cell that conducts nerve impulses away from the cell body). The higher the frequency, the larger the force, within limits. In contrast, in vertebrates each muscle is served by many motor axons, each of which is connected to only a small group of muscle fibres. In the twitch muscles that predominate in vertebrates, each muscle fibre is either inactive or fully active and force is varied by recruiting different numbers of muscle fibres. Like those of other animals, most arthropod muscles require an action potential to initiate each contraction.

Fibrillar muscle

Fibrillar muscle is found in the sound-producing, or tymbal, muscles of some cicadas and in the wing muscles of several orders of insects including the Diptera (flies), Coleoptera (beetles), Hymenoptera (wasps), and Hemiptera (bugs). Most fibrillar muscles work at high frequencies, often of several hundred cycles per second, but they are kept working by action potentials arriving at much lower frequencies. They contract at the resonant frequency of the tymbal or of the wing system. Clipping the wings of an insect that has fibrillar wing muscles increases the frequency of the wing beat, because reduction of the vibrating mass increases the resonant frequency.

All insect wing muscles work aerobically and produce high power outputs. Consequently they need many mitochondria, which may occupy 40 percent or more of their volume both in fibrillar and in non-fibrillar muscles. Non-fibrillar muscles that work at high frequencies also need large sarcoplasmic reticulums, but fibrillar ones do not.

Although insect muscles seem always to work aerobically, some crustacean muscles can work anaerobically. The leg muscles that the crab *Callinectes* uses for swimming include two types of fibres. One type resembles the red muscle fibres of vertebrates in that it is deep pink and contains a high proportion of mitochondria. The other resembles vertebrate white fibres because it is white with far fewer mitochondria, and presumably works anaerobically. Similar differences occur in other crustacean muscles. Crabs use anaerobic metabolism for short bursts of violent activity in the way that vertebrates do.

Echinoderms. The phylum Echinodermata comprises the starfishes, sea urchins, and their relatives. Their internal skeletons are made of porous blocks of calcium carbonate and they have muscles to work their skeleton. Echinoderms also have a hydraulic system, the water-vascular system, with movable projections from the body called tube feet.

Tube feet

The details of the tube feet differ among the different groups of echinoderms, but Figure 9 shows the arrangement in sea urchins. Five double rows of tube feet project through the test, so that every part of the body surface has tube feet near it. The tube feet are slender tubes, with

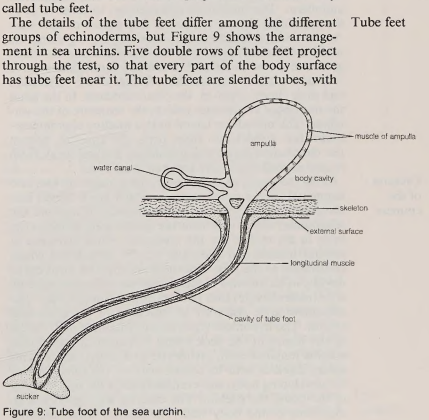


Figure 9: Tube foot of the sea urchin.

a sucker on the closed end. Muscles in the sucker enable it to attach to objects, so the tube feet can be used by the animal to anchor, to move, or to manipulate its prey. Connective tissue in the tube feet limits their diameter but allows them to lengthen, to shorten, and to bend. The tube feet have only longitudinal muscles, which extend the length of the cavity of the tube foot. They are extended by water that has been forced into them by muscles in the wall of the ampulla at their bases. (W.F.W./R.McN.A.)

VERTEBRATE MUSCLE SYSTEMS

Major types of vertebrate muscle. In terms of its microscopic structure, the musculature of vertebrates is usually divided into three types: striated, cardiac, and smooth muscle. Smooth and cardiac muscle are under the control of the involuntary, or autonomic, nervous system. Striated muscle, on the other hand, is mainly under the control of the voluntary, or central, nervous system. Smooth and cardiac muscle are also similar in their development, being generally associated with the yolk sac. Striated muscle develops directly from the middle of the three embryonic layers, arising largely from the mesodermal somites (see below). In the adult, smooth and cardiac muscle are associated with organs or tubes (viscera), and striated (skeletal) muscle with the bony or cartilaginous skeleton.

Although some evidence suggests that a twofold division of the musculature into visceral and skeletal muscle might be appropriate, one set of striated muscles is distinct in development and in innervation from all other striated muscle. In humans these include both the muscles of the jaw and some of the muscles of the shoulder and are called the branchiomeric, or branchial, muscles. Branchiomeric muscles, even in humans, are innervated by visceral nerve fibres as is the case with smooth and cardiac muscle, not the somatic nerve fibres (those that supply the outer body wall or soma), and thus are usually grouped with the smooth and cardiac muscles despite their striated nature.

Vertebrate muscle divisions

The two major divisions of the vertebrate musculature are thus the visceral musculature (smooth, cardiac, and branchiomeric) and the somatic musculature (the striated muscles of the body wall). Somatic musculature may be divided into appendicular, or limb, muscles and axial muscles. The axial muscles include the muscles of the tail, trunk, and eyeballs as well as a group of muscles called hypobranchial muscles, which separate and migrate from the others during development.

Basic pattern of development. The gastrula is the stage of embryonic development at which the embryo appears as three distinct layers of cells (the germ layers): the exterior ectoderm, the middle mesoderm, and the interior endoderm. The mesoderm differentiates to form most of the remaining tissues, structures, and organs of the body. As the embryo lengthens, the mesoderm lying along the midline differentiates to form the chordamesoderm, which gives rise to the notochord, a hollow, cartilaginous nerve tube and a major distinguishing feature of the vertebrates and their closest relatives, the protochordates. In the adult the notochord contributes only to the structure of the vertebrae. The mesoderm lateral to this midline chordamesoderm then divides into three parts: the epimere, nearest the chordamesoderm; the hypomere, farthest away from it; and a small mesomere between these two.

Division of the epimere

Along the length of the embryo, the epimere divides into segmental blocks called somites, which again divide into three cell blocks: closest to the notochord appears the sclerotome, which will form the greater part of the vertebrae; in the middle lies the myotome, which gives rise to somatic muscle; and to the side lies the dermatome, which contributes to the skin. Appendicular muscles form either directly as outgrowths of the myotomes or from wandering cells (mesenchyme) that bud off from the myotomes. The mesomere gives rise only to structures of the urogenital system. The hypomere remains unsegmented, and, except in the region of the neck where it remains a solid mass, it splits longitudinally, giving rise to a central space. This space, together with its counterpart on the other side of the developing body, will eventually form the major cavity of the body, the coelom. The exterior layer gives rise to the lining of the body wall. The interior layer, together with the adjacent epithelial lining of the yolk sac, develops into the muscles of the heart and other viscera. The solid mass of the hypomere in the neck region differentiates to form the various branchiomeric visceral muscles, which are associated with the visceral skeleton, the gill bars, or their derivatives. Posterior to (dorsal to) this region is the developing ear capsule, where the myotomes are rudimentary or absent. Farther forward, however, three more myotomes appear, which give rise to a distinct group of axial muscles, namely the external muscles of the eyes. The first few myotomes behind the ear region typically bend forward at their anterior (ventral) ends to produce slips of muscle that migrate to a position ventral to the gill pouches and that form the hypobranchial musculature (somatic muscles that run between the pectoral skeleton and the jaw).

Comparative anatomy. One problem in discussing the differences in arrangement of muscles between the various vertebrate groups is in deciding which muscles in each species are homologous; that is, which have the same evolutionary and developmental origin. The problem arises because the position and attachment of muscles change during evolution: a muscle lying in the same position and attached to the same bone or cartilage in one vertebrate may have different origins from those of another vertebrate species. Comparison of the development of muscles in the embryo of each species, and of their nerve supply, probably will give the best clues. No single method may be relied upon in all cases, and many different types of evidence are considered before the homology is decided upon.

Origin of muscle names

Vertebrate muscles are given names derived from Latin according to their attachments. In this system, the Latin names of the bony points of attachment are either joined, as in the human "sternocleidomastoid," which runs from the sternum and clavicle to the mastoid region of the skull, or they may be named for their form or their gross function. There are several standard terms that describe form and function. A muscle may have more than one point of origin: thus it may be described as having, for example, two "heads" as in "biceps femoris" (*bi* for two, *-ceps* for heads, *femoris* meaning "of the femur"). It may be long, "longus," or short, "brevis." It may run transversely across a body segment "transversus," or obliquely, "obliquus." It may lie close to the surface, "superficialis," or deep, "profundus." In describing function, flexors are muscles that tend to close the angle made by the two bones to which they are attached, extensors tend to increase the angle. Adductors pull a bone or cartilage closer to the axis of the body, or limb, while abductors pull away from the axis. Rotators turn one bone or cartilage with respect to another, or turn it with respect to the midline. Pronators turn the sole of the foot or the palm of the hand to face the ground, while the opposite function is performed by supinators. Constrictors and sphincters diminish the volume of spaces or the area of structures, and dilators increase them. Because human anatomy is better understood than that of other species, the names of muscles in humans often have been applied to grossly equivalent muscles in animals, a situation that often causes confusion.

Jawless fishes. The earliest known vertebrates were jawless fishes of the class Agnatha, and their only living representatives are the cyclostomes—the lampreys and the hagfishes. The modern agnathans retain much of the general organization of the ancestral vertebrates, and therefore, much of their musculature is relevant to an understanding of the evolution of muscles in more advanced vertebrates.

Cyclostomes

The cyclostomes are free-swimming animals with prominent axial somatic musculature, which during contraction produces undulating waves that propagate from head to tail to produce thrust. The axial muscles form a single segmented mass in which each embryonic myotome has given rise to a strip of muscle running vertically down the side of the fish. These muscle segments, known as myomeres, consist of relatively short fibres that insert into septa of connective tissue, the myocommata, between the adjacent myomeres. There is only a rudimentary axial skeleton and no appendicular skeleton, so there are no limb muscles. The eyes of cyclostomes are degenerate

structures, and the six axially derived muscles normally found associated with vertebrate eyes are diminished or absent. The branchiomeric muscles in cyclostomes are represented by a sheet of constrictors that compresses the gill pouches and helps the pumping mechanism draw water through the pharynx to the gills. Other muscles of the branchiomeric series have been modified for specialized feeding functions.

Chondrichthyes

The branchiomeric musculature of more primitive jawless fishes would probably have been similar for each of the gill arches. The sharks and other cartilaginous fishes (the class Chondrichthyes) have modified the structure of the first two arches, the cartilages of the anterior arch forming the mandible and upper jaw (palatoquadrate), and modifications also having taken place in the second, hyoid arch. The posterior five gill arches of more primitive sharks, however, are a good model for the condition in the ancestral jawless fishes. Each arch has a visceral skeleton comprising five cartilages named, from dorsal to ventral, the pharyngobranchial, epibranchial, ceratobranchial, hypobranchial, and basibranchial. The cartilages are arranged at angles to each other. Each cartilaginous arch is provided with a set of branchial muscles, which receives separate, visceral innervation. Superficially, a thin sheet comprising dorsal and ventral constrictor muscles runs in the flap of skin that covers each gill slit and forms the gill septum. Most fibres attach, dorsally and ventrally, to connective tissue sheathing the body (fascia). Some of the deeper fibres attach to the gill bar and may run between adjacent bars. These thin, broad muscles squeeze the pharynx closed as part of the pumping action necessary for gill breathing. Dorsal and deep to this layer, a levator muscle runs from the sheathing fascia to the pharyngobranchial, and it can elevate the gill arch. In some sharks, however, the most posterior sets of levator muscles, whose fibres run diagonally down and back, may join adjacent levators, become enlarged, and attach to the pectoral girdle. This mass is known as the trapezius and evolves into the tetrapod muscle of the same name. Adductor muscles are positioned so as to close the angle between the epibranchial and ceratobranchial, and an interarcual muscle performs the same function for the angle between the pharyngobranchial and epibranchial cartilages.

Jawed fishes. In the jawed fishes, including the sharks, the axial musculature of the trunk and tail (a single block in cyclostomes) differentiates into dorsal and ventral components, which are separated by connective tissue. The dorsal block of muscle is known as the epaxial musculature, and the ventral block, the hypaxial (Figure 10A). The epaxial block runs from the back of the skull to the end of the tail, while the hypaxial block is not present any farther forward than the pectoral (shoulder) girdle (because of the presence of the branchial [gill] apparatus). The hypaxial musculature in the tail forms a solid block of muscle, while in the trunk it encloses the body cavity. Ribs develop in the horizontal septum separating the two blocks of muscle and usually lie in the myocommata, the fascial tissue separating each myomere (Figure 10B). In fishes, the ribs primarily serve to improve the leverage of the myomeres in producing the undulatory movements of swimming. The ribs are short in sharks but may develop to considerable length in bony fishes. Unlike the cyclostomes, where the myomeres form a series of essentially vertical strips of muscle, the myomeres of all jawed fishes are folded in a complex fashion. This development is related to the development of a more powerful swimming ability in the jawed fishes. The myomeres are folded in a zigzag pattern, projecting strongly forward halfway down the side of the fish, with a smaller, backward projection both dorsal and ventral to this point: the effect is of a W on its side. These projections become sharper and more cone-shaped deep to the surface of the fish and thus come both to be overlapped by the folds of several anterior myomeres and to overlap those of several more posterior myomeres. The folding and overlapping of myomeres has the effect that contraction of a single myomere produces curvature over a considerable part of the body of the fish. The fishes who swim faster thus tend to have a greater degree of folding and overlapping. In the tunny, for example,

Myomeres

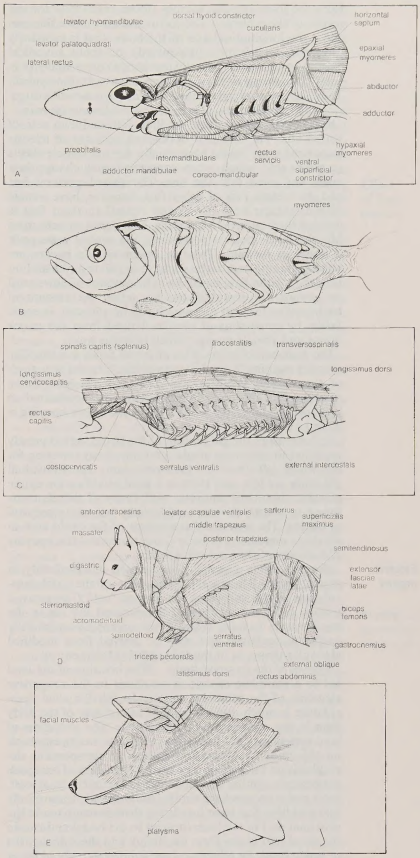


Figure 10: *Vertebrate trunk musculature.*
(A) Lateroventral view of anterior muscles of dogfish. (B) Lateral view of trunk muscles of salmon. (C) Axial muscles in lizard. (D) Lateral view of trunk muscles of a cat. (E) Lateral view of facial muscles of a dog.

From (A) W. Walker, *Vertebrate Dissection*, 4th ed. (1970), W.B. Saunders & Co., and (B,C,E) A. Romer, *The Vertebrate Body* (1964), W.B. Saunders & Co., and (D) *Chordate Anatomy* by H.V. Neal and H.W. Rand, Copyright © 1944 by McGraw-Hill Book Co. Used with permission of McGraw-Hill Book Company

one myomere may have an overlap with 20 others. The undulations of the body and caudal (tail) fin produced by these axial muscles can produce much greater thrust than is produced by the beating of the appendicular fins. The latter are mostly used in slow "precision" swimming, as when a fish is investigating food, while undulations of the body are used for faster, powerful swimming. The axial musculature of fishes contributes up to half the weight of the fish, while the appendicular muscle contributes less than a fifth of the fish's mass.

Eye muscles

In all higher vertebrates the most anterior element in the axial musculature is the set of six eye muscles derived

from the three pre-otic somites (those anterior to the ear region of the embryo). The rectus muscles move the eyes about the longitudinal axis of the body, that is superiorly (upward), or inferiorly (downward), or about a vertical axis, in other words, laterally (backward) or medially (forward), according to their position relative to the eyeball. They take appropriate names. The oblique muscles, superior and inferior, rotate the eyes about a transverse axis.

Jawed fishes have single midline fins and two sets of paired fins. The unpaired dorsal and anal fins of teleosts (advanced bony fishes) have axially derived muscle sheets on either side, which, when contracted, may change their angle and even fold the fins. The paired pectoral fins and the weaker pair of pelvic fins, however, have a mass of musculature both dorsal and ventral to them that is derived from mesenchymal cells. The dorsal muscle mass lifts the fin or pulls it posteriorly; the ventral mass pulls it down or forward. The two major muscle masses are attached at one end to the pectoral or pelvic girdle and on the other to the base of the fin. The amount of downward or upward movement of the fin versus the amount of backward or forward movement can be adjusted, in some fishes, by small slips of muscle derived from the major dorsal and ventral masses, which twist the fin.

The hypobranchial muscles of jawed fishes are straplike muscles running from the pectoral girdle to the structures of the visceral skeleton, the jaws, and gill bars. Some muscles, like the coracomandibularis, are specialized as jaw openers, although most of the work of jaw opening is done by gravity.

In bony fishes the gill septum of the hyoid arch is greatly modified to become a single, movable, bony covering for the whole gill chamber: the operculum. The individual gill septa are lost, and there is a great modification of the posterior branchial muscles, with many of the elements found in sharks (levators, adductors) becoming reduced or absent. The superficial constrictor of the hyoid arch in sharks is remodeled in bony fishes to control the opening and closing of this protective cover.

Electric organs

Electric organs appear to have arisen independently in several fishes. They are modifications of the axial musculature of the tail, as in the electric "eel" *Gymnotus,* a teleost, or of the muscles of the pectoral fins, as in the ray *Torpedo.* In a few cases electric organs lie superficially to the musculature and may be derived from modified glandular tissue, as in the Nile catfish *Malapterurus.*

Origins of the tetrapod limbs. The invasion of the land led to a complete change in emphasis in the propulsive elements of the muscular system. In fish the axial musculature is much more important as a mover of the body than is the appendicular musculature. The evolution of land vertebrates is characterized by an increasing emphasis on the limbs for propulsion and by a corresponding deemphasis on the axial musculature. The limbs of tetrapods are generally similar in overall pattern. Primitively, at least, most major groups have similar characteristic features: the fore and hind feet have five digits; there is one bone in the proximal part of the limb (nearest to the body) and two in the distal part (away from the body); and there are a wrist or ankle joint, an elbow or knee joint, and a shoulder or hip joint. Although most muscles have several roles, the major actions of tetrapod limb muscles are similar: some primarily resist the downward force of the body at hip and shoulder; others press the supporting fore or hind feet down onto the ground at wrist or ankle or pull back on the supporting limbs (at all three joints) to create thrust; others primarily pull the "swing" limbs forward into a new support position.

The limbs may originally have developed more as supportive struts. Structurally, the tetrapod limb can be derived from the pattern found in the paired fins of Sarcopterygii, a class of lobe-finned fishes. These were once a large radiation but largely have been replaced by the Actinopterygii, the class of ray-finned fishes. Today, the lobe-finned fishes are represented by *Latimeria,* the coelacanth, and the lungfishes, or *Dipnoi.* The lungfishes, denizens of shallow and seasonal waters, habitually use their fins as supports, but propulsion is largely achieved by undulations of the body as is the case with other fish.

Amphibians

Tetrapod musculature. In the living urodeles (the newts and salamanders) of the class Amphibia, the axial muscles are most important for propulsion. The limbs of urodeles are quite weak and tend to be carried forward passively with the undulations of the body. As the primary propulsive force is provided by the muscles of the trunk, urodeles retain large axial muscles. The axial muscles are still segmented, separated by myocommata, although the myomeres run vertically and without the elaborate folding seen in jawed fishes. The epaxial muscles, given the name "dorsalis trunci" in tetrapods, are little changed, although some modification has taken place to promote a facility for dorsoventral bending of the spine that occurs in tetrapods but rarely in fishes.

The anurans (frogs and toads) have rather similar, but considerably reduced, epaxial muscles. There is, however, a trend in tetrapods toward finer control of muscular action with increasing complexity. In the reptiles the epaxial muscles, although still retaining a semisegmental structure, are divided into several structural and functional units. The deepest set of muscles, the transversospinalis group, are short and run obliquely forward, over one to four vertebrae, from the transverse process of one vertebra to the lamina (the flat plate of bone at the base of the vertebral spine) of a more anterior vertebra (Figure 10C). The transversospinalis group is particularly responsible for rotatory movements of the spine. Superficial to transversospinalis lies longissimus, with much longer fibres, which is important in extension of the back. More superficially still, and lateral to these muscle blocks, iliocostalis is a flat, sheetlike muscle that runs from the pelvic girdle upward and laterally to attach to the ribs. It is particularly important in lateral flexion (bending) of the spine. This general pattern is further complicated in snakes, which have secondarily returned to the propulsive use of the axial muscles. In birds the vertebral column of the trunk region undergoes much fusion, and this complexity is reduced, as indeed it is in chelonians (turtles and tortoises). Mammals retain the broad pattern of the reptile epaxial musculature but (with the exception of the innervation of the musculature) have greatly reduced the segmentation that is present in reptiles (Figure 10D and 10E).

In the tails of urodeles the hypaxial muscles are also largely unchanged. As with all land vertebrates, however, the demands of support of the viscera when living in an air environment have brought about major modifications of the hypaxial musculature of the trunk. In typical tetrapods a strong series of ribs has developed for the same reason. Although urodeles have secondarily reduced their ribs, they show many of the typically tetrapod features of the hypaxial musculature. The muscles fall into three groups. A group of subvertebral muscles forms ventral to the vertebrae, in the region of their joints with the ribs at the transverse processes. It acts in ventral and lateral flexion (bending) of the spine. A rectus abdominis muscle runs longitudinally along the ventral aspect of the body wall between the pectoral and pelvic girdles, and laterally this is associated with the third group, the lateral hypaxial muscles. This consists of three major layers of muscle whose fibres are oriented in differing directions, a feature that gives additional strength to the body wall. Superficially lies the external oblique muscle, with fibres running longitudinally but somewhat ventrally; deep to this lies the internal oblique, with fibres running longitudinally and somewhat dorsally; and deepest lies the transversus muscle, whose fibres run dorsoventrally.

Trunk modifications

In the higher tetrapods the external and internal obliques tend to become further divided into layers in the abdominal region. The thoracic representatives of these muscles tend to become divided into discontinuous, rather thin muscle layers between the ribs (external and internal intercostals), superficial to the ribs (supercostals), and deep to the ribs (subcostals). While only the rectus abdominis tends to retain visible evidence of segmental origin, in its tendinous intersections (which are present even in humans) the segmental innervation of the hypaxial muscles is retained in all tetrapods.

Pectoral girdle

In tetrapods, unlike fishes, the pectoral girdle does not have a solid bony connection to the axial skeleton but

rather is supported by a series of muscles derived from the outer layer of hypaxial trunk muscles. This is no doubt another adaptation to life in an air environment, where the cushioning effect of water has been lost. These muscular slings are not readily demonstrated in the living amphibians, which are either skeletally degenerate as in urodeles or highly specialized toward leaping, as in the anurans (frogs and toads). In more typical tetrapods, there are two major derivatives of the external oblique attaching the scapula (shoulder blade) to the body: first, the serratus, made up of numerous fingerlike slips running from the scapula to the neighbouring ribs; second, levator scapulae, which are fused with serratus along its caudal (tail-end) border. Levator scapulae consist of fibres running more anteriorly to ribs or transverse processes of the neck. Mammals, and some reptiles, have a third such muscle, attaching the pectoral girdle to the region of the spine, called rhomboideus. The mammals also have utilized part of the hypaxial musculature to form a muscular septum between the region of the lungs and heart (the thoracic cavity) and the region of the digestive and reproductive viscera (the abdominal cavity). This is the diaphragm, which is the most important respiratory muscle in the mammalian body.

Eye movements

The six axially derived eye muscles of fishes undergo only small modifications in tetrapods. Eye movements are changed, partly according to changes in the orientation of the orbit such as the trend toward orbital frontality that is typical in the primates. Additional eye muscles may be derived by splitting some of these six muscles. An example of this is the retractor bulbi muscle, which is derived from the lateral rectus muscle. In amphibians and some reptiles it pulls the eyeball deeper into the orbit for protection, and in amphibians it is an aid in swallowing. Another example is the levator palpebrae superioris, derived from the superior rectus, which elevates the upper eyelid to open the eye.

The limb muscles of typical tetrapods are derived from the dorsal and ventral muscle blocks of the paired fins of fishes. In tetrapod development, this pattern of derivation from dorsal and ventral muscle blocks is repeated. As a consequence, the homologies of the muscles of the typical tetrapod limb often can be traced by considering the source of innervation of each muscle from the nerves of the dorsal (or extensor) compartment or the ventral (or flexor) compartment.

Latissimus dorsi

In the pectoral limb, the dorsal, extensor group of muscles includes several that appear consistently and with similar roles. Beginning with the muscles that act on the humerus (the proximal bone of the limb), all tetrapods have a large, sheetlike muscle, known as the latissimus dorsi, which runs from the side of the trunk to the humerus. The latissimus dorsi muscle retracts the humerus and thus propels the body forward. Acting to rotate, flex, or adduct the humerus, depending on limb posture, is a muscle known as subcoracoscapularis in amphibians, reptiles, and birds and subscapularis in mammals. It runs from the deep surface of the shoulder girdle to the humerus. In amphibians, the dorsalis scapulae arise from the anterior edge of the scapula. The same muscle is known as the deltoideus in reptiles and mammals, and in the latter, part of its origin moves from the scapula to the clavicle (collar bone). It is a major abductor of the shoulder in most tetrapods. At the elbow joint, all tetrapods have a muscle called triceps as the major extensor. It arises in several heads from the shoulder girdle and humerus. There are always a variable number of extensor muscles for the wrist and digits (fingers and toes) arising from the region of the elbow joint, on the lateral aspect of the humerus.

On the ventral, flexor aspect of the pectoral limb, the pectoralis is found in all tetrapods. The pectoralis runs from the chest wall to the humerus, on which it acts to pull the humerus downward and backward. This muscle is not only important in providing forward thrust in quadrupedal locomotion but is the chief depressor of the forelimb in birds and bats. The major elevator of the wing in birds, supracoracoideus, is present in all tetrapods. In mammals, the supracoracoideus retains its attachment to the humerus, but its previous point of origin (the coracoid plate) disappears and the muscle now appears as two separate blocks of muscle arising on either side of the spine of the scapula as an abductor muscle (supraspinatus) and a rotator and flexor (infraspinatus). Coracobrachialis and (except in amphibians) biceps arise from the tip of the coracoid and act to flex the elbow. In this they are aided by the brachialis muscle, which arises from the humerus. As on the extensor aspect, there are always a number of flexors of the wrist and digits. These arise on the medial side of the distal humerus.

Effect of limb posture

The muscles of the pelvic limb cannot be readily compared beyond the reptiles and mammals. Even in these cases, changes in limb posture have led to major changes in the arrangement and function of muscles. On the dorsal aspect, a single, large muscle in reptiles, puboischiofemoralis, runs from the bones of the pelvis to the femur (the proximal bone of the hind limb). This reptilian muscle appears to be represented by three mammalian hip muscles: psoas, iliacus, and pectineus. Iliofemoralis acts as an abductor of the hip in reptiles and appears to be represented by the gluteal muscles in mammals, but the function of the gluteal muscles is different. More similar in reptiles and mammals is the quadriceps or quadratus femoris, which consists of multiple heads (four in mammals) that arise from the pelvic girdle and femur and insert by a common tendon into the tibia (the larger bone of the distal pectoral limb). It is the sole extensor of the knee joint in both the reptiles and the mammals. The extensors of the ankle and digits in both reptiles and mammals are not dissimilar to those of the pectoral limb and take origin from the lateral and anterior surfaces of the two distal bones of the pelvic limb. On the ventral aspect of the hind limb, small, deep muscles run from the internal and external pelvis to the head of the femur and help in adduction and rotation. Of these, the puboischiofemoralis externus of reptiles appears to be represented by the obturator externus of mammals, and similarly the ischiotrochantericus of reptiles appears to be the homologue of the obturator internus of mammals. Again, the major adductor of the hip of reptiles, adductor femoris, appears to be homologous with some of the muscles called the adductors in mammals. There seem to be some homologies between the major flexors of the hip and thigh in reptiles, such as puboischiotibialis, and two deeper muscles, flexor tibialis externus and internus, and some functionally equivalent muscles in mammals: the gracilis, semimembranosus, and semitendinosus. In reptiles, the axial muscle of the tail is strong, and the caudifemoralis, a powerful flexor of the thigh which originates in the tail, is consequently large. The tail in mammals, although usually present, is much more gracile, and as a result caudofemoralis is represented by only a few small muscles. Another major change is in the flexors of ankle and digits. In reptiles, these insert by long tendons passing below the ankle joint, much as in the forelimb. In mammals, however, the equivalent long flexor, gastrocnemius, inserts on a new bony process, the calcaneal tuberosity or heel bone, which gives more efficient leverage.

Reptile and mammal homologies

The hypobranchial muscles of tetrapods are both reduced and modified in comparison with those of jawed fishes. In tetrapods these straplike muscles still arise from elements of the pectoral girdle but now pass to the new derivatives of the gill arches of fishes: the hyoid bone and laryngeal cartilages. They act primarily in the gross movements of these structures in swallowing and the production of sound—for example, as depressors of the hyoid (sternohyoid, omohyoid) or of the larynx (sternothyroid). Fibres of the hypobranchial muscles in the region of the hyoid are utilized to form the internal musculature of the tongue.

The branchial musculature is also modified in tetrapods from the condition seen in jawed fishes. The development of a shoulder muscle, the trapezius, from the levator muscles of the gill arches of fishes, as previously discussed, is taken further in tetrapods, by the separation of further slips of muscle to form muscles such as sternocleidomastoid, a muscle important for humans in movements of the head and in breathing. In mammals that lose the clavicle, these slips may further be modified to form muscles running from the head to the pectoral limb. Tetrapods,

with the exception of mammals, utilize part of the constrictor muscle of the hyoid arch to form the depressor mandibulae, which replaces the hypobranchial muscles as the major jaw-opening muscle. The restructuring of the posterior jaw in mammals leads to the further replacement of this new muscle by the digastric, which is a compound muscle made up of parts of the constrictors of the first and second branchial arches. Thus it is partly innervated by the mandibular division of the fifth cranial nerve (as is the case with other jaw muscles and the tensor tympani, one of the muscles of the ear), and partly by the seventh cranial nerve, the facial nerve (which also supplies an ear muscle associated with the stapes, an ear bone derived from the hyoid arch). The levator palatoquadrati, which elevates the upper jaw in jawed fishes, is retained as a jaw muscle in birds and in some reptiles, as they share the ability of fishes to move the upper jaw. The adductor mandibulae is much altered in tetrapods, although its overall function is retained. During the course of tetrapod evolution it becomes a superficial muscle, and in mammals it splits into several functional units arising from the undersurface and side of the skull and attaching to various points on the mandible. These are: the lateral pterygoid, which pulls the jaw forward; the medial pterygoid and its partner, the masseter, which close the jaw and move it from side to side; and the temporalis, which closes the jaw and pulls it backward. All are innervated by the first-arch cranial nerve, the fifth nerve. The intermandibularis of jawed fishes is retained as the mylohyoid of tetrapods, which is an elevator of the tongue.

Restructuring of the mammal jaw

Finally, the constrictor muscle of the hyoid arch, which in bony fishes is used to control the operculum, is remodeled in tetrapods as a sheathing superficial muscle of the neck, the sphincter colli. It derives its innervation from the nerve of the hyoid arch, the seventh, or facial, nerve. This cranial nerve is named from the further adaptation of the sphincter colli muscle in mammals, particularly in higher primates, as the many small muscles of facial expression, which allow people to smile, laugh, and frown.

MODIFICATIONS FOR UPRIGHT POSTURE AND HUMAN MUSCULATURE

Human muscles

Human muscle can be divided into striated (or skeletal), smooth, and cardiac. With a very few exceptions, the arrangement of smooth and cardiac muscle has undergone little modification with the assumption of the upright posture. A discussion of the changes in the striated, or somatic, muscles follows.

Evolutionary context. The arrangement of striated muscle in modern humans conforms to the basic pronograde (horizontal) quadrupedal vertebrate and mammaliam plan that was outlined in an earlier section. The primates inherited the primitive quadrupedal stance and locomotion, but since their appearance in the Cretaceous Period, several groups have modified their locomotor system to concentrate on the use of the arms for propulsion through the trees. The most extreme expression of this skeletal adaptation in living primates is seen in the modern gibbon family. Their forelimbs are relatively elongated; they hold their trunk erect; and for the short periods that they spend on the ground they walk only on their hind limbs (in a bipedal fashion).

Modern humans are most closely related to the living great apes, the orangutan, chimpanzee, and gorilla. Their most distant relative in the group, the orangutan, has a locomotor system that is adapted for moving among the vertical tree trunks of the Asian rain forests. It grips these trunks equally well with both fore and hind limbs and was at one time aptly called quadrumanal, or "four-handed."

There is little direct fossil evidence about the common ancestor of modern humans, chimpanzees, and gorillas, so inferences about its habitat and locomotion must be made. The ancestor was most likely a relatively generalized tree-dwelling animal that could walk quadrupedally along branches as well as climb between them. From such an ancestor, two locomotor trends were apparently derived. In one, which led to the gorillas and the chimpanzees, the forelimbs became elongated so that when these modern animals come to the ground they support their trunks by placing the knuckles of their outstretched forelimbs on the ground. The second trend involved shortening the trunk, relocating the shoulder blades, and, most importantly, steadily increasing the emphasis on hind limb support and truncal erectness. In other words, this trend saw the achievement of an upright bipedal, or orthograde, posture instead of a quadrupedal, or pronograde, one. The upright posture probably was quite well established by 3,000,000 to 3,500,000 years ago, as evidenced both by the form of the limb bones and by the preserved footprints of early hominids found from this time.

Human ancestor

Muscles of the lower limb. The major muscular changes directly associated with the shift to bipedal locomotion are seen in the lower limb. The obvious skeletal changes are in the length of the hind limb, the development of the heel, and the change in the shape of the knee joint so that its surface is flat and not evenly rounded (Figures 11, 12, and 13). The hind limbs of modern humans are proportional to body size, while the hind limbs of the apes are relatively short for their body size. The changes that occur in the bones of the pelvis are not all directly related to the shift in locomotion, but they are a consequence of it. Bipedality, by freeing the hands from primary involvement with support and locomotion, enabled the development of manual dexterity, and thus the manufacture and use of tools, which has been linked to the development in human ancestors of language and other intellectual capacities. The result is a substantially enlarged brain. Large brains clearly

Effect of bipedality

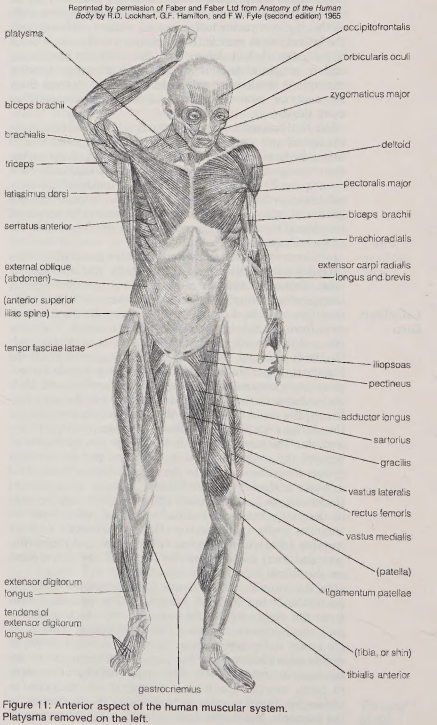


Figure 11: Anterior aspect of the human muscular system. Platysma removed on the left.

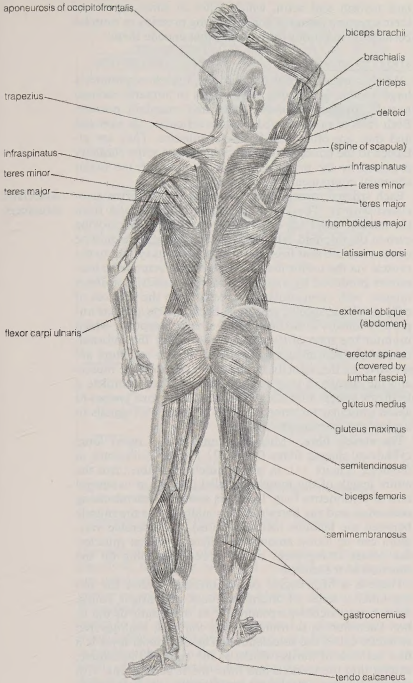


Figure 12: Posterior aspect of the human muscular system.
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affect the form of the skull, and thus the musculature of the head and neck. A larger brain also has a direct effect on the pelvis because of the need for a wide pelvic inlet and outlet for the birth of relatively large-brained young. The larger pelvic cavity means that the hip joints have to be farther apart. Consequently, the hip joints are subjected to considerable forces when weight is taken on one leg, as it has to be in walking and running.

To counteract this, the muscles (gluteus minimus and gluteus medius) that are used by the chimpanzee to push the leg back (hip extensors) have shifted in modern humans in relation to the hip joint so that they now act as abductors to balance the trunk on the weight-bearing leg during walking. Part of a third climbing muscle (gluteus maximus) also assists in abduction as well as in maintaining the knee in extension during weight bearing. The gluteal muscles are also responsible for much of the rotation of the hip that has to accompany walking. When the right leg is swung forward and the right foot touches the ground, the hip joint of the same side externally rotates whereas that of the opposite side undergoes a similar amount of internal rotation. Both these movements are made possible by rearrangements of the muscles crossing the hip.

The bones of the trunk and the lower limb are so arranged in modern humans that to stand upright requires a minimum of muscle activity. Some muscles, however, are essential to maintaining balance, and the extensors of the knee have been rearranged and realigned, as have the muscles of the calf.

Human foot

The foot is often, but erroneously, considered to be a poor relation of the hand. Although the toes in modern humans are normally incapable of useful independent movement, the flexor muscles of the big toe (hallux) are developed to provide the final push-off in the walking cycle. Muscles of all three compartments of the modern human lower leg contribute to making the foot a stable platform, which nonetheless can adapt to walking over rough and sloping ground.

Muscles of the upper limb. The major changes in the musculature of the upper limb involve the secondary effects that result from freeing the forelimb from a major supportive or propulsive role. The hand of a chimpanzee is dexterous, but the proportions of the digits and the rearrangement and supplementation of muscles are the major reasons for the greater manipulative ability of modern humans. Most of these changes are concentrated on the thumb. For example, modern humans are the only living great apes to have a separate long thumb flexor, and the short muscle that swings the thumb over toward the palm is particularly well developed in humans. This contributes to the movement of opposition that is crucial for the so-called precision grip; *i.e.,* the bringing together of the tips of the thumb and forefinger.

Pronation and supination of the forearm, which allows the palm of the hand to rotate 180 degrees, is not peculiar to humans. This movement depends upon the possession of both a small disk in the wrist joint and on an arrangement of the muscles such that they can rotate the radius to and fro. Both the disk and the muscle arrangement are present in other great apes.

Muscles of the head and neck. The muscle group of the head and neck is most directly influenced by the change to an upright posture. This group constitutes the muscles of the back (nape) and side of the neck. Posture is not the only influence on these muscles, for the reduction in the size of the jaws in modern humans also contributes to the observed muscular differences. Generally, these involve the reduction in bulk of nuchal (or nape) muscles. In the upright posture the head is more evenly balanced on the top of the vertebral column, so less muscle force is needed, whereas in a pronograde animal with large jaws, the considerable torque developed at the base of the skull must be resisted by muscle force. The poise of the human head does pose other problems, and the detailed attachment and role of some neck muscles (*e.g.,* sternocleidomastoid) is different in humans than in the apes.

Muscles of the trunk. The consequences of an upright posture for the support of both the thoracic and abdominal viscera are profound, but the muscular modifications in the trunk are few. Whereas in pronograde animals the abdominal viscera are supported by the ventral abdominal wall, in the orthograde posture most support comes from the pelvis. This inevitably places greater strain on the passage through the muscles of the anterior abdominal wall, the inguinal canal, which marks the route taken by the descending testicle in the male. Weakness in the canal can result in herniation.

Differences are also seen in the musculature (the levator ani) that supports the floor of the pelvis and that also controls the passage of feces. The loss of a tail in all the apes has led to a major rearrangement of this muscle. There is more overlap and fusion between the various parts of the levator ani in modern humans than in the apes, and the muscular sling that comprises the puborectalis in humans is more substantial than in the apes. (B.Wo./R.H.C.)

Muscle types

PRIMITIVE CONTRACTILE SYSTEMS

Cilia and flagella. Unicellular organisms such as the paramecium, a protozoan that lives in freshwater ponds and streams, propel themselves by the action of cilia. Cilia occur in large numbers and move in a coordinated way. Ciliated cells within the vertebrate body propel fluid and mucus along interior passages, such as the lining of the respiratory tract.

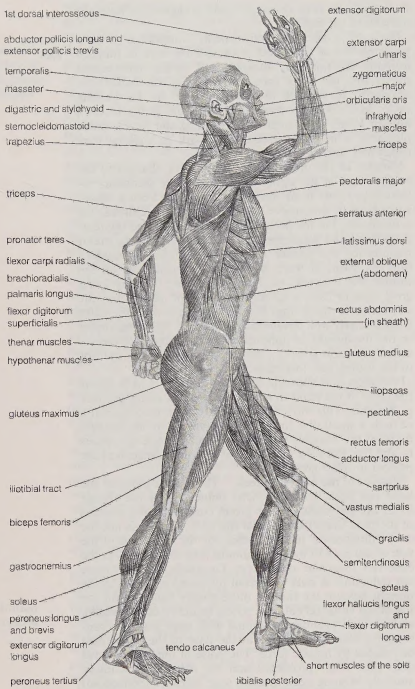


Figure 13: Lateral aspect of the human muscular system.

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Flagella are structurally similar to cilia, except that they are longer (sometimes up to 50 times longer) than cilia and usually number only one or two per cell. Sperm cells of most higher organisms move using flagella. Many types of unicellular algae and protozoans use flagella in swimming through the water.

Pattern of tubules

Both cilia and flagella contain a regular pattern of tubules extending along their lengths; there is an outer ring of nine pairs of tubules surrounding a central pair of tubules. Each tubule is composed of filaments comprising a string of globular subunits. The movement of a cilium or a flagellum requires energy, which is obtained from the breakdown of adenosine triphosphate (ATP), catalyzed by a protein attached to the outer tubules, dynein.

Some types of bacteria have flagella whose motion seems to depend on a cellular particle called the basal body, to which the flagellum is attached. Such flagella derive their energy from a difference in hydrogen ion concentration across the cell membrane.

Amoeboid motion. Amoeboid movement occurs as an extension of the cytoplasm, called a pseudopod ("false foot"), flows outward, deforms the cell boundary, and is followed by the rest of the cell. Many pseudopodia may be formed at the same time, and their actions do not seem to be coordinated.

Although amoeboid motion is characteristic of the amoeba, a unicellular protozoan, it is also found in non-muscle cells of multicellular organisms. These cells contain myosin and actin, which differ in some aspects of their structure from the corresponding proteins in muscles because of variations in the genes that encode them.

STRIATED MUSCLE

Whole muscle. Striated, or striped, muscle constitutes a large fraction of the total body weight in humans. Striated muscle contracts to move limbs and maintain posture. Both ends of most striated muscles articulate the skeleton and thus are often called skeletal muscles. They are attached to the bones by tendons, which have some elasticity provided by the proteins collagen and elastin, the major chemical components of tendons.

Associated structures

Each striated muscle has blood vessels and nerves associated with it. The vessels transport blood to and from the muscle, supplying oxygen and nutrients and removing carbon dioxide and other wastes. The signals that initiate contraction are sent from the central nervous system to the muscle via the motor nerves. Muscles also respond to hormones produced by various endocrine glands; hormones interact with complementary receptors on the surfaces of cells to initiate specific reactions. Each muscle also has important sensory structures called stretch receptors, which monitor the state of the muscle and return the information to the central nervous system. Stretch receptors are sensitive to the velocity of the movement of the muscle and the change in length of the muscle. They complete a feedback system that allows the central nervous system to assess muscular movement and to adjust motor signals in light of the movement.

The muscle fibre. Muscle is composed of many long, cylindrical-shaped fibres from 0.02 to 0.08 millimetre in diameter (Figure 14). In some muscles the fibres run the entire length of the muscle (parallel fibres), up to several tens of centimetres long. In others a tendon extends along each edge, and the fibres run diagonally across the muscle between the tendons (pennate fibres). Considerable variation can be found among the different skeletal muscles, the actual arrangement of the fibres depending on the function of the muscle.

There is a high degree of organization within the living fibre, a series of alternately dark and bright bands. Each band extends perpendicular to the length of the fibre. Each fibre is surrounded by a complex, multilayered structure called the sarcolemma. The outermost layer is a fine network of fibrils, which, at the ends of the muscle, extend into the tendons and form the structural link with them. The next layer of the sarcolemma is a foundation, or basement, membrane. The innermost layer is a plasma membrane similar to the ones that surround most cells. The plasma membrane consists of a lipid bilayer with proteins embedded in it. Some of the proteins are embedded entirely within the lipid layer; others extend to one or the other surface; still others span the whole width of the two layers. These proteins represent enzymes, receptors, and various channels (such as those involved in the movement of ions between the exterior and interior of the cell). The plasma membrane maintains the electrical potential, which plays a major role in stimulating muscle contraction.

Sarcoplasm

Sarcoplasm is the cytoplasm of a muscle fibre. It is a water solution containing ATP and phosphagens, as well as the enzymes and intermediate and product molecules involved in many metabolic reactions. The most abundant metal in the sarcoplasm is potassium. Sodium and magnesium are present in lower concentrations. Most of the calcium of muscle is bound to proteins or stored in the sarcoplasmic reticulum. Contraction is initiated by the release of calcium ions (Ca^{2+}) upon the depolarization of the membrane, which is induced by nerve impulses.

Each striated muscle cell, or fibre, contains many nuclei. This is the result of the fusion of singly nucleated cells that occurs during the embryological development of striated muscle. After fusion, the cells never again divide.

Mitochondria in the sarcoplasm of the muscle fibre contain the enzymes involved in the Krebs cycle and in oxidative phosphorylation. Granules in the sarcoplasm of muscle cells contain glycogen, the storage form of carbohydrate. The breakdown of glycogen and the metabolism of

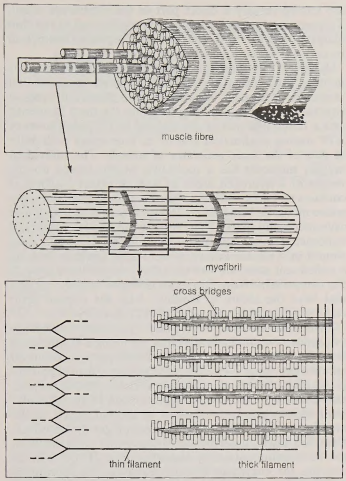


Figure 14: The spatial relationships of a striated muscle fibre, myofibrils, and sarcomeres (see text).
From E.P. Hammel, V.M.D., and K.M. Friedenberg, J. Vet. Med., M.R.C.V.S., in *Equine Medicine and Surgery*, ed. by E.J. Catcott (1972); American Veterinary Publications

the individual units of the resulting carbohydrate through glycolysis, the Krebs cycle, and oxidative phosphorylation are important sources of ATP, the immediate source of energy for muscle contraction. Muscles that contain many fibres that operate at a steady, low level of activity are red, owing to the presence of cytochromes (molecules involved in oxidative phosphorylation) and myoglobin (an oxygen-carrying molecule in the sarcoplasm). Muscles that work in bursts of activity contain fibres that have fewer mitochondria and fewer molecules of cytochromes or myoglobin, are white, and depend more heavily on reactions that do not require oxygen to make ATP.

The myofibril. Electron micrographs of thin sections of muscle fibres reveal groups of filaments oriented with their axes parallel to the length of the fibre. There are two sizes of filaments, thick and thin. Each array of filaments, called a myofibril, is shaped like a cylindrical column. Along the length of each myofibril alternate sets of thick and thin filaments (Figure 14) overlap, or interdigitate, presenting alternate bands of dark regions (with thick filaments and overlapping thin ones) and light regions (with only thin filaments). Within a fibre all the myofibrils are in register, so that the regions of similar density lie next to each other, giving the fibre the characteristic striated appearance it shows in the phase-contrast or polarized light microscope. Each light region is divided in two by a dark band. The unit between two dark bands is known as a sarcomere.

Each myofibril is about one or two micrometres (or microns; one micrometre = 10^{-6} metre) in diameter and extends the entire length of the muscle fibre. The number of myofibrils per fibre varies. At the end of the fibre the myofibrils are attached to the plasma membrane by the intervention of specialized proteins.

Forty to 80 nanometres usually separate adjacent myofibrils in a fibre. This space contains two distinct systems of membranes involved in the activation of muscle contraction (Figure 15). One system is a series of channels that open through the sarcolemma to the extra-fibre space. These channels are called the transverse tubules because they run across the fibre. The transverse tubular system is a network of interconnecting rings, each of which surrounds a myofibril. It provides an important communication pathway between the outside of the fibre and the myofibrils, some of which are located deep inside the fibre. The exact spatial relationship of the tubules to the filaments in the myofibril depends on the species of animal.

Transverse tubules

The other membrane system that surrounds each myofibril is the sarcoplasmic reticulum, a series of closed saclike membranes. Each segment of the sarcoplasmic reticulum forms a cufflike structure surrounding a myofibril. The portion in contact with the T tubule forms an enlarged sac (terminal cisterna).

Associated cisternae

In most vertebrates each transverse tubule has two cisternae closely associated with it, forming a three-element complex called a triad. The number of triads per sarcomere depends on the species: in frog muscle there is one per triad; in mammalian muscle there are two. In fishes and crustaceans only one cisterna is associated with each transverse tubule, thus forming a dyad. The sarcoplasmic reticulum controls the level of calcium ions in the sarcoplasm. The terminal cisternae apparently are the sites from which the calcium ions are released when the muscle is stimulated, and the longitudinal tubules are the sites at which calcium ions are effectively removed from the sarcoplasm. The removal of calcium ions (Ca^{2+}) from the sarcoplasm is accomplished by a protein that catalyzes the breakdown of ATP making the free energy of hydrolysis available for the energy-requiring process of Ca^{2+} transport.

The myofilament. As mentioned earlier, the myofibril is a columnlike array of filaments. Figure 15 is a diagram of a longitudinal section through a group of myofibrils. In the centre of the I band (the light band, of low density) there is a prominent dense line called the Z line, though in reality, considering the three-dimensional structure of the myofibril, it is more appropriate to speak of Z disks. The area between two Z lines, a sarcomere, can be considered to be the primary structural and functional unit directly responsible for muscle contraction. The myofibril can thus be thought of as a stack of sarcomeres. The A band, which contains thick filaments partly overlapped with thin filaments, appears dark.

Cross bridges. At high magnification small bridgelike structures can be seen on the thick filaments extending toward the thin filaments in the overlap region (Figure 14). They are called cross bridges and are believed to be responsible for the movement and force developed during contraction (for the relation of cross bridges to the molecular architecture of thick filaments, see below). In the middle of the A band, where only thick filaments are present, is a region called the H zone; it looks somewhat

From *Journal of Cell Biology* (1965)

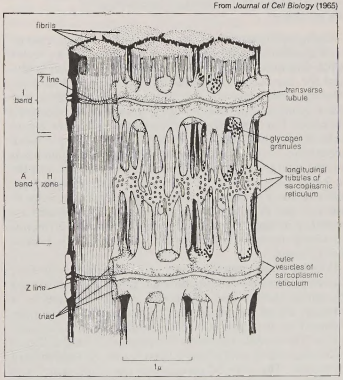


Figure 15: Ultrastructure of a group of myofibrils, showing the sarcoplasmic reticulum and transverse tubules, which constitute the two membrane systems within a muscle fibre.

lighter than the overlap region of the A band. Also in the A band is a narrow, lightly stained region that contains bare thick filaments without cross bridges and is called the pseudo-H zone. In the centre of the A band is a narrow, darkly stained region called the M band, in which occur fine bridges between the thick filaments. These bridges differ from the cross bridges between the thick and thin filaments and are in fact composed of an entirely different protein.

If cross sections of the myofibril at different levels of the sarcomere are examined in the electron microscope, the filaments can be seen end-on, and the three-dimensional nature of the lattice of filaments can be appreciated (Figure 16). The I band contains only thin filaments, with a diameter of six to eight nanometres. In the A band, in the overlap region, the thin filaments appear with thick ones (diameter of 12 nanometres) in an extremely regular pattern or lattice. In vertebrates the thick filaments are arranged in a hexagonal lattice and the thin ones are located at the centre of the equilateral triangles formed by the thick filaments. Sections through the H zone contain only thick filaments arranged in the same hexagonal pattern they form in the overlap region. In the M band the hexagonal array of thick filaments can be seen with M bridges running between them.

From H.E. Huxley, *The Contraction of Muscle* (Copyright © 1958), Scientific American, Inc., all rights reserved

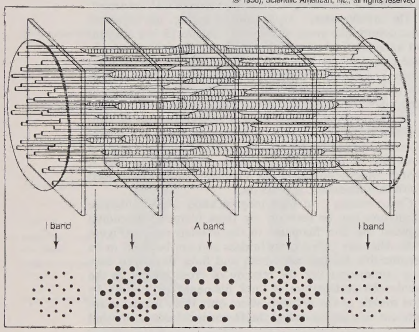


Figure 16: Muscle fibril, showing perspective model of the sarcomere.

Sliding of filaments. The discovery that during contraction the filaments do not shorten but that the two sets—thick and thin—merely move relative to each other is crucial for our current understanding of muscle physiology.

Filaments during contraction

During contraction the thin filaments move deeper into the A band, and the overlap of the thick and thin filaments increases. If a longitudinal section of the sarcomere is considered, the thin filaments on the left side of the A band would move to the right into the A band and the filaments on the right of the A band would move to the left into the A band. Directionality of the motion partly results from the structural polarity of both the thick filaments, since in the two halves of the filament the myosin molecules are oriented in opposite directions, and the actin filaments, in which the actin molecules are oriented with respect to the Z bands.

Proteins of the myofilaments. To understand the finer structural details of the myofilaments and the mechanism by which sliding, and ultimately muscle contraction, is brought about one must turn to the molecular components of the filaments and of the structures associated with them. The myofilaments are composed of several different proteins, constituting about 50 percent of the total protein in muscle. The other 50 percent consists of the proteins in the Z line and M band, the enzymes in the sarcoplasm and mitochondria, collagen, and the proteins in membrane structures. Of the myofilament proteins, myosin and actin are known to play a direct part in the contractile event. Troponin and tropomyosin, which are located in the thin filaments together with calcium ions, regulate contraction by controlling the interaction of myosin and actin.

Myosin. The main constituent of the thick filaments is myosin. Each thick filament is composed of about 250 molecules of myosin. Myosin has two important roles: a structural one as the building block for the thick filaments; and a functional one as the catalyst of the breakdown of ATP during contraction and in its interaction with actin as part of the force generator of muscle. The individual myosin molecule has a molecular weight (based on the weight of a hydrogen atom as one) of about 500,000; it contains two major protein chains and four small ones, the entire molecule being about 160 nanometres in length and asymmetrically shaped. The rodlike tail region, about 120 nanometres long, consists of two chains of protein each wound into what is known as an α-helix together forming a coiled-coil structure. At the other end of the molecule the two protein chains form two globular headlike regions that have the ability to combine with the protein actin and carry the enzymatic sites for ATP hydrolysis.

Role of myosin

The myosin molecule can be split by proteolytic cleavage to produce two fragments, light meromyosin (LMM) and heavy meromyosin (HMM). The LMM portion, about 80 nanometres long, contains most of the α-helical tail region of the original myosin molecule. The HMM portion, also about 80 nanometres long, consists of two globular head regions attached to a part of the tail region of the myosin molecule. It forms the cross bridges that protrude from the thick filaments (see below) and interacts with the thin actin-containing filaments. The HMM portion contains the enzymatic site that catalyzes the splitting of ATP. Under appropriate conditions single myosin heads (subfragment-1, or S-1) and actin binding ability also can be obtained.

There are some structural differences in myosins isolated from different muscles within the same animal and from muscles at different stages of development. These so-called isoforms are products of genes belonging to a family. Some differences in corresponding protein components are due to different ways of processing the messenger RNA produced by the same gene. While the basic pattern of myosin structure is preserved, there are many differences in the sequence of amino acids (primary structure). Many other proteins involved in muscle contraction (*e.g.*, actin, troponin) also have isoforms characteristic of different types of muscle.

Isoforms

Thick filament assembly. In the middle portion of the thick filament the molecules are assembled in a tail-to-tail fashion. Along the rest of the filament they are arranged head to tail. The tail parts of the molecules form the core of the filament: the head portions project out from the filament. The cross bridges are actually the globular head regions of myosin molecules extending outward from the filament, and the smooth pseudo-H zone is the region of tail-to-tail aggregation in which there are only tails and no heads.

The precise three-dimensional arrangement of the cross bridges projecting from the thick filament cannot be seen easily in electron micrographs but can be determined from X-ray diffraction study of living muscle (Figure 17). The three bridges project 120 degrees from the opposite sides of the filament every 14.3 nanometres along the length of the filament. Each successive set of bridges is located in a position rotated 40 degrees farther around the filament. The pattern of nine bridges (three sets of three bridges) repeats itself every 42.9 nanometres along the thick filament. Some variation may exist from species to species and muscle to muscle.

Thin filament proteins. The thin filaments contain three different proteins—actin, tropomyosin, and troponin. The latter is actually a complex of three proteins.

Actin, which constitutes about 25 percent of the protein of myofilaments, is the major component of the thin filaments in muscle. An individual molecule of actin is a single protein chain coiled to form a roughly egg-shaped unit. Actin in this form, called globular actin or G-actin, has one calcium or magnesium ion and one molecule of

Actin

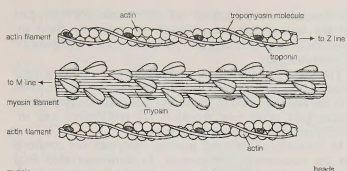


Figure 17: *The structure of actin and myosin filaments.* Actin filaments consist of globular (not strictly spherical) actin monomers, long strands of tropomyosin molecules, and the regulatory protein complex troponin. The myosin filament consists of a backbone made up of the rod parts of many myosin molecules (at bottom), with two myosin heads in each molecule projecting from the surface of the backbone.
Adapted from J.M. Squire, *Muscle: Design, Diversity, and Disease* (1986). The Benjamin/Cummings Publishing Co.

ATP bound to it. Under the proper conditions G-actin is transformed into the fibrous form, or F-actin, that exists in the thin filament in muscle. When the G-to-F transformation takes place, the ATP bound to G-actin breaks down, releasing inorganic phosphate (P_i) and leaving an adenosine diphosphate (ADP) molecule bound to each actin unit. Actin molecules repeat every 2.75 nanometres along the thin filament. They give rise to a helical structure that can be viewed as a double or single helix. The apparent half-pitch is about 40 nanometres long. Actin is believed to be directly involved in the process of contraction since the cross bridges can become attached to it.

Tropomyosin is a rod-shaped molecule about 40 nanometres long with a molecular weight of about 70,000. Two strands of tropomyosin molecules run diametrically opposed along the actin filaments. Tropomyosin has a structure similar to that of the myosin tail, being a coiled unit of two protein chains. Each tropomyosin molecule is in contact with seven actin units.

Troponin is a complex of three different protein subunits. One troponin complex is bound to every tropomyosin molecule. A troponin molecule is located approximately every 40 nanometres along the filament. Troponin and tropomyosin are both involved in the regulation of the contraction and relaxation of muscles. One of the subunits (TnC) is the receptor for Ca^{2+} released from the sarcoplasmic reticulum on activation of the muscle. It is thought that calcium-binding then causes further structural changes in the interaction of actin, tropomyosin, and another troponin subunit (TnI) that lead to contraction by activating the actin-myosin interaction.

Z lines and M bridges

The exact structure of the Z line has not yet been completely established, but it is thought that four filaments extend from the end of each thin filament to four different thin filaments on the other side of the Z line. This type of arrangement would give the Z line a three-dimensional structure resembling a series of pyramid-like units. The Z line contains proteins that form links with actin and establish lateral connections among Z disks (α-actinin, desmin) and establish connections between the Z disks and the cell membrane (*e.g.*, vinculin).

The fine M bridges are composed of proteins that have not yet been fully characterized. The M bridges run between sites on the thick filaments at which myosin molecules are joined tail to tail. It may be that the M bridges keep the filaments in register during contraction. A continuous network of filaments extending from Z disk to Z disk has also been identified; it contains some large proteins (titin, nebulin).

Actin-myosin interaction and its regulation. Mixtures of myosin and actin are used in the test tube to study the relationship between the ATP breakdown reaction and the interaction of myosin and actin. The ATPase reaction can be followed by measuring the change in the amount of phosphate present in the solution. The myosin-actin interaction also changes the physical properties of the mixture. If the concentration of ions in the solution is low, myosin molecules aggregate into filaments. As myosin and actin interact in the presence of ATP, they form a tight, compact gel mass; the process is called superprecipitation. Actin and myosin interaction can also be studied on muscle fibres whose membrane is destroyed by glycerol treatment; these fibres still develop tension when ATP is added. A form of ATP that is inactive unless irradiated with a laser beam has been found to be useful in the study of the precise time course underlying contraction.

Superprecipitation

If troponin and tropomyosin are also present, however, the actin and myosin do not interact, and ATP is not broken down. This inhibitory effect corresponds to the state of relaxation in the intact muscle. When calcium ions are added, they combine with troponin, inhibition is released, actin and myosin interact, and ATP is broken down. This corresponds to the state of contraction in intact muscle. The exact mechanism by which troponin, tropomyosin, and calcium ions regulate the myosin-actin interaction is not fully agreed upon. In the thin filament there are one troponin and one tropomyosin molecule for every seven actin units. According to one view, Ca^{2+} binding to troponin, actually the TnC subunit, induces a change in the position of tropomyosin, moving it away from the site where myosin also binds (steric blocking). Alternatively, the calcium-induced movement of tropomyosin in turn induces changes in the structure of actin, permitting its interaction with myosin (allosteric model). In smooth muscles, Ca^{2+} activates an enzyme (kinase) that catalyzes the transfer of phosphate from ATP to myosin, and the phosphorylated form is then activated by actin.

A somewhat different scheme of regulation operates in the muscle of mollusks. As in vertebrate muscles, calcium ions act as the initiator of contraction. The difference is that the component that binds calcium ions in the molluscan muscle is myosin rather than a component of the actin-containing thin filaments. The interaction of actin and myosin provides a basis for molecular models of force generation and contraction in living muscle.

(R.E.Da./N.A.C./J.Ge.)

The neuromuscular junction. The signal for a muscle to contract originates in the nervous system and is transmitted to the muscle at the neuromuscular junction, a point of contact between the motor nerve and the muscle. In higher organisms each muscle fibre is innervated by a single motor nerve fibre; in other species (*e.g.*, crustaceans) inhibitory fibres are also present. As the nerve approaches the muscle, it loses its myelin coat but remains partially covered by processes of the Schwann cells, which elsewhere surround the nerve and produce myelin. The nerve then branches several times, indenting the surface of the muscle to form the end plate that occupies only a small region of the total surface area of the muscle. The narrow (50 nanometres) synapse separates the nerve from the muscle and contains the basement membrane (basal lamina). In the subneural region the muscle membrane is deeply folded, forming secondary synaptic clefts into which the basement membrane penetrates.

Schwann cells

The neural signal is an electrical impulse that is conducted from the motor nerve cell body in the spinal cord along the nerve axon to its destination, the neuromuscular junction. No electrical continuity exists between the nerve and the muscle; the signal is transmitted by chemical means that require specialized presynaptic and postsynaptic structures.

Storage of acetylcholine in the nerve terminal. The nerve terminal contains many small vesicles (membrane-enclosed structures) about 50 nanometres in diameter, each of which contains 5,000–10,000 molecules of acetylcholine. Mitochondria are also present, providing a source of energy in the form of ATP. Acetylcholine is formed in the nerve terminal from choline and acetyl-CoA through the catalytic action of the enzyme choline acetyltransferase. Choline is obtained by the active uptake of extracellular choline, a breakdown product of previously released acetylcholine. Concentrations of acetylcholine (and ATP) in the cytoplasm are several hundredfold lower than in the vesicles. Packaging of the transmitter into the vesicles occurs within the nerve terminal and is an energy-requiring process.

Vesicles

Release of acetylcholine from the nerve terminal. The

vesicles cluster close to specialized regions of the nerve terminal membrane called the active zones. Freeze-fracture electron microscopy reveals an orderly array of small particles (about 10 nanometres in diameter) within these active zones, which are believed to represent voltage-gated calcium channels. The channels are opened by depolarization (increase in membrane potential) of the nerve terminal membrane and selectively allow the passage of calcium ions.

The nerve impulse is a wave of depolarization traveling along the axon of the motor nerve such that the resting membrane potential of about −70 millivolt is reversed, becoming briefly positive. At the nerve terminal the nerve impulse causes voltage-gated calcium channels at the active zones to open until depolarization subsides. This allows calcium ions to enter the nerve terminal along their concentration gradient. The region of raised calcium concentration within the nerve terminal is localized close to the active zones and, by a process that is not yet understood, causes vesicles in this region to fuse with the nerve terminal membrane and to open outward (exocytosis), thereby discharging their contents into the synaptic cleft. A nerve impulse causes the release of about 50–100 vesicles of acetylcholine in humans, and somewhat more in some other species.

Discharge of acetylcholine

At high rates of stimulation, sufficient to cause a smooth contraction (tetanus) of the muscle, the quantity of transmitter released per impulse declines for the first few impulses (synaptic depression), which may be due to a reduction in the number of vesicles ready for release.

Following the voltage-dependent influx of calcium into the nerve terminal, it is necessary for calcium to be removed to prevent continuous discharge of neurotransmitter. Mechanisms underlying this process are likely to involve sodium–calcium exchange across the nerve terminal membrane and possibly calcium uptake by mitochondria.

Acetylcholine is released from the nerve terminal by two other processes, independently of the nerve impulse. Neither of these processes leads to muscle contraction. The first occurs spontaneously when individual vesicles randomly fuse with the nerve terminal membrane and discharge their contents, generating a small potential change (about 0.5–1 millivolt), the miniature end plate potential. This potential is below the threshold at which an action potential is triggered in the muscle cell and thus does not lead to muscle contraction. The frequency of such events varies; in humans they occur at each end plate about once every five seconds. The second process of acetylcholine release occurs as a continuous "molecular leakage" of neurotransmitter from the nerve terminal rather than from vesicles. The overall amount released in resting muscle by this means greatly exceeds the spontaneous release of individual vesicles.

The acetylcholine molecules diffuse across the synaptic cleft and react with the acetylcholine receptors. The number of available acetylcholine binding sites greatly exceeds the number of acetylcholine molecules released. Acetylcholine is either rapidly broken down by the enzyme acetylcholinesterase, which is anchored in the basement membrane, or diffuses out of the primary cleft, thus preventing constant stimulation of acetylcholine receptors. Drugs that inactivate acetylcholinesterase and thereby prolong the presence of acetylcholine in the cleft can lead to repetitive firing of the muscle cell in response to a single nerve stimulus.

Acetylcholine receptors. Acetylcholine receptors are ion channels that span the postsynaptic membrane, and they have extracellular, intramembranous, and cytoplasmic portions. They are located principally over the peaks of the postsynaptic folds, where they are present at high density. They consist of five subunits arranged around the central ion channel. One of the subunits is represented twice. The different subunits are products of separate genes. This implies that the acetylcholine receptor has been highly conserved in evolution and suggests that the genes coding for the different subunits may have evolved from a single primeval acetylcholine receptor gene.

Structure

Models of acetylcholine receptors indicate that its structure contains an extracellular *N*-terminal portion, several intramembranous portions (of which one provides part of the wall of the ion channel) separated by short intracellular and extracellular portions, and a cytoplasmic *C*-terminal part.

The supply of junctional acetylcholine receptors is continuously renewed. Receptors are internalized by the muscle cell and degraded in lysosomes (specialized cytoplasmic organelles), while new receptors are synthesized and inserted into the muscle membrane.

In normally innervated muscle, receptors are confined to the neuromuscular junction. In non-innervated fetal muscle and in denervated adult muscle, however, acetylcholine receptors are found elsewhere as well. These receptors have slightly different properties from junctional receptors, notably a much higher rate of turnover.

Acetylcholine/acetylcholine receptor interaction. The resting membrane potential of the muscle cell is held at about −80 millivolt. Binding of acetylcholine to each of the two alpha subunits causes the receptor molecule to alter its configuration so that the ion channel is opened for about one millisecond (0.001 second). This permits the entry of small positive ions, mainly sodium. The resulting local depolarization (the end plate potential) causes voltage-gated sodium channels located around the end plate to open. At a critical point (the firing threshold for the muscle cell) a self-generating action potential is triggered, causing the membrane potential to reverse and become briefly positive. The action potential propagates over the muscle fibre membrane to activate the contractile process.

Firing threshold

The amplitude of the end plate potential is normally sufficient to bring the membrane potential of the muscle cell well above the critical firing threshold. The extent to which it does so represents a "safety factor" for neuromuscular transmission. The safety factor will be reduced by any event that, by interfering with presynaptic or postsynaptic function, reduces the size of the end plate potential. (J.M.N.-D.)

Mechanical properties. *The physical aspects.* Vertebrates are able to move about and to exert and bear forces because of the contraction of the striated muscles. These activities usually involve several structures operating in different ways. The skeleton to which the muscles are attached operates as a lever system. When a muscle shortens, it moves the joints that it spans. In addition, in coordinated movement usually several muscles contract in different ways. As some muscles shorten, others develop a force while at a fixed length, and still others may be lengthened by an external force even as they contract.

The force that a muscle develops is a "pulling" force, never a "pushing" force. If the load is small enough, the muscle can shorten and produce a pulling motion (an isotonic condition). If the load is just equal to the maximum force the muscle can develop, the length of the muscle will remain the same (an isometric condition). An even larger load will stretch the muscle.

The size and the rate of the mechanical responses to stimulation, whether by a nerve in the body or by direct electrical shocks of an isolated muscle, depend on the muscle and the temperature. In a frog sartorius muscle (of the leg) at 0° C (32° F), the action potential reaches its peak of depolarization about 1.5 milliseconds after the stimulus (Figure 18).

Time course of contraction

The very early tension changes require much more rapid and sensitive measuring and recording instruments than are necessary for studying other aspects of the contraction process. The latent period, the first seven milliseconds, is the amount of time needed for the electrical signal, which appears as an action potential at the surface membrane, to be translated and travel to the contractile apparatus within the muscle fibres. The explanation for latency relaxation (a four-millisecond period during which the tension drops slightly), however, is not so clear. It may be related to a change in shape of the sarcoplasmic reticulum, which releases a large amount of calcium ions at about the time latency relaxation occurs. The tension begins to rise after 15 milliseconds.

Twitch and tetanus responses. Skeletal muscles respond to a single electric shock of sufficient magnitude by rapid,

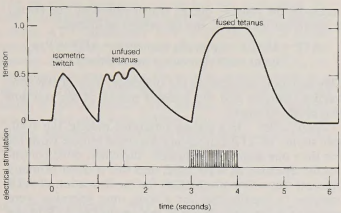


Figure 18: The effect of the rate of stimulation on the development of force in a frog muscle (at 0° C, or 32° F).

intense contractions called phasic contractions. If the ends of a frog sartorius muscle (at 0° C) are fixed to prevent shortening, the tension increases for about 200 milliseconds and then begins to decrease, at first rather rapidly and then more slowly. More happens during this mechanical response to a single stimulation, called a twitch, than the tension record suggests.

Absolute refractory period

The mechanical response to repeated stimulation depends on the rate of the stimulation. Muscle, like other excitable tissues, has a period following its action potential during which the membrane will not respond to stimulation regardless of the strength. This absolute refractory period in the frog sartorius at 0° C lasts about 10 milliseconds after stimulation. Therefore, a second pulse coming within that time span will not elicit any response. If, however, the pulses are 300 milliseconds apart, the muscle will be relaxing when the second pulse is given, and the tension will appear in waves in phase with the stimulation, causing an unfused tetanus. It is possible to stimulate the muscle at a frequency between these extremes so that the tension developed by the muscle remains constant. This latter type of contraction is called a fused tetanus, and the rate of stimulation that produces it is called the fusion frequency. The exact rate depends upon the particular muscle and the temperature.

Usually, the maximum tetanus tension is from 1.2 to 1.8 times greater than the maximum tension during a twitch. Within the muscle many elastic structures, connected in series with the contractile elements, are stretched during contraction. The attachment of the muscle fibres to the tendons at the end of the muscle and the attachment of the thin filaments to the Z line contribute to this elastic component. In single fibres, however, most of the elasticity of the series elastic elements is contributed by the actin-myosin cross bridges themselves. Full maximum tension is not apparent at the end of the muscle until the contractile elements have shortened enough to stretch the elastic elements—somewhat like taking up the slack in rope before a pull on one end can be felt at the other end. In a twitch, the activity of the muscle is so brief that the contractile elements cannot extend the elastic elements completely before relaxation begins; as a result, the tension at the ends of the muscle does not reach the maximum possible level. During a tetanus, on the other hand, the activity of the contractile elements is maintained, and they can eventually shorten enough to extend fully the series elastic elements. When this has been accomplished, the maximum tension is apparent at the ends of the muscle.

Effects of series elasticity

Length-tension relationship. The force developed by a muscle, whether it is contracting or resting, is strongly dependent on the length of the muscle (Figure 19). Resting skeletal muscle does not exert any force at lengths less than the normal length of the resting muscle in the body (l_o). When resting skeletal muscle is extended somewhat beyond l_o, however, a passive force begins to assert itself. The exact length at which this passive force occurs depends on the particular muscle. This force is characterized as passive because it is developed in noncontracting or inactive muscles by the elastic elements of the muscle.

Skeletal muscles do not develop any force when they are stimulated at lengths of less than about 50 percent l_o. The amount of force developed, however, increases during isometric contractions at lengths from 50 to 100 percent of l_o. Once beyond l_o, the passive force becomes a factor: the total force has two components, a passive one, resulting from elasticity, and an active one, resulting from contraction. For isometric contractions the active force developed during contraction decreases beyond l_o at about 150 percent l_o, the muscle fails to develop any active force.

The structural basis for the dependence of the magnitude of active force on the length of skeletal muscle has been established in experiments with single fibres rather than whole muscles. The active force has been correlated with the relative position of thick and thin filaments during contraction at each sarcomere length. The tension increases as the sarcomere length shortens from 3.65 to 2.25 μ (Figure 19A, 1 and 2) because more sites for actin-myosin cross-bridge interaction become available as the overlap of the thick and thin filaments increases (19B, 1 and 2). The force is constant from sarcomere length 2.25 to 2.00 μ (19A, 2 and 3) as the thin filaments move over the bare region devoid of cross bridges in the centre of the thick filaments (19B, 2 and 3). As the sarcomeres shorten further, from 2.00 to 1.67 μ (19A, 3 to 5), the thin filaments overlap each other, preventing effective interaction with myosin in the thick filaments (19B, 3 and 5) and consequently diminishing the force. Finally, from sarcomere length 1.67 to 1.27 μ (19A, 5 to 6) the thick filaments run up against the Z lines (19B, 6), and internal resistance causes an even greater diminution of the force.

From *Journal of Physiology* (1966)

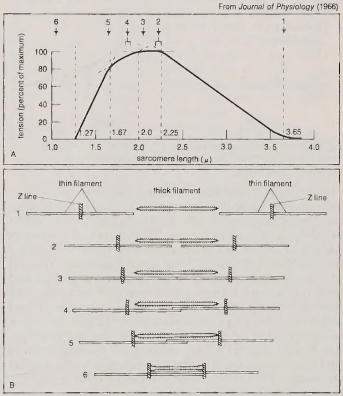


Figure 19: (A) The amount of force developed during an isometric tetanus of a single muscle fibre at various sarcomere lengths. (B) Relative positions of the thick and thin filaments at various sarcomere lengths.

Load–velocity relation. When a muscle is to lift a constant load (isotonic conditions) after stimulation starts, the force increases, just as in an isometric contraction, and, when the force is equal to the load, the muscle begins to shorten and lifts the load. When the activity of both the muscle and the force in it begin to decline, the load stretches the muscle back to its initial length. The tension in the muscle is equal to the load during the shortening and the lengthening of the muscle, except during brief periods of acceleration as the muscle begins to move. Only after the muscle has returned to its initial length does the tension begin to diminish. The size of the load also determines the velocity of shortening, and this relationship between load and velocity also applies to cardiac and smooth muscle. It can be mathematically described by Hill's equation:

$$V = \frac{(P_o - P)b}{P + a},$$

in which V is the velocity of shortening: P_o is the maximum force developed under isometric conditions; P is the force developed at a particular muscle length; and b and a are physical constants. A graphic interpretation of these values results in a rectilinear hyperbola called the force–velocity curve (Figure 20). From this curve can be determined both the velocity of shortening when the load is known and the force developed to overcome the load when the velocity is known.

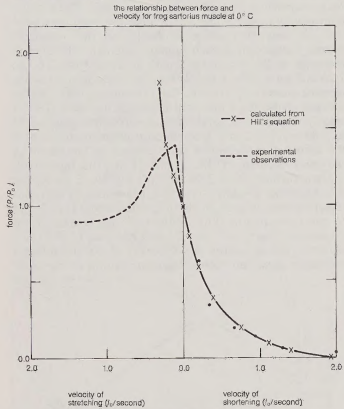


Figure 20: The force–velocity curve: relationship of the velocity of movement to the amount of force developed during tetanic stimulation (see text).

Energy transformations. When a chemical reaction occurs, energy is absorbed or released. In a contracting muscle, chemical reactions release energy that appears either as mechanical work or as heat. The first law of thermodynamics, or the law of conservation of energy, states that the heat and work produced must equal the energy released by the chemical reactions. The muscles that shorten and do external work liberate more energy as heat and work than do those that contract under isometric conditions and do not shorten or do external work. In light of the law of conservation of energy (first law of thermodynamics), this finding means that the amount of chemical reaction that takes place during contraction depends on the type of contraction performed by the muscle. In other words, the flow of energy is subject to regulation.

The mechanical work of muscles

The efficiency of the process of muscle contraction depends on the fate of the free energy released in chemical reactions; *i.e.*, whether it is converted primarily into work or degraded into heat. The second law of thermodynamics sets limits to the amount of energy that can be transformed into mechanical work. Although the production of heat can detract from the efficiency of working muscle, energy that appears as heat is not always wasted. In warm-blooded animals, for example, the heat released by muscles maintains a constant body temperature regardless of the environmental temperature. When an animal shivers in the cold a large amount of heat is generated in the muscles. The muscles alternately contract and relax, releasing energy chiefly as heat.

Source of energy for muscle work. Muscles use the free energy released by chemical reactions by coupling the chemical reaction to physical changes in the contractile proteins. The exact molecular details of this fundamental coupling process are not yet completely known. Of the reactions that have been identified, the splitting of ATP is the energy-yielding reaction nearest to the contractile event. Water participates in this reaction in which ATP is broken down to ADP and phosphate (P_i); the reaction that occurs in the muscle, during which chemical free energy is converted into work, can be written as follows:

$$\text{ATP} + \text{H}_2\text{O} + \text{contractile elements} \rightarrow \text{ADP} + \text{P}_i + \text{contractile elements} + \text{work} + \text{heat.}$$

This equation emphasizes the obligatory role of the contractile elements and the coupled nature of the reaction that produces work.

Energy stores. In a resting vertebrate muscle, the available supply of ATP can sustain maximal muscle work for less than one second. The muscle, therefore, must continuously replenish its ATP store, and this is done in many different ways. One mechanism for the formation of ATP operates so rapidly that for a long time scientists were unable to detect any change in the amount of ATP in the muscle as a result of contraction. This immediate rebuilding of ATP is accomplished by the reactions of compounds called phosphagens. All of them contain phosphorus in a chemical unit called a phosphoryl group, which they transfer to ADP to produce ATP (these compounds are also referred to as high-energy phosphates). Whereas different phosphagens occur in various animals, all of them contain two common chemical units—a guanidino group and a phosphoryl group.

Phosphagens

The reaction for the rebuilding of the ATP utilized during contraction in vertebrate muscle can be written as follows:

$$\text{ADP} + \text{PCr} \rightarrow \text{ATP} + \text{Cr.}$$

The phosphagen, phosphorylcreatine (PCr), gives rise to creatine (Cr) upon the formation of ATP. This reaction is catalyzed by the enzyme ADP : creatine phosphoryl transferase.

Resting skeletal muscle has about 10 times more phosphagen compound than ATP. During rapid and intense contraction, the phosphagen can be utilized to rebuild ATP rapidly and maintain its level as long as the phosphagen lasts, which in a maximally working human muscle is just a few seconds. After contraction ATP is utilized to form phosphagen (PCr) from creatine (Cr); ADP is also formed.

$$\text{ATP} + \text{Cr} \rightarrow \text{ADP} + \text{PCr}$$

This formation of PCr occurs at the same time that ATP is produced by various reactions that are described in a later section.

As mentioned earlier, changes in the ATP level during contraction are difficult to measure since it is rapidly reformed from ADP and Cr. Such changes can be observed, however, when the muscle is treated with the chemical 2,4-dinitro–fluorobenzene (DNFB), which inhibits the enzyme ADP : creatine phosphoryl transferase. In DNFB-treated muscles, the ATP level decreases during contraction; the ADP and phosphate (P_i) levels increase, and phosphorylcreatine and creatine levels remain constant. The mechanical properties of DNFB-treated muscle during maximal contraction are the same as those of untreated muscles, except that DNFB-treated muscle runs out of ATP sooner and therefore contracts for a shorter time.

The amount of phosphagen is higher in skeletal muscle than it is in cardiac or smooth muscle. This correlates with the type of activity of the muscles. Skeletal muscle operates in bursts of activity, whereas cardiac and smooth muscle contract in a regular pattern. Skeletal muscle needs an immediate supply of a large amount of ATP, which is provided by the phosphagen reaction; cardiac and smooth muscle, which use ATP at a lower rate, rely on slower reactions to fill their energy requirements.

Metabolic pathways producing ATP. *ATP from glucose.* In skeletal muscle most of the ATP is produced in metabolic pathways involving reactions of the sugar glucose or some other carbohydrate derived from glucose. During contraction, for example, glucose is made available for these reactions by the breakdown of glycogen, the storage form of carbohydrate in animal cells. The concentration of Ca^{2+} is transiently increased on activation of muscle. The ions are also activators of the process of glycogen breakdown. During the recovery period the glycogen supply is replenished by synthesizing glycogen from glucose supplied to the muscle tissue by the blood.

The glycolytic pathway. In all but the most brief, intense contractions—during which phosphagen is utilized to form ATP—additional ATP is supplied by a set of chemical reactions called the glycolytic pathway, or the Embden–Meyerhof–Parnas pathway. These reactions are especially important when the muscle is doing work at a high rate. The enzymes that catalyze these reactions are located in the sarcoplasm, as is glucose, the major starting material. The glycolytic pathway can be summarized as follows: reactions of glucose to lactate are coupled to formation of ATP from ADP and phosphate.

$$\underset{\text{glucose}}{C_6H_{12}O_6} + 2ADP + 2P_i \rightarrow \underset{\text{lactate}}{2C_3H_6O_3} + 2ATP + 2H_2O$$

As already indicated, ATP is broken down in the contractile reaction to form ADP and P_i, which can then be recycled into the pathway. The lactate, a waste product, diffuses out of the muscle and is transported by the blood to the liver. The removal of lactate from the muscle is slower than its production; if the muscle contracts for an extended period, the accumulation of lactate in the muscle causes fatigue and ultimately muscle cramps.

Most of the lactate taken to the liver is converted to glucose, from which glycogen is formed in a series of reactions that require ATP to provide more ATP. About one-sixth of the lactate is oxidized to carbon dioxide by reactions that require oxygen (see below) after the exercise is done; a so-called oxygen debt accumulates during brief intense exercise. Animals breathe hard after intense exercise to supply the oxygen needed for the reconversion of lactate.

The relative speed of glycolysis

The glycolytic pathway can operate up to 1,000 times faster in a contracting muscle than it does in a resting muscle. Two regulatory mechanisms play roles in the increase in the rates of these reactions. First, reacting compounds (reactants) accumulate; for example, more glucose is available because glycogen breakdown increases during contraction, and ADP and P_i accumulate. The second type of regulation depends on the activity of the enzyme phosphofructokinase, which catalyzes one of the early steps in glycolysis. This enzyme can bind either ATP or adenosine monophosphate (AMP). When ATP is bound, the activity of the enzyme is low; that is, the reaction it catalyzes proceeds slowly. When AMP is bound, the enzyme has a high activity. During contraction the ATP level drops and that of ADP increases; ADP, in turn, produces AMP as well as ATP, in a reaction catalyzed by the enzyme adenylate kinase, or myokinase. The AMP then can bind with the phosphofructokinase, thereby accelerating glycolysis and the production of ATP. The formation of ATP in the myokinase reaction enables the muscle to use the energy in the ADP formed during contraction.

The oxidative pathways. A large amount of ATP is produced by the complete oxidation of carbon-containing compounds (*e.g.*, glucose) to carbon dioxide and water in reactions of the Krebs cycle and oxidative phosphorylation. These reactions take place inside the membrane-bound components of cells called mitochondria. Carbohydrate can enter the oxidative pathways at a branch point in the glycolytic pathway. At the branch point, two kinds of reaction can occur: pyruvate, a three-carbon compound, can either react to form lactate or lose a carbon dioxide molecule to form a two-carbon unit, which then enters the Krebs cycle. If the muscle is working hard and using ATP rapidly, lactate is formed. If it is working slowly, a larger fraction of the carbon enters the oxidative pathways.

During reactions of the Krebs cycle, carbon dioxide and hydrogen atoms are removed from the compounds that enter the cycle. The carbon dioxide diffuses out of the muscle and is carried by the blood to the lungs, where it is exhaled. The electrons from the hydrogen atoms are passed through an electron-transport chain consisting of the series of reactions involving cytochrome molecules. These events occur in the mitochondria, in which ADP is also combining with phosphate (P_i) to form ATP. In the last step of this reaction sequence, the hydrogen atoms combine with oxygen to form water. The net reaction for each glucose molecule that enters the glycolytic pathway and proceeds through the Krebs cycle and oxidative phosphorylation is summarized below.

$$\underset{\text{glucose}}{C_6H_{12}O_6} + 6O_2 + 36ADP + 36P_i \rightarrow 6CO_2 + 36ATP + \underset{}{6H_2O}$$

Efficiency of oxidative pathways

Although the oxidative pathways result in the formation of more ATP from each glucose molecule than does the glycolytic pathway, the complete process is much slower than glycolysis. The slowest steps are those involving the passage of the carbon-containing compounds from the sarcoplasm into the mitochondria and the delivery of oxygen, which ultimately comes from the air that is breathed. In red blood cells oxygen is combined with hemoglobin, a protein containing four identical subunits, during its transfer from the lungs to the muscles. Muscle contains myoglobin, which has a structure similar to a single subunit of hemoglobin. Myoglobin, which combines with and can store oxygen, is responsible for transporting much of the oxygen through the sarcoplasm to the mitochondria. Myoglobin is especially important in the heart and "red" muscles, which rely heavily on oxidative metabolism for the production of ATP.

During intense exercise of skeletal muscle, ATP is supplied almost entirely by carbohydrate metabolism. During rest or very light exercise, however, skeletal muscle depends largely on the oxidation of stored fats—actually of their breakdown products, fatty acids—for the production of ATP. Two-carbon units and hydrogen atoms are removed from fats in a stepwise fashion. The two-carbon units enter the Krebs cycle, as do the identical units derived from carbohydrates, as the compound acetyl coenzyme A. The hydrogen atoms from the breakdown of the fat and from the reactions of the Krebs cycle proceed through oxidative phosphorylation, and ATP is produced.

Heart muscle, which operates constantly but at a lower level of intensity than does skeletal muscle, depends on oxidative reactions for ATP. Most of the two-carbon units are derived from either fatty acids or ketones, components of fat, brought to the heart by the blood.

Molecular mechanisms of contraction. *Excitation–contraction coupling.* The nerve impulse that ultimately results in muscle contraction appears as an action potential at the sarcolemma, the membrane that surrounds the muscle fibre. This electrical signal is communicated to the myofilaments inside the fibre in the following way. When the action potential reaches the opening of the transverse tubules (channels that open through the sarcolemma to the space outside the fibre; see above *The myofibril*) in the surface of the fibre, it travels down into the fibre along the tubular membranes, which are continuous with the surface membrane, to within a fraction of a micrometre of each functional contractile unit (Figure 15). In frog muscle the transverse tubules surround the myofibril at the level of each Z line, and in mammalian muscles they are located at the edge of the A bands and I bands. At the triads (the three-element complex consisting of one transverse tubule and two cisternae, which are enlarged saclike membranes) the transverse tubule walls are close to the membranes of the terminal cisternae of the sarcoplasmic reticulum.

The effect of calcium ions

By some as yet unknown mechanism, the change in the electrical properties of the transverse tubule during an action potential causes the rapid release by the terminal cisternae of relatively large amounts of calcium ions into the sarcoplasm. As the concentration of calcium ions increases in the sarcoplasm, they become bound to the troponin in the thin filaments. This releases (or removes) the troponin–tropomyosin-mediated inhibition of the myosin-actin interaction. As the stimulation of the muscle continues, the terminal cisternae continue to release calcium ions. At the same time, however, some of the calcium ions are being removed from the sarcoplasm by another portion of the sarcoplasmic reticulum, the longitudinal tubules. Once the calcium ions are inside the lumen (cavity) of the longitudinal tubules, many of them slowly diffuse back to the terminal cisternae, where they are bound to a protein, calsequestrin, as a storage site. The removal of calcium ions from the sarcoplasm by the sarcoplasmic reticulum is energy requiring. The breakdown of ATP is the chemical reaction that supplies the energy, and two calcium ions are apparently removed from the sarcoplasm for each ATP molecule that is split.

The development of muscular force. In the early 1950s it became clear that there were two types of filaments in muscle and that neither extended the entire length of the muscle (see Figure 14). Furthermore, it was found that the overall length of the filaments did not change during contraction. Those findings ruled out most of the then existing theories about the mechanism of muscle contraction and, based on shape or length changes in structural elements, provided the basis for the now widely accepted sliding-filament theory.

Sliding-filament theory

Shortening of the entire muscle occurs as the thin filaments on both sides of the A band slide farther into the A band. As the sliding progresses, the areas of the sarcomere containing only one type of filament—that is, the I band and the H zone—decrease in size because more and more of the thin and thick filaments overlap each other. On the other hand, the A band remains the same length because the thick filaments do not change in length except in extreme shortening. The distance from the Z line to the edge of the H zone also remains virtually the same length because that distance is determined by the length of the thin filaments. The sliding-filament theory must be expanded to explain certain aspects of contraction: how the force that moves the filaments past each other is generated and how ATP takes part in the process of contraction.

Cross-bridge theories

The sliding of the filaments is thought to result from the interaction of the cross bridges with the thin filaments during contraction. Each time a bridge links to a thin filament and operates in a specific way (see below), it causes a small movement of the thin filament along the thick filament. Since muscles are able to shorten considerably, requiring sliding of the filaments through large distances, there must be repeated cycles of interaction between a given cross bridge and successive sites on the thin filament.

The myosin heads attached to the actin filament are thought to change their angle with respect to the thin filaments. This change leads to force development, the elastic element residing in some part of the cross bridge (*i.e.*, the portion of myosin connecting the core of the thick filaments to actin) or in the actin-myosin junction itself. The precise connection between various chemical steps in the hydrolysis of ATP and force generation is still under investigation. Similarly, the precise nature of the structural change that corresponds to force generation is not fully understood—instead of the rotation of the whole myosin head about the point of contact between actin and myosin, a bending motion may take place within the head. Some theories suggest purely electrostatic interactions between thick and thin filaments without specific interaction between actin and the myosin heads. The many similarities, however, between factors that affect actin and myosin interactions in solution and those that modulate the behaviour of whole muscle fibres make models of contraction and force development based on specific protein–protein interaction more fruitful. (R.E.Da./N.A.C./J.Ge.)

CARDIAC MUSCLE

The heart is the pump that keeps blood circulating throughout the body and thereby transports nutrients, breakdown products, antibodies, hormones, and gases to and from the tissues. The heart consists mostly of muscle, the myocardial cells (collectively termed the myocardium), arranged in ways that set it apart from other types of muscle. The outstanding characteristics of the action of the heart are its contractility, which is the basis for its pumping action, and the rhythmicity of the contraction.

Contractility and rhythmicity

Heart muscle differs from its counterpart, skeletal muscle, in that it exhibits rhythmic contractions. The amount of blood pumped by the heart per minute (the cardiac output) varies to meet the metabolic needs of the peripheral tissues (muscle, kidney, brain, skin, liver, heart, gastrointestinal tract). The cardiac output is determined by the contractile force developed by the muscle cells of the heart (myocytes; Figure 21) as well as the frequency at which they are activated (rhythmicity). The factors affecting the frequency and force of heart muscle contraction are critical in determining the normal pumping performance of the heart and its response to changes in demand.

Structure and organization. The heart is a network of highly branched cardiac cells 110 micrometres in length and 15 micrometres in width, which are connected end to end by intercalated disks (Figure 21). The cells are organized into layers of myocardial tissue that are wrapped around the chambers of the heart. The contraction of the individual heart cells produces force and shortening in these bands of muscle with a resultant decrease in the heart chamber size and the consequent ejection of the blood into the pulmonary and systemic vessels. Important components of each heart cell involved in excitation and metabolic recovery processes are the plasma membrane and transverse tubules in registration with the Z lines, the longitudinal sarcoplasmic reticulum and terminal cisternae, and the mitochondria. The thick (myosin) and thin (actin, troponin, and tropomyosin) protein filaments are arranged into contractile units (that is to say, the sarcomere extending from Z line to Z line) that have a characteristic cross-striated pattern similar to that seen in skeletal muscle.

Myocyte excitation and recovery

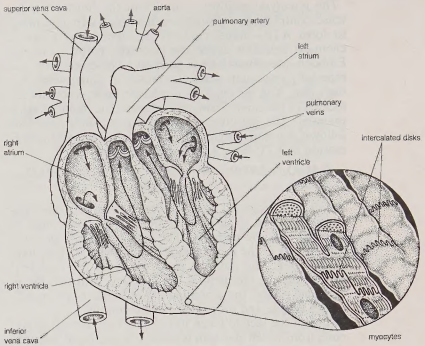


Figure 21: The four-chambered mammalian heart consisting of the right and left atria and the right and left ventricles. Blood enters the right atrium from the superior and inferior venae cavae, passes from the right atrium to the right ventricle, and then is pumped to the lungs through the pulmonary artery. The blood is returned to the left atrium from the lungs through the pulmonary veins, passes to the left ventricle, and then is pumped to the peripheral tissues through the aorta. Inset shows the heart muscle cells (myocytes).

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The frequency of contraction. The rate at which the heart contracts and the synchronization of atrial and ventricular contraction required for the efficient pumping of blood depend on the electrical properties of the myocardial cells and on the conduction of electrical information from one region of the heart to another. The action potential (activation of the muscle) is divided into five phases (0–4) and is graphed in Figure 22. Each of the phases of the action potential is caused by time-dependent changes in the permeability of the plasma membrane to potassium ions (K^+), sodium ions (Na^+), and calcium ions (Ca^{2+}). The resting potential of the myocytes of the ventricle (phase 4) begins with the outside of the cell being positive—*i.e.*, having a greater concentration of positive ions. Atrial and ventricular myocytes are normally quiescent (non-rhythmic); however, when the resting membrane potential is depolarized to a critical potential (E_{crit}), a self-generating action potential follows, leading to muscle contraction. Phase 0, the upstroke, is associated with a sudden increase in membrane permeability to Na^+. Phases 1, 2, and 3 result from changes in membrane permeability and conductance to Na^+, K^+, and Ca^{2+}.

The electrical activity of heart muscle cells differs substantially from that of skeletal muscle cells in that phases 1, 2, and 3 are considerably prolonged (200 milliseconds versus five milliseconds, respectively). Another significant

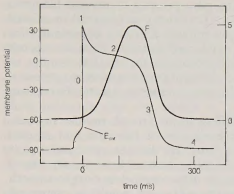


Figure 22: The time course of each of the phases of the ventricular action potential (0–4) and the isometric force (F) developed by an isolated heart muscle bundle.

difference in excitability is that heart muscle cannot be tetanized (*i.e.,* induced to spasm) by the application of repetitive stimuli (see above *Striated muscle*), thus ensuring the completion of the contraction/relaxation cycle and the effective pumping of blood.

Sources of myocyte excitation

Because atrial and ventricular cells are normally quiescent, exhibiting action potentials only after the muscle is depolarized to the critical membrane potential (E_{crit}), the source of the rhythmic contractions of the heart must be sought elsewhere. In contrast to atrial and ventricular myocytes, the myocytes of the sinoatrial (SA) node, the atrioventricular (AV) node, the bundle branches, and the Purkinje fibre system are made up of specialized cardiac muscle cells that exhibit a spontaneous upward drift in the resting potential toward E_{crit}, resulting in the generation of the action potential with all of its phases. The normal rhythmicity of cells from each of these regions depends on the rate at which spontaneous depolarization occurs and the resting membrane potential from which it starts. The region with the fastest intrinsic rate, the SA node, sets the pace for the whole heart. The pacemaker activity is propagated to the rest of the heart by means of the low electrical resistance pathways through the muscle cells (*e.g.,* intercalated disks) and the presence of specialized conducting tissue (bundle branches, Purkinje system). The time course of activation and the shape of the action potentials in different parts of the heart are responsible for the synchronous activation and contraction of the muscles of the atrium followed by those of the ventricle.

The normal rhythm of the heart (*i.e.,* the heart rate) can be altered by neural activity. The heart is innervated by sympathetic and parasympathetic nerves, which have a profound effect on the resting potential and the rate of diastolic depolarization in the SA nodal region. The activity of the sympathetic nervous system may be increased by the activation of the sympathetic nerves innervating the heart or by the secretion of epinephrine and norepinephrine from the adrenal gland. This decreases the resting potential of the myocytes of the SA node while increasing the rate of diastolic depolarization. The result is an increase in the heart rate. Conversely, stimulating the parasympathetic nervous system (vagal nerves to the heart) increases the resting potential and decreases the rate of diastolic depolarization; under these circumstances the heart rate slows. The sympathetic nervous system is activated under conditions of fright or vigorous activity (the so-called "fight or flight" reaction), where the increase in force and rate of heart contraction are easily felt; the parasympathetic system exerts its influence during periods of rest.

Excitation/contraction coupling. Immediately following depolarization of the plasma membrane and the ensuing action potential, the heart muscle develops force and then relaxes. The surface action potential is transmitted to the interior of the muscle by means of the T tubular system. Calcium ions enter the muscle cell during the plateau phase of the action potential (phase 2), triggering the release of calcium from the terminal cisternae of the sarcoplasmic reticulum. Calcium diffuses to the myofilaments and combines with the troponin-tropomyosin system (associated with the thin actin filaments), producing a conformational change that allows actin and myosin to interact. This interaction in the presence of ATP results in cross-bridge cycling and ATP hydrolysis. The force developed in the whole muscle is the sum of all the forces developed by each of the millions of cycling cross bridges of the muscle. The free calcium ions in the cytosol are removed by an energy-dependent calcium uptake system involving calcium ion pumps located in the longitudinal sarcoplasmic reticulum. These calcium pumps lower the concentration of free calcium in the cytosol, resulting in the dissociation (release) of calcium from the troponin-tropomyosin system. The troponin-tropomyosin system is then transformed back to its original state, preventing myosin and actin from interacting and thus causing relaxation of the muscle. At the same time calcium is extruded from the cell into the surrounding medium.

Cross-bridge cycling

Force and velocity of contraction. There are a number of factors that change the force developed by heart muscle cells. In a manner similar to that seen in skeletal muscle, there is a relationship between the muscle length and the isometric force developed. As the muscle length is increased, the active force developed reaches a maximum and then decreases. This maximum point is the length at which the heart normally functions. As with skeletal muscle, changes in length alter the active force by varying the degree of overlap of the thick myosin and thin actin filaments. The force developed by heart muscle also depends on the frequency at which the muscle is stimulated. As the stimulus frequency is increased, the force is increased until the maximum is reached, at which point it begins to decrease. An increase in the level of circulating epinephrine and norepinephrine from the sympathetic nervous system also increases the force of contraction. All of these factors can combine to allow the heart to develop more force when required. At any given length the velocity of contraction is a function of the load lifted, with the velocity decreasing as the load is increased. The force–velocity relationship is similar to that of skeletal muscle and takes the shape of a rectangular hyperbola. When force–velocity curves are measured at different lengths, there is a change in maximum force while the maximum velocity of shortening (V_{max}) remains unchanged. Under conditions where there is an increase in inotropic performance of the muscle (frequency, epinephrine or norepinephrine) there is a shift in both the maximum velocity and maximum force developed.

Response of the heart to stress. Demands on the heart vary from moment to moment and from day to day. In moving from rest to exercise the cardiac output may be increased tenfold. Other increases in demand are seen when the heart must pump blood against a high pressure such as that seen in hypertensive heart disease. Each of these stresses requires special adjustments. Short-term increases in demand on the heart (*e.g.,* exercise) are met by increases in the force and frequency of contraction. These changes are mediated by increases in sympathetic nervous system activity, an increase in the frequency of contraction, and changes in muscle length. The response to long-term stress (hypertension, thyrotoxicosis) results in an increase in the mass of the heart (hypertrophy) providing more heart muscle to pump the blood, which helps meet the increase in demand. In addition, subtle intracellular changes affect the performance of the muscle cells. In the pressure overload type hypertrophy (hypertensive heart disease) the pumping system of the sarcoplasmic reticulum responsible for calcium removal is slowed while the contractile protein myosin shifts toward slower cross-bridge cycling. The outcome is a slower, more economical heart that can meet the demand for pumping against an increase in pressure. At the molecular level the slowing of calcium uptake is caused by a reduction in the number of calcium pumps in the sarcoplasmic reticulum. The change in V_{max} and economy of force development occur because each myosin cross-bridge head cycles more slowly and remains in the attached force-producing state for a longer period of time. In the thyrotoxic type of hypertrophy, calcium is removed more quickly while there is a shift in myosin. At the molecular level there are more sarcoplasmic reticular calcium pumps, while the myosin cross-bridge head cycles

Short- and long-term stress

more rapidly and remains attached in the force-producing state for a shorter period of time. The result is a heart that contracts much faster but less economically than normal and can meet the peripheral need for large volumes of blood at normal pressures.

SMOOTH MUSCLE

Because vertebrate smooth muscle is located in the walls of many hollow organs (Figure 23), the normal functioning of the cardiovascular, respiratory, gastrointestinal, and reproductive systems depends on the constrictive capabilities of smooth muscle cells. Smooth muscle is distinguished from the striated muscles of the skeleton and heart by its structure and its functional capabilities.

Characteristics of smooth muscle

As the name implies, smooth muscle presents a uniform appearance that lacks the obvious striping characteristic of striated muscle. Vascular smooth muscle shortens 50 times slower than fast skeletal muscle but generates comparable force using 300 times less chemical energy in the process. These differences in the mechanical properties of smooth versus striated muscle relate to differences in the basic mechanism responsible for muscle shortening and force production. As in striated muscle, smooth muscle contraction results from the cyclic interaction of the contractile protein myosin (*i.e.*, the myosin cross bridge) with the contractile protein actin. The arrangement of these contractile proteins and the nature of their cyclic interaction account for the unique contractile capabilities of smooth muscle.

Structure and organization. Smooth muscle contains spindle shaped (Figure 23) cells 50 to 250 micrometres in length by five to 10 micrometres in diameter. These cells possess a single, central nucleus. Surrounding the nucleus and throughout most of the cytoplasm are the thick (myosin) and thin (actin) filaments. Tiny projections that originate from the myosin filament are believed to

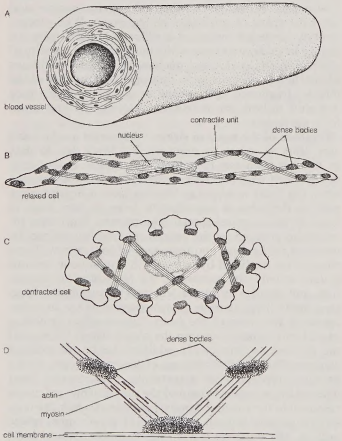


Figure 23: *The artery wall and the ultrastructure of the smooth muscle cells within it.*
(A) Smooth muscle cells are circumferentially oriented and interconnected within the wall by a dense connective tissue matrix. (B) A relaxed smooth muscle cell with a smooth membrane boundary and central nucleus. Contractile units traverse the cell interior. (C) A contracted smooth muscle cell with large membrane blebs formed as the contractile proteins generate force and pull at the dense amorphous plaques on the cell membrane. (D) Attachment sites (dense bodies) for the contractile proteins, actin filaments are located in the cytoplasm and on the membrane. Thick myosin filaments interdigitate with the thin actin filaments.

be cross bridges. The ratio of actin to myosin filaments (approximately 12 to 1) is twice that observed in striated muscle and thus may provide a greater opportunity for a cross bridge to attach and generate force in smooth muscle. An increased probability for attachment may, in part, account for the ability of smooth muscle to generate, with far less myosin, comparable or greater force than striated muscle.

Smooth muscle differs from striated muscle in lacking any apparent organization of the actin and myosin contractile filaments into the discrete contractile units called sarcomeres. Recent advances have shown that a sarcomere-like structure may nonetheless exist in smooth muscle. Such a sarcomere-like unit would be composed of the actin filaments that are anchored to dense, amorphous bodies in the cytoplasm as well as dense plaques on the cell membrane (Figure 23). These dense areas are composed of α-actinin, a protein, found in the Z lines of striated muscle, to which actin filaments are known to be attached. Thus, force generated by myosin cross bridges attached to actin is transmitted through actin filaments to dense bodies and then through neighbouring contractile units, which ultimately terminate on the cell membrane.

Changes with contraction

Relaxed smooth muscle cells possess a smooth cell membrane appearance, but upon contraction, large membrane blebs (or eruptions) form as a result of inwardly directed contractile forces that are applied at discrete points on the muscle membrane (Figure 23). These points are presumably the dense plaques on the cell membrane to which the actin filaments attach. As an isolated cell shortens it does so in a corkscrewlike manner. It has been hypothesized that, in order for a single cell to shorten in such a unique fashion, the contractile proteins in smooth muscle are helically oriented within the muscle cell. This helical arrangement agrees with earlier speculation that the contractile apparatus in smooth muscle may be arranged at slight angles relative to the long axis of the cell. Such an arrangement of contractile proteins could contribute to the slower shortening velocity and enhanced force-generating ability of smooth muscle.

The contractile proteins interact to generate a force that must be transmitted to the tissue in which the individual smooth muscle cells are embedded. Smooth muscle cells do not have the tendons present in striated muscles, which allow for transfer of muscular force to operate the skeleton. Smooth muscles, however, are generally embedded in a dense connective tissue matrix that connects the smooth muscle cells within the tissue into a larger functional unit (Figure 23).

Mitochondria

Other organelles of the cell interior are related to energy production and calcium storage. Mitochondria are located most frequently near the cell nucleus and at the periphery of the cell. As in striated muscles, these mitochondria are linked to ATP production. The sarcoplasmic reticulum is involved in the storage of intracellular calcium. As in striated muscle, this intracellular membrane system plays an important role in determining whether or not contraction occurs by regulating the concentration of intracellular calcium.

Initiation of contraction. Smooth muscle cells contract in response to neuronal or hormonal stimulation, either of which results in an increase in intracellular calcium as calcium enters through membrane channels or is released from intracellular storage sites. The elevated level of calcium in the cell cytoplasm results in force generation. The rise in the level of intracellular calcium, however, initiates contraction through a mechanism that differs substantially from that in striated muscle. In striated muscle, myosin cross bridges are prevented from attaching to actin by the presence of the troponin-tropomyosin system molecules on the actin filament (see above *Striated muscle*). In smooth muscle, although tropomyosin is present, troponin is not, which means that an entirely different regulatory scheme operates in smooth muscle. Regulation of the contractile system in smooth muscle is linked to the myosin filament; regulation in striated muscle is linked to the actin filament.

In order for the smooth-muscle myosin cross bridge to interact cyclically with actin, a small protein on the myosin

molecule, called the light chain, must be phosphorylated (receive a phosphate group). This phosphorylation is the result of a series of interdependent biochemical reactions that are initiated by the rise in intracellular calcium. For the cell to relax, the concentration of intracellular calcium falls, thus inactivating these biochemical processes associated with light chain phosphorylation. The phosphate molecule that was added in the previous steps, however, still must be removed from the light chain so that attachment of the cross bridge to actin is prevented. Phosphatases are enzymes in the muscle cell that cleave the phosphate group from the myosin light chain.

Release of chemical energy

Cross-bridge cycle and ATP breakdown. Smooth-muscle contraction requires the release of chemical energy stored in ATP molecules. The release of this chemical energy by the myosin cross bridge and the resultant mechanical work is commonly referred to as the cross-bridge cycle, which in smooth muscle is believed to be a multistep process similar to that in striated muscle. Therefore, the mechanical properties of smooth muscle, as of striated muscles, are intimately linked to this multistate cross-bridge cycle. For instance, there is a correlation between the rate at which the cross bridges cycle and the maximum shortening velocity of the muscle. Since the actomyosin ATPase cross-bridge cycle in smooth muscle is considerably slower than that in striated muscle, the slower shortening velocity in smooth muscle must be due, in part, to the reduced turnover rate of the cross bridge. The slower cycling rate could also account for the high economy of ATP utilization that characterizes smooth-muscle force production, since fewer cycles are required and less energy is consumed in the generation of force.

Mechanical properties. The relationship between smooth muscle's ability to shorten and to generate force is characterized by the force–velocity relationship. The form of this relationship is qualitatively similar to that in striated muscle; however, the smooth-muscle force–velocity relationship differs from that of striated muscle in having a slower maximum shortening velocity (V_{max}) and greater force per cross-sectional area of muscle (F_{max}). As mentioned above, the slower shortening velocity may relate to the slower cycling rate of the cross bridge as well as the orientation of the contractile proteins within the muscle cell.

Force-generating capabilities

The force-generating capabilities of smooth muscle are greater than those of striated muscle despite the fact that there is considerably less myosin in smooth muscle. Possible explanations for this relate to the arrangement of the contractile apparatus within the cell, which gives rise to more cross bridges effectively operating in conjunction with one another. Second, enhanced force production could be related to the greater amount of time that the cross bridge spends in the attached, high force-producing state (*i.e.,* duty cycle). Evidence for such an increase in the duty cycle does exist in smooth muscle.

When fully contracted, the amount of force that smooth muscle can generate depends on the muscle length. Therefore, as in striated muscle, an optimal length for force production exists, with force being reduced at both lesser and greater lengths (for an explanation of underlying mechanism, see above *Striated muscle*). The similarity in shape for both the force–velocity and length–tension relationships between smooth and striated muscle suggests that in smooth muscle both a cross-bridge mechanism and sliding of contractile filaments must occur.

Constant force

Smooth muscle cells often must generate constant force for prolonged periods of time. In order to do this without depleting the muscle's energy supply, smooth muscle appears to have adapted by altering the cross-bridge cycling rate during the time course of a single contraction. If shortening velocity is a reasonable indicator of cross-bridge cycling, then the observed reduction in shortening velocity with time of contraction suggests that the cross-bridge cycling rate must be slowing with contraction. At present it is not clear whether the cycling rate of the entire cross-bridge population slows with duration of contraction or whether a subset of slowly cycling cross bridges (*i.e.,* latch bridges) appears with a contraction time that hinders the action of the normally cycling bridges. Regardless of the mechanism, the modulation of cross-bridge cycling rate represents a highly economical means of generating force in a muscle that often exists in a tonic state of contraction.

Smooth muscle in disease states. Smooth muscle cells lining the artery walls have been implicated in cardiovascular diseases such as atherosclerosis and hypertension (high blood pressure). In hypertension an increase in the size of the individual cells (hypertrophy) and of their number (*i.e.,* hyperplasia) has been hypothesized. The increased quantity of smooth muscle in the artery wall could increase the constrictive ability of the artery or the artery wall thickness, either of which could constrict the lumen of the artery, thus reducing blood flow through the vessel. To compensate for this resistance to blood flow, the cardiovascular system responds by elevating blood pressure to assure that the various tissues of the body are adequately supplied with blood. A consequence of the need to raise blood pressure, however, is a greater workload for the heart, and thus individuals who are diagnosed with high blood pressure are at a higher risk of heart attack or stroke. Drugs that relax smooth muscle in an effort to lower blood pressure have been successful in reducing the risk of cardiovascular complications. (N.R.A./D.M.W.)

Diseases and disorders of muscle

Muscle diseases and disorders that result from direct abnormalities of the muscles are called primary muscle diseases; those that can be traced as symptoms or manifestations of disorders of nerves or other systems are not properly classified as primary muscle diseases. Because muscles and nerves (neurons) supplying muscle operate as a functional unit, disease of both systems results in muscular atrophy (wasting) and paralysis.

INDICATIONS OF MUSCLE DISEASE

Muscular atrophy and weakness are among the most common indications of muscular disease (see below *Muscle weakness*). Though the degree of weakness is not necessarily proportional to the amount of wasting, it usually is so if there is specific involvement of nerve or muscle. Persistent weakness exacerbated by exercise is the primary characteristic of myasthenia gravis.

Pain is ordinarily present in muscle disease because of defects in blood circulation or injury or inflammation of the muscle. Pain is rare, except as a result of abnormal posture or fatigue, in muscular dystrophy—a familial disease characterized by progressive wasting of the muscles. Cramps may occur with disease of the motor or sensory neurons; with certain biochemical disorders (*e.g.,* hypocalcemia, a condition in which the blood level of calcium is abnormally low); when the muscle tissues are affected by some form of poisoning; from disease of the blood vessels; and with exercise, particularly when cold.

Muscle enlargement—muscular hypertrophy—occurs naturally in athletes. Hypertrophy not associated with exercise occurs in two unusual forms of muscular dystrophy, known as myotonia congenita and hypertrophia musculorum vera. (The latter condition combines increased muscle size with strength; in the former, muscle cramping is an additional feature.) Pseudohypertrophy, muscular enlargement through deposition of fat rather than muscle fibre, occurs in other forms of muscular dystrophy, particularly the Duchenne type.

Tetany, tetanus, and fasciculation

Tetany is the occurrence of intermittent spasms, or involuntary contractions, of muscles, particularly of the arms and legs and the larynx, or voice box; it results from low levels of calcium in the blood and from alkalosis, an increased alkalinity of the blood and tissues. Tetanus, also called lockjaw, is a state of continued muscle spasm, particularly of the jaw muscles, caused by toxins produced by a particular bacillus, *Clostridium tetani.*

The twitching of muscle fibres controlled by a single motor nerve cell, a process called fasciculation, may occur in a normal person but may indicate that muscular atrophy is due to disease of motor nerve cells in the spinal cord. Fasciculation is seen most clearly in muscles close to the surface of the skin.

Glycogen is a storage form of carbohydrate, and its breakdown is a source of energy. Muscle weakness is found in a rare but important group of hereditary diseases, the so-called glycogen-storage diseases, in which various enzyme defects prevent the release of energy by the normal breakdown of glycogen in muscles. As a result, abnormal amounts of glycogen are stored in the muscles and other organs. The best-known type clinically affecting muscles is McArdle's disease, in which the muscles are unable to degrade glycogen to lactic acid on exertion because of the absence of the enzyme phosphorylase. Abnormal accumulations of glycogen are distributed within muscle cells. Features of the condition include pain, stiffness, and weakness in the muscles on exertion. McArdle's disease usually begins in childhood. No specific treatment is available, and persons affected are usually required to restrict exertion to tolerable limits. The condition does not appear to become steadily worse, but there are threats to continuing activity and to life when the muscle protein myoglobin is excreted in the urine. Other glycogen-storage diseases result from deficiency of the enzymes phosphofructokinase or acid maltase. With acid maltase deficiency both heart and voluntary muscles are affected, and death occurs within a year or so of birth as a rule.

McArdle's disease

MUSCLE WEAKNESS

Signs and symptoms. Weakness is a failure of the muscle to develop an expected force. Weakness may affect all muscles or only a few, and the pattern of muscle weakness is an indication of the type of muscle disease. Often associated with muscle weakness is the wasting of affected muscle groups. The many reasons why a muscle is not fully activated in weakness may include less than maximal voluntary effort; disease of the brain, spinal cord, or peripheral nerves that interferes with proper electrical stimulation of the muscle fibres; or a defect in the muscle itself. Only when all causes have been considered can weakness be attributed to failure of the contractile machinery (*i.e.,* the anatomy) of the muscle cell.

Clinical presentation

The effect of weakness in a particular muscle group depends on the normal functional role of the muscle and the degree to which force fails to develop. A weakness in muscles that are near the ends of the limbs usually results in a tendency to drop things if the upper limb is affected or in foot drop if the lower limbs are affected. The overall disability is not as great as weakness of more proximal (closer to the body) muscles controlling the pelvic or shoulder girdles, which hold large components of the total body mass against the force of gravity. Weakness of the proximal muscles that control the shoulder blade (or scapula), for example, results in "winging" (*i.e.,* when the sharp inner border protrudes backward) as the arms are held outstretched. If the weakness is severe, the arms cannot be raised at all.

Assessment. Muscle disease may be detected by assessing whether the muscle groups can withhold or overcome the efforts of the examiner to pull or push, or by observing the individual carrying out isolated voluntary movements against gravity, or more complex and integrated activities such as walking. The weakness of individual muscles or groups of muscles can be quantified by using a myometer, which measures force based on a hydraulic or electronic principle. The recording of contraction force repeatedly over a period of time is valuable in determining whether the weakness is improving or worsening.

Assessment of muscle weakness

The assessment of muscle weakness (and wasting) is directed toward discovering evidence of muscle inflammation or damage. These changes are discerned by blood tests or by measuring alterations of the electrical properties of contracting muscles. Another investigative tool is the muscle biopsy, which provides muscle specimens for pathological diagnosis and biochemical analysis. Muscle biopsies can be taken by a needle or by a surgical procedure.

Classification of muscle weakness. Muscle contraction results from a chain of events that begins with a nerve impulse traveling in the upper motor neuron from the cerebral cortex in the brain to the spinal cord. The nerve impulse then travels in the lower motor neuron from the spinal cord to the neuromuscular junction, where the neurotransmitter acetylcholine is released. Acetylcholine diffuses across the neuromuscular junction, stimulating acetylcholine receptors to depolarize the muscle membrane. The result is the contraction of the muscle fibre. Contraction depends on the integrity of each of these parts; disease or disorder in any part causes muscle weakness.

Upper motor neuron disease. Muscle weakness typical of upper motor neuron disease is seen in stroke (cerebrovascular accident), producing weakness of one side of the body. The arm is typically flexed, the leg is extended, and the limbs have increased tone. Some movement may be preserved, though the use of the hand is particularly limited. In comparison with muscle weakness due to disease of the lower motor neuron or muscle, in the upper motor neuron weakness the muscle bulk is usually well preserved. Other causes of upper motor neuron disorders include multiple sclerosis, tumours, and spinal cord injury.

Lower motor neuron disease. Degeneration of the lower neuron produces a flaccid muscle weakness. Muscle wasting is a prominent feature because the shrinkage and eventual death of neurons leads to denervation of the muscle. Diseases of the motor neurons lying in the spinal cord are termed motor neuron diseases. The most common is motor neuron disease itself, termed in the United States amyotrophic lateral sclerosis and generally known as Lou Gehrig's disease. Patients are generally between 50 and 70 years of age and have upper and lower motor neuron weakness. Paralysis progresses rapidly, and death often results within three years. The spinal muscular atrophies are a group of disorders affecting infants, juveniles, and young adults, often with an autosomal recessive mode of inheritance (*i.e.,* requiring the gene from both parents for expression). The infantile type is fatal within one year, but the older cases tend to be less severe. No cause is yet known for any of these diseases, and no cure is available.

Lou Gehrig's disease

Diseases of the peripheral nerves (peripheral neuropathies, or polyneuropathies) can produce symptoms and signs similar to the motor neuron diseases. Sensory disturbance due to involvement of the nerve fibres carrying sensory impulses is usually also involved. Symptoms usually begin in the hands and feet and progress toward the body. Peripheral neuropathies can cause degeneration of the axons, the core of the nerve fibres. The axons can regenerate but only at a rate of one to two millimetres per day. Thus, after injury to a nerve at the elbow, the hand will not recover for six to nine months. Toxins and damage to blood vessels tend to cause axonal types of neuropathy.

Peripheral neuropathy also can be caused by degeneration of the myelin sheaths, the insulation around the axons. These are termed demyelinating neuropathies. Symptoms are similar to neuropathies with axonal degeneration, but since the axons remain intact, the muscles rarely atrophy. Recovery from demyelinating neuropathies can be rapid. Diphtheria and the autoimmune diseases like Guillain-Barré syndrome cause demyelinating neuropathies. Other causes of peripheral neuropathy include diabetes mellitus, nerve trauma, inherited factors, and chronic renal failure.

Neuromuscular junction disorders. Diseases of the neuromuscular junction typically involve the generation of an end-plate potential that is too low to propagate an action potential in the muscle fibre. These diseases are associated with weakness and fatigability with exercise. Diseases of neuromuscular transmission may be acquired or inherited and may be the result of an autoimmune disorder such as myasthenia gravis (see below *Primary diseases and disorders*), a congenital disorder, or a toxin such as in botulism and some drug-induced disorders.

General causes

PRIMARY DISEASES AND DISORDERS

It appears that the maintenance of muscle mass and function depends on its use. For example, weight lifters and sprinters have muscle fibres with a greater capacity for glycolysis (and thus ATP production) and sudden force generation. Striated muscles can regenerate after damage and can adapt to the loads they carry. Thus, in a muscle biopsy from an individual with any of the muscular dystrophies, there is likely to be a mixture of the cellular changes associated with damage and those associated with regeneration and growth (hypertrophy).

Muscular activities in which the muscle resists an extending force (eccentric contractions) cause more damage to the muscle cells than contraction of the muscle at constant length (isometric contraction) or where shortening occurs (concentric contractions). The greater damage with eccentric contraction occurs despite the fact that the metabolic rate may be one-sixth of that of an equivalent concentric or isometric contraction.

Muscles that are immobilized, as by a plaster cast following fracture of a long bone, tend to waste rapidly through shrinkage of the muscle fibres. A consistent finding is that the oxidative capacity of the muscle is reduced. These changes are reversible with muscle-strengthening exercises. In animals with inherited muscle diseases, the progress of the disease is slowed by immobilizing the limb. Recent evidence in human muscular dystrophy, however, suggests that exercise can strengthen the muscle.

The muscular dystrophies. The muscular dystrophies are a group of hereditary disorders characterized by progressive muscular atrophy and weakness. In most varieties the muscles of the limb girdles—the pelvic and shoulder muscles—are involved.

Measurement of the activity of serum creatine kinase, analysis of a muscle biopsy, and recordings from an electromyograph frequently establish that the muscle weakness is due to primary degeneration of the muscles. Creatine kinase is an enzyme of muscle fibres that is released into the bloodstream when the fibres degenerate as in the muscular dystrophies. Muscle biopsies reveal the characteristic degeneration and necrosis of muscle fibres, as well as the phagocytic actions of wandering macrophages and the attempted regeneration of damaged fibres. Electromyography shows differences in the electrical patterns of normal muscle, myopathy, and chronic denervation, such as in the spinal muscular atrophies.

Duchenne's muscular dystrophy

In contrast to the several varieties of muscular dystrophy that are relatively benign, the Duchenne type, which predominately affects boys, is severe. It causes difficulty in walking at about the age of four years, loss of the ability to walk at about the age of 11, and death at about the age of 18 or later, usually because of respiratory failure. There is a paradoxical increase in the size of the calf muscles, giving rise to the term pseudohypertrophic muscular dystrophy (because the increase in size is the result of replacement with fat and fibrous tissue rather than growth of fibres, as in true hypertrophy). Duchenne's muscular dystrophy is an X-linked condition; a defect of a large gene on the X chromosome is responsible for the disease. Females do not manifest the disease but transmit the gene for the disease to half of their sons and half of their daughters (who themselves become carriers). Muscle degeneration appears to be due to lack of a large protein called dystrophin, which causes a disruption of the membrane covering the muscle fibre; the result is the entry of excess amounts of calcium ions into the cell and cell degeneration.

Other muscular dystrophies

Becker's muscular dystrophy is similar to the Duchenne type except that Becker's appears later in life and is more benign. It is due to different damage to the same gene on the X chromosome that causes Duchenne's muscular dystrophy.

Facioscapulohumeral muscular dystrophy starts in the face, the muscles around the shoulder blades, and the upper arms. It is more slowly progressive than Duchenne's muscular dystrophy, and most patients have a normal life span. The leg weakness frequently causes "drop foot" and a waddling gait. Facioscapulohumeral muscular dystrophy is inherited in an autosomal dominant fashion; thus, the individual will receive the gene from one parent and will pass the disease to approximately half the children.

Limb-girdle muscular dystrophy is similar to facioscapulohumeral muscular dystrophy, but the face is not involved. Where inheritance is observed, it is usually autosomal recessive; *i.e.,* both parents must donate the affected gene for expression of the disease.

There are a number of other muscular dystrophies, each characterized by an individual pattern of muscle weakness and inheritance. Ocular muscular dystrophy, or myopathy, predominantly affects muscles moving the eyes. Oculopharyngeal muscular dystrophy affects not only the eye muscles but also those of the throat and is usually dominant with onset in the later years of life. Distal myopathy particularly affects the muscles of the feet and hands.

Remedial devices and measures, including physical therapy, spinal supports, and splints for the limbs, may be useful. Prevention of obesity is considered important, especially in Duchenne's muscular dystrophy, and infections are promptly treated. The identification of carriers of the trait and genetic counseling represent the best hope of reducing the incidence of this group of diseases.

Myasthenia gravis. Myasthenia gravis is an acquired autoimmune disorder that involves a failure in the transmission of nerve impulses to the muscles and is characterized by persistent muscular weakness and a tendency of muscles to be easily fatigued. Individuals affected have weakness, particularly of the face, limbs, and neck. Symptoms include double vision, difficulty swallowing and breathing, and excessive muscle fatigue during exercise with partial recovery after rest.

Autoimmune antibodies (those produced against the body's own cells) cause the destruction of acetylcholine receptors of the neuromuscular junction. Removal of the thymus, treatment with high doses of corticosteroids (which depress the immune response), and blood exchange to remove the autoimmune antibodies are frequently effective in controlling this potentially fatal disease.

Toxic myopathies. Striated muscle may be damaged by a number of drugs and toxins. Some, such as intramuscular injection of bupivicaine, cause damage to the muscle fibres by disrupting the membrane and allowing calcium to enter and destroy the cell. Other drugs, such as chloroquine, emetine, and vincristine, seem to disrupt the internal biochemistry of the muscle fibre. Still others, such as corticosteroids, affect the muscle metabolism; this is particularly true of the fluoro-substituted corticosteroids, which cause increased catabolism and thereby produce proximal muscle weakness especially of the upper limbs. Finally, other drugs, such as hydralazine, produce an autoimmune lupuslike disorder and are associated with dermatomyositis or polymyositis.

There are rare individuals who suffer malignant hyperthermia, a potentially lethal attack of muscle rigidity and hyperthermia, when exposed to general anesthetic agents such as succinylcholine and halothane. During or after induction of the anesthesia, the patient develops rigidity and an increase in central body temperature. Death may occur in five to 15 minutes when the central temperature reaches above 110° F (43° C). There is a high death rate in such attacks; should the patient recover, there will be recurrences with future exposures to these drugs. The condition tends to run in families, and it may be inherited as an autosomal dominant trait. The cause is not completely known but apparently relates to an abnormality in the chemistry of calcium in the muscle fibre. Excess calcium is released into the sarcoplasm during exposure to the general anesthetic agents, stimulating the mitochondria to burn glycogen and thereby produce heat. The excess calcium also causes the muscle fibres to contract and become rigid. Drugs that prevent calcium release in the muscle appear to prevent the attack and are given at the first sign of attack. After the onset of the attack, the anesthetic agent should be removed and the patient cooled.

Inflammatory myopathies. Bacterial myositis, inflammation of muscle tissues as the result of infection with bacteria, is commonly localized and is the aftermath of injury. *Staphylococcus* and *Streptococcus* organisms are usually responsible. General indications of infection, such as fever and increased numbers of white blood cells, are accompanied by local signs of inflammation, such as reddening, swelling, and warmth. Abscess formation is rare, except in the tropics. In general, bacterial myositis responds to treatment with antibiotics and with minor surgery.

Common pathogens

Viral myositis may also occur. The best example of this is Bornholm disease, also called epidemic myalgia, devil's grip, and epidemic pleurodynia, caused by the Coxsackie virus. Affected persons recover completely after a brief period of intense muscular pain and fever.

In addition to bacteria and viruses, the muscles may be invaded by animal organisms, including protozoa and

helminths, or worms. Trichinosis is an infection with the roundworm *Trichinella spiralis*. It results from eating infested pork that has not been thoroughly cooked. Reproduction of the worm takes place in the intestines. Larvae migrate from the intestinal walls and bury themselves in muscle tissue. Fever, muscular pains, and sometimes weakness result from the invasion of the muscles. Most persons recover after about two months, but death can result from invasion of the heart muscle.

Auto-immune diseases

The autoimmune diseases of muscle, grouped together under the term polymyositis, frequently are associated with inflammation of the skin in a characteristic distribution. The eyelids, cheeks, knuckles, elbows, knees, and backs of the hands are frequently involved. The combination of polymyositis and the typical dermatitis is classified as dermatomyositis. Muscle weakness can be proximal or diffuse. Frequently swallowing is difficult and the neck is weak. The disease can develop acutely within a few days or chronically over years. The muscle biopsy shows infiltration of the striated muscle by white blood cells, mainly lymphocytes. These collect between the muscle fibres and around small blood vessels and appear to damage the muscle fibres. Vascular damage is a major feature, particularly in the childhood form of dermatomyositis.

The cause of the autoimmune reaction to the striated muscle is not known. The disease frequently occurs in association with other autoimmune diseases, such as rheumatoid arthritis and progressive systemic sclerosis, and it can be associated with carcinoma in a significant proportion of older patients, particularly those with dermatomyositis.

High-dose corticosteroid treatment, often combined with a cytotoxic immunosuppressant drug (*i.e.,* one that destroys the cells and suppresses the immune system), such as cyclophosphamide, frequently is successful in suppressing the disease and allowing destroyed muscles to regenerate.

Endocrine and metabolic myopathies. *Hormones.* Striated muscle is directly or indirectly affected in most disorders caused by the underproduction or overproduction of hormones. This is true because the rates of synthesis or breakdown of the proteins of muscle are affected. If the thyroid gland is overactive (thyrotoxicosis, hyperthyroidism), there is muscle wasting of both type 1 fibres (oxidative-rich fibres responsible for endurance) and type 2 fibres (glycogen-rich fibres responsible for rapid, sprint-type muscle contraction). If the thyroid exhibits underactivity (myxedema, hypothyroidism), there is a predominance of type 1 fibres and sometimes a decrease in type 2 fibre size. If the adrenal gland is overactive (Cushing's syndrome), there is selective atrophy of the type 2 fibres. This pattern is seen as well in prolonged treatment with corticosteroid drugs (such as prednisolone for asthma), which can result in profound wasting and weakness of proximal muscles.

Osteo-malacia

Vitamin D deficiency. A similar mechanism underlies the wasting and weakness associated with lack of vitamin D (osteomalacia) in which marked atrophy of type 2 fibres may be seen. The actions of vitamin D in muscle are not fully understood, but it appears that at least one of its metabolites, 25-hydroxycholecalciferol, may influence the resting energy state of the muscle and also protein turnover. Unlike the inherited diseases of muscle, endocrine causes of disease may be eminently treatable.

Mitochondrial myopathies. The mitochondria are the cellular structures in which biochemical processes produce energy (in the form of heat and work) from the oxidation of fuels such as glucose and fat. The first observation of a mitochondrial myopathy was in a patient with unregulated mitochondrial oxidative metabolism, resulting in excessive heat production. Since then a number of biochemical defects in mitochondria have been discovered. There is no single entity that can be diagnosed as a "mitochondrial myopathy." In those mitochondrial defects in which a defective oxidative metabolism exists, a common result is a tendency for the muscles to generate large amounts of lactic acid. This is a consequence of needing to provide energy from the nonoxidative breakdown of the glycogen stored in the muscle.

Glycogen storage diseases

Glycogenoses. In 1951 Brian McArdle recognized a disorder of muscle that gave cramplike pains yet was not associated with the normal production of lactic acid from exercise. The defect was identified later as an absence of phosphorylase, the enzyme involved in the first step in the cascade (the splitting off of the glucose-1-phosphate units from glycogen). Since blood-borne glucose could still be used to make glycogen, this disorder is classified among the 10 glycogen storage diseases (glycogenoses).

Lipid storage myopathies. Lipid storage myopathy is a potentially confusing term because the more severe forms of muscle disease (*e.g.,* muscular dystrophy) are often associated with the replacement of the lost muscle fibres with fat cells. In the lipid storage myopathies the fat, or triglyceride, is deposited as tiny droplets within the cytoplasm of the muscle fibre. Normal type 1 muscle fibres have a greater amount of lipid droplets than type 2 muscle fibres.

In the early 1970s two disorders of muscle fat metabolism were discovered to affect a component of the shuttle system transporting free fatty acids into mitochondria for subsequent oxidation. This shuttle requires the fatty acid (acyl) molecule to attach to the carrier molecule, carnitine, in the presence of the enzyme acylcarnitine transferase. The acylcarnitine that is formed crosses the outer and inner mitochondrial membranes and then is split in the presence of another form of the enzyme acyltransferase to give carnitine and the acyl molecule, which is then oxidized. A deficiency of carnitine results in the storage of fats in the cytoplasm. Deficiency of acylcarnitine transferase results in muscle damage on severe exertion. Recognition is important because the conditions are potentially treatable.

Symptoms of myotonia

Myotonic diseases. Myotonia is a difficulty in relaxing a muscle after contraction; it may manifest as difficulty in relaxing the hand after a handshake. Though slow relaxation may be due to delayed disengagement of the thick and thin filaments of myosin and actin, most cases of myotonia are due to continuing electrical activity of the sarcolemma. In this most common type of myotonia, a single nerve action potential causes multiple firing of the sarcolemma, thereby continuing muscular contraction. The cause of this problem lies in abnormal ion channels or ion pumps in the sarcolemma, although the exact cause is not known. In many forms of myotonia, cold exacerbates the problem. Weakness is a problem in the myotonic syndromes; it tends to be more pronounced after inactivity, with a rapid "warm up" on commencing exercise.

Myotonic dystrophy, or dystrophia myotonica of Steinert, is the most common of the myotonic disorders. It is an autosomal dominant disorder affecting many systems of the body in addition to muscle. There is premature balding, cataract formation, mental impairment, gonadal atrophy, endocrine deficiencies, gastrointestinal tract dysfunction, and muscle fibre degeneration. While the disease has manifested itself by the age of 25 years in most cases, some patients or family members may escape developing significant symptoms throughout their lives.

Myotonia congenita of Thomsen is also an autosomal dominant disorder, but it is not associated with any dystrophic features. The onset is at birth, usually with severe difficulty in relaxing the muscle after a forced contraction, such as a sneeze. Myotonia can occur in a number of other conditions including the periodic paralyses.

Drugs that suppress the extent of the myotonia, such as quinine, procainamide, and phenytoin, have had variable success on the weakness. No cure of these diseases is yet available.

THE PERIODIC PARALYSES

Patients with periodic paralysis suffer from recurrent attacks of muscle paralysis that may last from half an hour to 24 hours. Attacks particularly affect the legs and to a lesser extent the arms and trunk muscles. During an attack the muscles may be slightly swollen and tender. Attacks frequently occur with rest after vigorous exercise.

Types of periodic paralysis

There are two types of periodic paralysis. In hypokalemic periodic paralysis, the serum potassium falls during the attack, which also can be precipitated by anything that tends to lower the serum potassium. Hyperkalemic periodic paralysis, on the other hand, is associated with an increase in serum potassium. An attack may be precipitated by oral therapy with potassium.

Both periodic paralyses are autosomal dominant disorders. Though neither is likely to lead to fatal muscle weakness, the temporary incapacity and embarrassment are severe. In the attack, the muscle fibres lose their electrical potential (become depolarized) and thereby become incapable of excitation. The disease appears to be due to changes in the movements of ions through membranes of the skeletal muscle. Potassium appears to be one of the ions responsible for the condition. Abnormal ion channels or ion pumps in the membrane may be the cause. Treatment by drugs appropriately altering the serum potassium can be effective, and acetazolamide, which affects the acidity of the blood and cells, is often effective.

FATIGUE

Fatigue is a failure of the muscle to sustain force in a prolonged contraction or to reattain force in repeated contractions. The mechanisms underlying fatigue share several features with those underlying weakness: electrical excitation of the muscle cell; electromechanical coupling; and the major processes supplying energy for contraction, work, and heat production.

The action potential that is conducted along the length of the muscle cell has its origin in a depolarization of the postsynaptic membrane of the neuromuscular junction caused by the release of acetylcholine from the presynaptic nerve terminal. The synapse is thus potentially a key control point in the chain of command for muscular contraction. Complete failure of neuromuscular transmission occurs from poisoning with curare or botulinum toxin and results in complete paralysis. Incomplete or variable neuromuscular transmission is a feature of myasthenia gravis, the diagnosis of which can be confirmed by finding evidence of fatigue in response to electrical stimulation of the nerve supplying the muscle. This behaviour is a consequence of the immunologic damage to the postsynaptic membrane of the synapse by antibodies to the acetylcholine receptor.

Curare poisoning

Electrical stimulation of a muscle via its nerve is a means by which some of the mechanisms underlying human muscle fatigue can be analyzed. By stimulating the nerve at a range of frequencies and measuring the force of the contractions produced, it is possible to plot the frequency:force curve. Failure of force at high stimulation frequencies is seen with myasthenia gravis. In conditions in which normal muscle is cooled or lacks blood supply, there is also a high-frequency fatigue.

After severe exercise a form of fatigue may persist that is characterized by a lower force production at the lower stimulation frequencies with no decrease in the amplitude of the evoked action potential recorded from the muscle. This type of fatigue would be expected with the failure of excitation-contraction coupling, the inward spread of the action potential by the transverse tubular system, resulting in the release of intracellular calcium, which activates the actin-myosin interaction and subsequent contraction.

There is a relationship between the development of fatigue and the depletion of energy stores in exercising muscle. In prolonged exercise, such as marathon running, fatigue is associated with glycogen depletion due to oxidative glycolysis. Intense exercise that lasts only a few minutes is associated with the accumulation of lactate and an intracellular acidosis due to anaerobic (nonoxidative) glycolysis. In both types of exercise there is a reduction of phosphocreatine, although no appreciable depletion of ATP. In contrast, in patients with myopathies, more striking changes are seen with only low total work or power output. Fatigue in patients with McArdle's disease, in whom there is absent glycogenolysis, is not associated with the usual acidosis. Pronounced acidosis is a finding in patients with defective mitochondrial metabolism in whom there may be a slow resynthesis of phosphocreatine after exercise. (R.A.He./R.H.T.E./W.G.Br.)

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(W.F.W./R.McN.A./J.Ge./B.Wo./J.M.N.-D./N.R.A./D.M.W./W.G.Br.)

Museums

A museum, in the traditional and commonly accepted meaning of the term, is an institution dedicated to preserving and interpreting the primary tangible evidence of humankind and the environment. In its preserving of this primary evidence, the museum differs markedly from the library, with which it has often been compared, for the items housed in a museum are mainly unique and constitute the raw material of study and research. In the museum the object, in many cases removed in time, place, and circumstance from its original context, communicates itself directly to the viewer in a way not possible through other media. It is this attribute that has seen the founding of museums for a variety of purposes: to serve as recreational facilities, scholarly venues, or educational resources; to contribute to the quality of life of the areas where they are situated; to attract tourism to a region; to promote civic pride or nationalistic endeavour; or even to transmit overtly ideological concepts. Given such a variety of purposes, museums reveal remarkable diversity in form, content, and even function. Yet, despite such diversity, they are bound by a common goal: the preservation and interpretation of some material aspect of society's cultural consciousness.

This article covers three major aspects of museums: their history, their types, and their operation. For coverage of related topics in the *Macropædia* and *Micropædia,* see the *Propædia,* section 10/61, and the *Index.*

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The history of museums

ETYMOLOGY

From *mouseion* to *museum*

The word *museum* has classical origins. In its Greek form, *mouseion,* it meant "seat of the Muses" and designated a philosophical institution or a place of contemplation. Use of the Latin derivation, *museum,* appears to have been restricted in Roman times mainly to places of philosophical discussion. Thus the great Museum at Alexandria, founded by Ptolemy I Soter early in the 3rd century BC, with its college of scholars and its library, was more a prototype university than an institution to preserve and interpret material aspects of the heritage. The word *museum* was revived in 15th-century Europe to describe the collection of Lorenzo de' Medici in Florence, but the term conveyed the concept of comprehensiveness rather than denoting a building. By the 17th century *museum* was being used in Europe to describe collections of curiosities. Ole Worm's collection in Copenhagen (see Figure 1) was so called, and in England visitors to John Tradescant's collection in Lambeth (now a London borough) called the array there a museum; the catalog of this collection, published in 1656, was titled *Musaeum Tradescantianum.* The idea of an institution called a museum and established to preserve and display a collection to the public was well established in the 18th century. Indeed, Denis Diderot outlined a detailed scheme for a national museum for France in the ninth volume of his *Encyclopédie,* published in 1765.

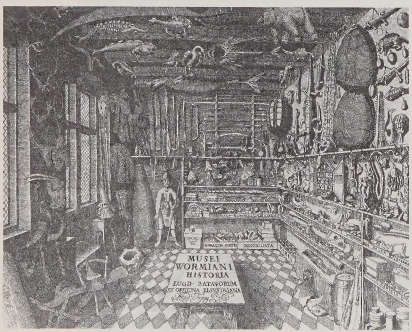


Figure 1: Ole Worm's cabinet of curiosities, a private collection that was eventually transferred to the Danish royal cabinet, Copenhagen. From an engraved frontispiece in the *Musei Wormiani Historia* (1655).
Library, The Academy of Natural Sciences of Philadelphia

Use of the word *museum* during the 19th and most of the 20th century denoted a building housing cultural material to which the public had access. Later, as museums continued to respond to the societies that created them, the emphasis on the building itself became less dominant. Open-air museums, comprising a series of buildings preserved as objects, and ecomuseums, involving the interpretation of all aspects of an outdoor environment, provide examples of this. In addition, so-called virtual museums exist in electronic form on the Internet. Although virtual museums provide interesting opportunities for and bring certain benefits to existing museums, they remain dependent upon the collection, preservation, and interpretation of material things by the real museum.

Museology and museography

Along with the identification of a clear role for museums in society, there gradually developed a body of theory the study of which is known as museology. For many reasons, the development of this theory was not rapid. Museum personnel were nearly always experienced and trained in a discipline related to a particular collection, and therefore they had little understanding of the museum as a whole, its operation, and its role in society. As a result, the practical aspects of museum work—for example, conservation and display—were achieved through borrowing from other disciplines and other techniques, whether or not they particularly met the requirements of the museum and its public.

Thus not only was the development of theory slow, but the theory's practical applications—known as museography—fell far short of expectations. Museums suffered from a conflict of purpose, with a resulting lack of clear identity. Further, the apprenticeship method of training for museum work gave little opportunity for the introduction of new ideas. This situation prevailed until other organizations began to coordinate, develop, and promote museums. In some cases museums came to be organized partly or totally as a government service; in others, professional associations were formed, while an added impetus arose where universities and colleges took on responsibilities for museum training and research.

The words derived from *museum* have a respectable, if confused, history. Emanuel Mendes da Costa, in his *Elements of Conchology,* published in 1776, referred to "museographists," and a *Zeitschrift für Museologie und Antiquitätenkunde* appeared in Dresden in 1881. But the terms *museology* and *museography* have been used indiscriminately in the literature, and there is a tendency, particularly in English-speaking countries, to use *museology* or *museum studies* to embrace both the theory and practice of museums.

THE PRECURSORS OF MUSEUMS

Evidence from antiquity and the classical age. The origins of the twin concepts of preservation and interpretation, which form the basis of the museum, lie in the human propensity to acquire and inquire. Collections of objects have been found in Paleolithic burials, while evidence of inquiry into the environment, and communication of the findings, can be seen in the cave and mobiliary art of the same period. A development toward the idea of the museum certainly occurred early in the 2nd millennium BC at Larsa, in Mesopotamia, where copies of old inscriptions were made for use in the schools. But the idea also involves the interpretation of original material—criteria that seem to have been met by objects discovered by Sir Leonard Woolley in the 6th-century-BC levels of the Babylonian city of Ur. Woolley's findings indicated that the Babylonian kings Nebuchadrezzar and Nabonidus certainly collected antiquities in their day. In addition, in a room next to the unearthed temple school there was found not only a collection of antiquities but also a tablet describing 21st-century-BC inscriptions. Woolley interpreted the tablet as a museum label. This discovery seems to suggest that Ennigaldi-Nanna, Nabonidus' daughter and a priestess who ran the school, had a small educational museum there.

The archaeological and historical records do not provide evidence that the museum as it is known today developed in such early times; nor does the word *museum* support this, despite its classical origin. Nevertheless, the collection of things that might have religious, magical, economic, aesthetic, or historical value or that simply might be curiosities was undertaken worldwide by groups as well as by individuals. In the Greek and Roman empires the votive offerings housed in temples, sometimes in specially built treasuries, are but one example: they included works of art and natural curiosities, as well as exotic items brought from far-flung parts of the empires, and they were normally open to the public, often upon payment of a small fee. Closer to the concept of a museum was the Greek *pinakotheke,* such as that established in the 5th century BC on the Acropolis at Athens, which housed paintings honouring the gods. Nor was there a lack of public interest in art at Rome. Indeed, art abounded in the public places of Rome, but there was no museum. The inaccessibility of the collection of more than one Roman emperor was the subject of public comment, and Agrippa, a deputy of Augustus, commented in the 1st century BC to the effect that paintings and statues should be available to the people.

The Greek *pinakotheke*

In Asia veneration of the past and of its personalities also led to the collection of objects. Collecting commenced at least as early as the Shang dynasty, which ruled China from approximately the mid-16th to the mid-11th century BC, and it was well developed by the Ch'in dynasty (3rd century BC)—as attested by the tomb of the Ch'in emperor Shih huang-ti, near Sian (Xian), which was guarded by an army of terra-cotta warriors and horses. Together with other grave goods, these objects are preserved on-site in the Museum of Ch'in Figures. The palace of Shih huang-ti is recorded as having many rare and valuable objects.

Successive Chinese emperors continued to promote the arts, manifest in fine works of painting, calligraphy, metalwork, jade, glass, and pottery. For example, the Han emperor Wu-ti (reigned 141/140–87/86 BC) established an academy that contained paintings and calligraphies from each of the Chinese provinces, and the last Han emperor, Hsien-ti (abdicated AD 220), established a gallery containing portraits of his ministers.

In Japan the Tōdai Temple, housing a colossal seated bronze statue of the Great Buddha (Daibutsu), was built in the 8th century at Nara. The temple's treasures still can be seen in the Shōsō-in repository there.

Medieval and Renaissance Europe. In medieval Europe collections were mainly the prerogative of princely houses and the church. Indeed, there was often a close link between the two, as in the case of the fine treasures of the emperor Charlemagne, which were divided among a number of religious houses early in the 9th century. Such treasures had economic importance and were used to finance wars and other state expenses. Other collections took the form of alleged relics of Christendom, in which there was a considerable trade. At this time Europe's maritime links with the rest of the world were largely through the northern Mediterranean ports of Lombardy and Tuscany, which, together with the ecclesiastical significance of Rome, brought considerable contact between the Italian peninsula and the Continent. There is evidence of the movement of antiquities, and of a developing trade in them, from the 12th century. Henry of Blois, bishop of Winchester, is reported to have bought ancient statues during a visit to Rome in 1151 and to have dispatched them to England, a journey of about one month's duration.

Trade in antiquities and relics

The movement of antiquities was not confined to those of Italy. Exotic material from other areas entering Italian ports soon found its way into royal collections, while the Venetian involvement in the Fourth Crusade early in the 13th century resulted in the transfer of the famous bronze horses from Constantinople to the San Marco Basilica in Venice.

The influences that led to the European Renaissance were already at work in Italy, and as a result the first great collections began to form. A reawakening of interest in Italy's classical heritage and the rise of new merchant and banking families at this northern Mediterranean gateway to the Continent produced impressive collections of antiquities, as well as considerable patronage of the arts. Outstanding among the collections was that formed by Cosimo de' Medici in Florence in the 15th century. The collection was developed by his descendants until it was bequeathed to the state in 1743, to be accessible "to the people of Tuscany and to all nations." In order to display some of the Medici paintings, the upper floor of the Uffizi Palace (designed to hold offices, or *uffizi*) was converted and opened to the public in 1582. Indeed, many of the palaces holding such collections were open to visitors and were listed in the tourist guides of the period.

Elsewhere in Europe, royal collections were developed. King Matthias I of Hungary maintained his paintings at Buda and kept Roman antiquities at Szombathely Castle during the 15th century. Maximilian I of Austria acquired a collection for his castle in Vienna. Samples of both scientific material and art were featured in the "green vaults" of the Dresden palace of Augustus of Saxony, while the archduke Ferdinand of Tirol housed a varied collection that included Benin ivories and Chinese paintings at Ambras Castle near Innsbruck. Other notable central European collections included those of the Holy Roman emperor Rudolf II at Prague and of Albert V, duke of Bavaria, who from 1563 to 1571 had buildings designed and erected to house his collections in Munich. The collection of the Polish king Sigismund II Augustus was housed at Wawel Castle, Kraków.

Royal patronage was crucial to the encouragement of the arts at this time. Rudolf II sponsored astrologers and alchemists as well as artists. Francis I of France invited famed French and Italian craftsmen and artists to rebuild

and embellish his château at Fontainebleau, and there he kept his outstanding collection of art. It was not until the 17th century that the first important royal collection was formed in England by Charles I, only to be much dispersed after his execution in 1649. Following the Restoration, Charles II also maintained a collection, but this was lost in a fire at Whitehall Palace in 1698. Early in the reign of Charles II, displays of arms and armour were being prepared at the Tower of London; clearly intended for the public benefit, these displays marked an important step in the development of a museum of the Royal Armouries.

Specialized personal collections. The developing interest in human as well as natural history in the 16th century led to the creation of specialized collections. In Italy alone more than 250 natural history collections are recorded in that century, including the fine herbarium of Luca Ghini at Padua and the more eclectic collection of Ulisse Aldrovandi at Bologna. Other notable natural history collections of the time elsewhere in Europe were those of Conrad Gesner, Félix Platter, and, a little later, the John Tradescants, father and son. Among the specialized historical collections were those of portraits of great men assembled by Paolo Giovio at Como, the archaeological collection of the Grimani family of Venice, and the fine collection of illuminated manuscripts gathered by Sir Robert Cotton in England. A number of the latter had been acquired from monasteries closed during the Reformation. In due time these various collections found their way into museums. So did the collections of Ferrante Imperato of Naples, Bernard Paludanus (Berant ten Broecke) of Amsterdam, and Ole Worm of Copenhagen.

Cabinet, Kammer, and *galleria*

A collection such as these was normally known as a *cabinet* in 16th-century England and France, while in German-speaking Europe the equivalents *Kammer* or *Kabinett* were used. Greater precision was sometimes applied, the terms *Kunstkammer* and *Rüstkammer,* for example, referring respectively to a collection of art and a collection of historical objects or armour. Natural specimens were to be found in a *Wunderkammer* or *Naturalienkabinett.* In England the term *gallery,* borrowed from Italian *galleria,* referred to a place where paintings and sculpture were exhibited. One Italian collection of natural specimens was called a *museo naturale.*

In 1565 Samuel van Quicheberg published a work on the nature of collections, advocating that they represent a systematic classification of all materials in the universe. His view reflects a spirit of system and rational inquiry that had begun to emerge in Europe. Collections of natural and artificial objects were to play an important part in this movement. This can be seen in antiquarian studies, in the work of Nicolas-Claude Fabri de Peiresc at Aix-en-Provence in France early in the 17th century, for example, or in the classification of the plant and animal kingdoms by Carolus Linnaeus a century later. For the less-specialized collector, works such as *Museographia,* by Casper F. Neickel (pseudonym of Kaspar Friedrich Jenequel), published at Leipzig in 1727, were generally available to aid in classification, care of a collection, and the identification of potential sources from which collections might be developed.

Another product of the age was the learned society, many of which were established to promote corporate discussion, experimentation, and collecting. Some commenced as early as the 16th century. Better-known societies, however, date from later years; examples are the Royal Society in London (1660) and the Academy of Sciences in Paris (1666). By the turn of the century, organizations covering other subject areas were being established, among them the Society of Antiquaries of London (1707), and learned societies were also appearing in provincial towns. This was the beginning of a movement that, through the collections formed and the promotion of their subjects, contributed much to the formation of museums.

TOWARD THE MODERN MUSEUM

Many of the collections formed during the Renaissance were symbols of social prestige and served as an important element in the traditions of the nobility and the ruling families, but over time a developing spirit of inquiry brought to collecting a different meaning and purpose as well as a much wider group of practitioners. These new collectors, concerned with enjoyment and study and the advancement of knowledge, while equally concerned with the continuity of their collections, had no such guarantee of succession. If this guarantee could not be found in the family unit, then the route of succession had to be found elsewhere, and the corporate unit provided greater security. Furthermore, if knowledge were to have lasting significance, it had to be transmitted in the public domain.

Ensuring the continuity of collections

The earliest recorded instance of a public body receiving a private collection occurs in the 16th century with the bequests of the brothers Domenico Cardinal Grimani and Antonio Grimani to the Venetian republic in 1523, to be supplemented in 1583 with a further bequest from the family. The motivation seems to have been both to promote scholarship and to grace the seat of government. At the time of the Reformation in Switzerland, material was transferred from ecclesiastical establishments to the authorities of Zürich and other municipalities, eventually forming important components of their museums. The city of Basel, concerned that the fine cabinet of Basilius Amerbach might be exported, purchased it in 1662 and nine years later arranged for its display in the university library. In 1694 the head abbot of Saint-Vincent-de-Besançon in France bequeathed his collection of paintings and medallions to the abbey to form a public collection. To some extent the emerging learned societies also were becoming repositories for such collections, in addition to developing their own. In the case of Ole Worm's collection, as in other cases, lack of interest among the owner's family after his death resulted in the transfer of the collection in 1655 to the royal cabinet in Copenhagen.

The first public museums. The first corporate body to receive a private collection, erect a building to house it, and make it publicly available was the University of Oxford. The gift was from Elias Ashmole; containing much of the Tradescant collection, it was made on the condition that a place be built to receive it. The resulting building, which eventually became known as the Ashmolean Museum, opened in 1683. (The Ashmolean later moved to another new building nearby, and its original building is now occupied by the Museum of the History of Science.)

The 18th century saw the flowering of the Enlightenment and the encyclopaedic spirit, as well as a growing taste for the exotic. These influences, encouraged by increasing world exploration, by trade centred on northwestern Europe, and by developing industrialization, are evident in the opening of two of Europe's outstanding museums, the British Museum, in London, in 1759 and the Louvre, in Paris, in 1793. The British Museum was formed as the result of the government's acceptance of responsibility to preserve and maintain three collections "not only for the inspection and entertainment of the learned and the curious, but for the general use and benefit of the public." These were housed at Montagu House, in Bloomsbury, specially purchased for this purpose. The collections had been made by Sir Robert Cotton, Robert Harley, 1st earl of Oxford, and Sir Hans Sloane. The Cotton and Harley collections were composed mainly of manuscripts. The Sloane collection, however, included his specimens of natural history from Jamaica and classical, ethnographic, numismatic, and art material, as well as the cabinet of William Courten, comprising some 100,000 items in all. Although public access to the British Museum was free of charge from the outset, for many years admission was by application for one of the limited number of tickets issued daily. Despite this, François de la Rochefoucauld, visiting from France in 1784, observed with approval that the museum was expressly "for the instruction and gratification of the public."

The British Museum

It was a matter of public concern in France that the royal collections were inaccessible to the populace, and eventually a selection of paintings was exhibited at the Luxembourg Palace in 1750 by Louis XV. Continuing pressure, including Diderot's proposal of a national museum, led to arrangements for more of the royal collection to be displayed for the public in the Grande Galerie of the Louvre palace. However, when the Grande Galerie was opened to

the public in 1793, it was by decree of the Revolutionary government rather than royal mandate, and it was called the Central Museum of the Arts. There were many difficulties, and the museum was not fully accessible until 1801. The collection at the Louvre grew rapidly, not least because the National Convention instructed Napoleon to appropriate works of art during his European campaigns; as a result many royal and noble collections were transported to Paris to be shown at what became known as the Musée Napoléon. The return to its owners of this looted material was required by the Congress of Vienna in 1815. Nevertheless the Napoleonic episode awakened a new interest in art and provided the impetus that made a number of collections available to the public.

The extensive collections of the Vatican also saw considerable reorganization during the 18th century. The Capitoline Museum was opened to the public in 1734, and the Palazzo dei Conservatori was converted to a picture gallery in 1749. The Pio-Clementino Museum, now part of the museum complex in Vatican City, opened in 1772 to house an extensive collection of antiquities. The Neoclassical architecture of this building set a standard that was emulated in a number of European countries for half a century.

The spread of the European model. Before the end of the 18th century the phenomenon of the museum had spread to other parts of the world. In 1773 in the United States the Charleston Library Society of South Carolina announced its intention of forming a museum. Its purpose was to promote the better understanding of agriculture and herbal medicine in the area. Another early institution, the Peale Museum, was opened in 1786 in Philadelphia by the painter Charles Willson Peale. The collections rapidly outgrew the space available in his home and were displayed for a time at Independence Hall. After a number of vicissitudes the collections were finally dispersed in the middle of the 19th century, but not before the fine Chinese collection had formed a major exhibition in London.

Early museums in America

European colonial influence was responsible for the appearance of museums elsewhere. In Jakarta, Indon., the collection of the Batavia Society of Arts and Science was begun in 1778, eventually to become the Central Museum of Indonesian Culture and finally part of the National Museum. The origins of the Indian Museum in Calcutta were similar, based on the collections of the Asiatic Society of Bengal, which commenced in 1784. In South America a number of national museums originated in the early 19th century: the Argentine Museum of Natural Sciences in Buenos Aires was founded in 1812; and Brazil's National Museum in Rio de Janeiro, which owes its origin to a selection of paintings presented by John VI, exiled king of Portugal, was opened to the public in 1818. Among others were the National Museum, Bogotá, Colom. (1824), and the national museums of natural history in Santiago, Chile (1830), and Montevideo, Uruguay (1837). In Canada the zoological collection of the Pictou Academy in Nova Scotia (founded in 1816) was probably opened to the public by 1822. In South Africa a museum based on the zoological collection of Andrew (later Sir Andrew) Smith was founded in Cape Town in 1825. It is likely that an amateur naturalist and diplomat, Alexander Macleay, was responsible for the initiatives that led to the opening in 1829 of what was to become the Australian Museum in Sydney.

New public collections in Europe. By this time a number of new collections were available to the public in Europe. Many of these resulted from royal and noble patronage, while others were created on the initiative of public authorities. The Prado Museum in Madrid dates from 1785, when Charles III commissioned the erection of a new building to serve as a museum of natural science. Construction was interrupted by the Napoleonic Wars, and when the building opened in 1819 it instead housed an art gallery to display part of the royal collection. In Prussia Frederick William III had a picture gallery built in Berlin to house some of his collection, and the gallery was opened to the public in 1830. This was the beginning of a remarkable complex that developed over the next century to house various portions of the national collection on a single site, now known as the Museuminsel. Another development in Germany was the erection of the Alte Pinakothek (1836) at Munich to display the painting collections of the dukes of Wittelsbach. This building was designed to exacting standards by Leo von Klenze, who was also responsible for the New Hermitage, one of the five buildings of the Hermitage museum in St. Petersburg, where in 1852 Nicholas I made available to the public the major collection of the Russian tsars. The Royal Museums in Brussels originated by royal warrant in 1835 in the interests of historical study and the arts. In the Netherlands a national art gallery was opened at the Huis ten Bosch in 1800; it was later moved to Amsterdam and eventually became the Rijksmuseum (State Museum). The National Gallery in London, founded on the personal collection of the merchant and philanthropist John Julius Angerstein, opened initially at Angerstein's house in 1824. In 1838 it moved to purpose-built premises on Trafalgar Square.

The National Gallery

Museums and national identity. Contributing to the establishment of museums in the early 19th century was a developing national consciousness, particularly among the peoples of central Europe. In 1807 the National Assembly of Hungary founded a national museum at Pest from collections given to the nation five years earlier by Count Ferenc Széchenyi. In Prague the natural history collections of the counts of Sternberg and other noble families were formed into a museum and opened in 1823 with the intention of promoting national identity. The Moravian Museum in Brno opened in 1817, and others followed at Zagreb and Ljubljana in 1821. At the centre of the Austro-Hungarian Empire, in Vienna, the imperial collections acted as the national museum; regional museums were formed at Graz, Innsbruck, and Salzburg during the period 1811–34. In Nürnberg the Germanic National Museum was directed by a proponent of a unified Germany, Hans von Aufsess, and by mid-century most of the German states had a museum. Farther north, in Poland, a national museum, although conceived in 1775, was not established until 1862, but Princess Izabella Czartoryska maintained a museum in the castle park at Puławy, near Warsaw, for eight years at the beginning of the 19th century, and two private collections were opened to the public at about the same time in Wilanów and Warsaw.

Increasing interest in antiquities led to the excavation of local archaeological sites and had an impact on museum development. In the years 1806–26, in Russian lands to the north of the Black Sea, four archaeological museums were opened, at Feodosiya, Kerch, Nikolayev, and Odessa (all now located in Ukraine). The Museum of Northern Antiquities was opened in Copenhagen in 1819 (it was there that its first director, Christian Jürgensen Thomsen, developed the three-part system of classifying prehistory into the Stone, Bronze, and Iron ages). This museum was merged with three others (of ethnography, antiquities, and numismatics) in 1892 to form the National Museum of Denmark. In France the Museum of National Antiquities opened at Saint-Germain-en-Laye late in the 18th century. It still acts as a national archaeological repository, as does the State Historical Museum in Stockholm, which houses material recovered as early as the 17th century. The national archaeological museum in Greece was started at Aegina in 1829. Certain European countries, however—the United Kingdom and Germany, for example—do not have well-developed national collections of antiquities, and as a result regional museums in those countries are the richer.

In Britain, social reforms to overcome problems resulting from industrialization contributed to the development of municipal museums. The support of museums by local authorities was seen as a means of providing both instruction and entertainment to the increasingly urbanized population and became the subject of special legislation in 1845. Museums were also viewed as a vehicle for promoting industrial design and scientific and technical achievement. Such promotion was the motivation behind the precursor of the Victoria and Albert Museum (for decorative arts) and the Science Museum, both in South Kensington, London; the founding collections were acquired from the Great Exhibition of 1851—the first of the

world's fairs. International exhibitions have contributed significantly to the formation of a number of museums since then, including the Technical Museum of Industry and Trade in Vienna and the Palace of Discovery in Paris.

The Smithsonian Institution

The Smithsonian Institution, in Washington, D.C., came into existence through the remarkable bequest of nearly one-half million dollars from James Smithson, an Englishman. He wished to see established in the United States an institution "for the increase and diffusion of knowledge among men." In 1846 the U.S. Congress accepted his bequest and passed legislation establishing the Smithsonian as an institution charged with representing "all objects of art and curious research . . . natural history, plants, [and] geological and mineralogical specimens" belonging to the United States. The U.S. National Museum opened in 1858 as part of the Smithsonian's scientific program and formed the first of its many museums, most of which stand along the Mall in Washington, D.C.

The first of the historic house museums to be developed by a local society (a type characteristic of the United States) was Hasbrouck House, at Newburgh, N.Y., which had served as the final headquarters of George Washington in the Revolutionary War. The purchase of the house by the State of New York in 1850 established another precedent, whereby public authorities provide and maintain museum buildings while a body of trustees assumes responsibility for the collections and staff. Two other well-known museums, both in New York City, provide examples of this system: the American Museum of Natural History, founded in 1869, and the Metropolitan Museum of Art, opened in 1870.

The middle of the 19th century saw the establishment of a number of other well-known museums. In Canada the collection of the National Museum commenced in 1843 in Montreal as part of the Geological Survey, while the precursor of the Royal Ontario Museum in Toronto, the Ontario Provincial Museum, was founded in 1855. In Australia the National Museum of Victoria was established at Melbourne in 1854; it was followed by the National Gallery of Victoria in 1861 and the Science Museum of Victoria in 1870. In Cairo the Egyptian Museum was established in 1858. These all followed the European model, and even in South America art collections tended to be predominately of European origin, to the neglect of indigenous works of art.

The first museum boom. It was during the second half of the 19th century that museums began to proliferate in Europe; civic pride and the free education movement were among the causes of this development. About 100 opened in Britain in the 15 years before 1887, while 50 museums were established in Germany in the five years from 1876 to 1880. This was also a period of innovation. The Liverpool Museums in England, for example, began circulating specimens to schools for educational purposes; panoramas and habitat groups were used to facilitate interpretation. As first gas lighting and then electric lighting became available, museums extended their hours into the evenings to provide service to those unable to visit during the day.

The museum boom in South America

The increase in the number of museums was not, however, a peculiarity of Europe or North America. In South America particularly, new museums were founded both in the capital cities and in the provinces. Some of these were provided by universities, as in the case of the Geological Museum in Lima, Peru (1891), or the Geographical and Geological Museum at São Paulo, Brazil (1895). Others were created by provincial bodies: the regional museums at Córdoba (1887) and Gualeguaychu (1898), both in Argentina, and at Ouro Prêto, Brazil (1876); the Hualpen Museum, Chile (1882); or the Municipal Museum and Library at Guayaquil, Ecuador (1862). New specialist national museums also appeared in certain countries, while at Tigre, in Argentina, a maritime museum was founded in 1892. Early in the following century, memorial museums were created, including those dedicated to Bartolomé Mitre, a former president of Argentina, in Buenos Aires (1906) and to Simón Bolívar in Caracas, Venez. (1911).

By this time the Indian Museum, in Calcutta, and the Central Museum of Indonesian Culture, Jakarta, were well-established institutions in Asia, but a number of new museums were appearing as well. In Japan a museum to encourage industry and the development of natural resources was opened in 1872; this provided the basis for the present-day Tokyo National Museum and National Science Museum. Although some learned-society museums existed in China in the late 19th century, the first museum in the strict sense of the word was the Nan-t'ung Museum in Kiangsu province, founded in 1905, to be followed within a decade by the Museum of the History of China in Peking (Beijing) and the Northern Territory Museum in Tientsin. The collections established in the Grand Palace at Bangkok in 1874 became, about 60 years later, the National Museum of Thailand. The National Museum of Ceylon (now Sri Lanka) opened to the public in 1877; the Sarawak Museum (now in Malaysia) opened in 1891; and the Peshāwar Museum, in Pakistan, opened in 1906.

In central and southern Africa, museums were founded early in the 20th century. Zimbabwe's national museums at Bulawayo and Harare (then known as Salisbury) were founded in 1901, the Uganda Museum originated in 1908 from collections assembled by the British District Commissioners, and the National Museum of Kenya in Nairobi was commenced by the East Africa and Uganda Natural History Society in 1909. Mozambique's first museum, the Dr. Alvaro de Castro Museum in Maputo, was founded in 1913. Meanwhile in North Africa the Egyptian Museum in Cairo had been relocated to its new building in 1902, and certain of the collections had been transferred to form two new institutions: the Museum of Islāmic Art (1903) and the Coptic Museum (1908). In South Africa there was steady museum development in a number of the provinces, for example in Grahamstown (1837), Port Elizabeth (1856), Bloemfontein (1877), Durban (1887), Pretoria (1893), and Pietermaritzburg (1903).

A period of reassessment. The first half of the 20th century saw the profound social consequences of two world wars, the Russian Revolution of 1917, and periods of economic recession. For museums in Europe this was a period of major reassessment. Governments, professional associations, and other organizations reviewed the role of museums in a changing society and made a number of suggestions to improve their service to the public. In some countries new approaches were developed; in others, museums continued to reflect their diverse ancestry, and some decades were to pass before resources generally became available for the implementation of major changes.

State control in Soviet Russia

Change was notably radical in Russia, where collections and museums were brought under state control following the Russian Revolution of 1917. Lenin's belief that culture was for the people and his efforts to preserve the country's cultural heritage led to a trebling of the number of museums in 20 years. Not only was much of the country's artistic, historic, and scientific heritage brought together in museums, but other types of museums emerged as well. Particular attention was given to amassing material related to Russia's three revolutions. The earliest museum to result from such collections opened in 1919 in the Winter Palace at Petrograd (St. Petersburg); after 1924 the Central Museum of the Revolution in Moscow became the focal point for these collections. Another type was the memorial museum housing the personal effects of well-known figures. These were often used as a means of communicating political propaganda—the Central Lenin Museum in Moscow, opened in 1936, serving this purpose.

In Germany a large number of regional museums were established after World War I to promote the history and important figures of the homeland, and they undoubtedly encouraged the nationalistic tendencies that led to the Nazi era.

In the main, however, museums were not well organized to meet changing social conditions. In Britain a diversity of providers—government at both national and local levels, universities, societies, companies, and individuals—did not encourage cohesive policymaking at a national level. In central Europe associations attempted to develop and run individual museums, but they were unable to provide the necessary resources. Outside Europe the influ-

ence of social change was less marked, and there was little evidence of museums being organized as a national force. In the United States museum development was influenced by a desire to establish a coherent past—a movement that was widely encouraged through private patronage.

In the industrialized world new types of museums appeared. Some nations made conscious attempts to preserve and display structures and customs of their more recent past. Examples, following Sweden's pioneering reerection of significant buildings, include the open-air museums at Arnhem in The Netherlands (the Open Air Museum, opened in 1912) and at Cardiff, Wales (the Welsh Folk Museum, opened in 1947). The preservation and restoration of buildings or entire settlements in situ also began; particularly well known is Colonial Williamsburg, founded in Virginia in 1926 (see Figure 5). A new type of science museum also emerged in which static displays of scientific instruments and equipment were replaced with demonstrations of the applications of science. London's Science Museum, founded in 1857, eventually was moved to specially built premises in 1919. Similarly the Deutsches Museum (German Museum) in Munich was transferred to new premises in 1925. Both established worldwide reputations for excellence in interpreting science and technology for the general public.

After World War II: new developments and new roles. The years immediately following World War II were a period of remarkable achievement for museums. This was reflected both in international and national policy and in the individual museums as they responded to a rapidly changing, better-educated society. Museums became an educational facility, a source of leisure activity, and a medium of communication. Their strength lay in the fact that they were repositories of the "real thing," which—unlike the surrounding world of plastics, reproduced images, and a deteriorating natural and human environment—could inspire and invoke a sense of wonder, reality, stability, and even nostalgia.

Postwar renovation and reconstruction

In Europe particularly there was a period of postwar reconstruction. Many art treasures had been removed to places of safety during the war, and they now had to be recovered and redisplayed; buildings also had to be refurbished. In some cases museums and their collections had been destroyed; in others collections had been looted (though in some cases restitution followed). Reconstruction provided opportunities for the realization of some of the ideas that had been advanced earlier in the century. A new approach emerged in which curators in the larger museums became members of a team comprising scientists as conservators, designers to assist in exhibition work, educators to develop facilities for both students and the public, information scientists to handle the scientific data inherent in collections, and even marketing managers to promote the museum and its work. There was a perceptible shift from serving the scholar, as befits an institution holding much of the primary evidence of the material world, to providing for a lay public as well. As a result of such innovations, museums found a new popularity and attracted an increasing number of visitors. Many of the visitors were tourists, and governments, particularly in certain European countries, soon acknowledged the museums' contribution to the economy.

Statistics from the United States give an indication of the increase in the number of museums and in museum visiting. Of 8,200 museums reported for 1988, 75 percent had been founded since 1950 and 40 percent since 1970. In the 1970s nearly 350 million visits per year were made to American museums; in 1988 the recorded figure was 566 million. Elsewhere the Russian state museums alone were known to receive about 140 million visits annually, while some of the oldest established museums in Europe—such as the British Museum, the Louvre, and the Hermitage—each regularly attracted more than 3 million visits a year. Some science and technology museums were even more popular.

Despite such growth, there has remained a great disparity in museum provision. More than two-thirds of the world's museums are still located in the industrialized countries, with a ratio of one museum to fewer than 50,000 inhabitants in Europe and the United States. In India or Nigeria, on the other hand, the ratio is approximately one museum for every 1.5 million inhabitants.

Among other factors that have contributed to the development of museums since the mid-20th century is an increased awareness of the environment and the need to preserve it. Many sites of scientific significance have been preserved and interpreted, sometimes under the aegis of a national park service, and historic sites and buildings have been restored, the latter sometimes being used as museums. This has led to the development of historic and natural landscapes as museums, such as the renovation of Mystic Seaport in Connecticut as a maritime museum, the use of Ironbridge Gorge as a museum to interpret the cradle of the Industrial Revolution in England, and the restoration of the walled medieval cities at Suzdal and Vladimir in Russia. In Australia the heyday of the gold rush has been re-created in the form of the Sovereign Hill Historical Park, at the gold-mining town of Ballarat. Gorée, a small island off the Senegal coast that served as a major entrepôt for the Atlantic slave trade, has been restored as a historic site with a number of supporting museums (see Figure 7).

The ecomuseum

A related development has been the ecomuseum, such as the Ecomuseum of the Urban Community at Le Creusot–Montceau-les-Mines in France. Here a bold experiment involves the community as a whole, rather than specialists, in interpreting the human and natural environment, thereby generating a better understanding among its inhabitants of the reasons for cultural, social, and environmental change. Some of these projects have involved the acquisition and preservation of massive artifacts, but perhaps no undertaking has been as spectacular as the recovery from the seabed of ships such as the *Vasa,* the Sung-dynasty ship from Ch'üan-chou, the *Mary Rose,* or the Hanseatic cog from Bremerhaven; all these vessels are now preserved in museums in Sweden, China, England, and Germany, respectively.

Contemporary museum development has been much influenced by changing policies in public sector finance. In many countries the contribution of public funds to museums has remained static or has fallen, so that museums' governing bodies and directors have had to seek funding from alternative sources. This not only has affected the way museums are organized but also has accentuated the need for marketing and fund-raising expertise. Thus, with Russian state museums having acquired greater budgetary autonomy since the collapse of the Soviet Union, the Hermitage in St. Petersburg has drawn on international expertise and financing to conduct major renewal work. In the United Kingdom the National Museum of Arms and Armour raised substantial funding from the private sector to build its new Royal Armouries Museum in Leeds; in addition it established a public company to operate the museum after it opened in 1996.

Another reflection of the changed financial situation has been the introduction of admission charges. In 1984 none of the British national museums charged an entry fee, but 10 years later almost half were doing so. The number of American museums charging fees for admission increased over a similar period from 32 percent to 55 percent.

Despite constraints in public funding, governments have not been inactive. In 1982, for instance, Australia opened its National Gallery of Art in Canberra. Also in Australia the National Gallery of Victoria has been developed as part of Melbourne's arts complex, while Sydney's Powerhouse Museum (1988), provides a major attraction in that city. In Paris the Pompidou Centre (1977) combines a gallery of modern art and special exhibition galleries with other cultural activities, while the "Grand Louvre" project has included the opening of the pyramid (1989) and the renovation of the Richelieu, Denon, and Sully wings—all considerably enlarging the capacity of the Louvre. The Museum of London, amalgamating the collections of two previous museums, was opened in 1976 to tell the story of the capital and its immediate environs. In 1964 the National Museum of Anthropology, just one of a fine complex of museums in Mexico City, opened a magnificent new building to display the country's archaeological

richness (see Figure 4). Additions to the Smithsonian's museums in Washington, D.C., have included the National Air and Space Museum (1976; see Figure 3) and the Hirshhorn Museum and Sculpture Garden (1974). A spectacular development from an architectural point of view is the Canadian Museum of Civilization at Hull, Quebec, which opened in 1989. Other new museum buildings have included the Vasa Museum in Stockholm (1990), the Olympic Museum in Lausanne, Switz. (1993), and the Holocaust Memorial Museum in Washington, D.C. (1993).

Many buildings of historical significance have been adapted to house museums. Among these is the Orsay Museum (see Figure 2), formerly a major railroad station in Paris, which was reopened in 1986 as a national museum of the 19th century, and the Tate Gallery of the North at Liverpool (1988), an art museum housed in a warehouse in the Albert Dock, by the River Mersey.



Figure 2: The main gallery of the Orsay Museum, Paris. Formerly the Gare d'Orsay, a major railroad station, the building was reopened in 1986 as a French national museum of the 19th century.
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Nor have developments been restricted to the industrialized countries. A desire to preserve their local history has led many Caribbean islands to establish small museums.

Museums in the Third World

Several African states also have given high priority to the provision of museums. Museums have been established in the principal cities of Nigeria by its National Museums and Monuments Commission to assist in developing cultural identity and promoting national unity. The Jos Museum, one of the earliest of these, also administers a museum of traditional buildings, while others have developed workshops where traditional crafts can be demonstrated. Crafts are also a feature of the National Museum in Niamey, Niger, and products of these workshops are exported to Europe and North America.

Types of museums

For purposes of description and discussion, it is often convenient to group museums according to type. However, with their diverse origins, varying philosophies, and differing roles in society, museums do not lend themselves to rigid classification. Certain museums provide for a specialist audience—for example, children, societies, universities, or schools. Some have particular responsibilities for a defined geographic area, such as a city or region. Others may offer unusual perspectives, resulting in alternative interpretations of artistic, historical, or scientific collections. (This last can occur at museums where the primary ethos is nationalistic, religious, or political.)

Sometimes museums are classified according to the source of their funding (*e.g.*, state, municipal, private), particularly in statistical work. Classifying by source of funding, however, fails to indicate the true character of the museums' collections. For example, institutions funded by the national government—national museums—may hold outstanding international collections, as do the British Museum, the Hermitage, and the Louvre; may hold specialized collections, as do a number of the national museums of antiquities on the European continent; or may have an essentially local character, as does the Smithsonian Institution's Anacostia Neighborhood Museum in Washington, D.C.

An analysis of museums based on the nature of their collections, although it fails to indicate disparities of scale and quality, does have the merit of distinguishing between general and specialized museums. In addition, by emphasizing collections, this method focuses on the very raison d'être of museums. In this section, museums are classified into five basic types—general, natural history and natural science, science and technology, history, and art. The basic characteristics of each type are described in turn.

GENERAL MUSEUMS

General museums hold collections in more than one subject and are therefore sometimes known as multidisciplinary or interdisciplinary museums. Many were founded in the 18th, 19th, or early 20th century. Most originated in earlier private collections and reflected the encyclopaedic spirit of the times. Certain general museums reflect the influence of cultural contact made through trade. Some museums hold a number of important specialized collections that would qualify them to be grouped in more than one category of specialization. This is true particularly of many of the large general museums, which may have collections in one or more fields equal to if not exceeding both the quantity and quality of material exhibited in a specialized museum. Some national museums display general collections within their main building; indeed, many commenced in this fashion, but the necessity of finding additional space later caused a division of the collections and encouraged the growth of specialized museums.

Regional and local general museums

Most common among general museums are those which serve a region or a locality. Many of these owe their foundation to civic pride and a desire to promote knowledge of the area. They are widespread in eastern and western Europe and are found as well in India, Australia, New Zealand, and North and South America. Their prime responsibility is to reflect the natural and human history, traditions, and creative spirit of the area. In many cases the community thus served is culturally homogeneous; where it is not, the museum may develop specific programs to foster mutual understanding among the diverse peoples. In cities that have a sizable immigrant population, such as, for example, Bradford or Leicester in England, the regional museum has engaged actively in such work. Sometimes special exhibitions prepared by the national museum or other agencies provide opportunities at regional museums for the community to appreciate the wider aspects of the national or even international heritage.

The general museum, particularly at the regional or local level, faces severe problems because of the high cost of employing the large numbers of specialists necessary to care for the variety of collections involved, particularly if a strong research program is maintained. In some museums research has diversified as curators, particularly in archaeology, history, and the natural sciences, have become involved in recording the environment of an area or in preparing data banks in order to advise planners and developers who are considering projects to be conducted on sites of scientific or historical interest. Other general

museums have maintained their more traditional roles but have concentrated their efforts on public services, as at the Kanazawa Bunko Museum, Yokohama, Japan, where a multidisciplinary approach is apparent in its exhibitions.

Certain museums provide for a particular audience, often acquiring general collections to suit the purpose. One of these is the children's museum (also frequented by adults), well-known examples of which are the Brooklyn Children's Museum, New York City; the Children's Museum, Boston; the National Children's Museum of New Delhi; and the Mont Riant Children's Museum of Algiers.

NATURAL HISTORY AND NATURAL SCIENCE MUSEUMS

Museums of natural history and natural science are concerned with the natural world; their collections may contain specimens of birds, mammals, insects, plants, rocks, minerals, and fossils. These museums have their origins in the cabinets of curiosities built up by prominent individuals in Europe during the Renaissance and Enlightenment. Specimens from the natural world were also included (albeit as part of an encyclopaedic collection) in some of the earliest museums: the Ashmolean Museum at Oxford, Eng., the British Museum in London, and the National Museum of Natural History in Paris. With the development of the natural sciences in the 19th century, museums exhibiting objects from the natural world flourished and their number multiplied. In the United States and Latin America their collections often included objects of physical and social anthropology as well as the natural sciences.

Expanding roles of natural science museums

More recently, natural science museums have responded to new trends of nature conservation and broader environmental matters. Some have established programs for recording biological data for the area they serve, to facilitate environmental planning (often in conjunction with local planning authorities), and to provide information to assist in the interpretation of ecological displays.

Major museums such as the Natural History Museum in London, the Smithsonian Institution's National Museum of Natural History in Washington, D.C., and the American Museum of Natural History in New York City hold enormous comparative collections from the natural world, including the type specimens from which species have been named. Such museums are international centres of taxonomic work and sustain considerable research programs.

SCIENCE AND TECHNOLOGY MUSEUMS

Museums of science and technology are concerned with the development and application of scientific ideas and instrumentation. Like museums of natural science and natural history, science museums have their origins in the Enlightenment. Some of them developed from the collections of learned societies, others from private collections such as the Teylers Museum at Haarlem, Neth., in the 18th century. A later development in science museums involved the applications of science, so that museums began to preserve the material evidence of technological as well as scientific endeavour. Some science and technology museums now concentrate on demonstrating science and its applications; in these museums the preservation of process is emphasized over the preservation of objects.

Demonstration models

Science museums are particularly popular with children as well as adults and often provide opportunities for their visitors to participate through demonstration models and interactive displays. Well-known examples of these are at the Deutsches Museum in Munich, the Science Museum in London, and (of a more specialized nature) the National Air and Space Museum in Washington, D.C. (shown in Figure 3). Other specialized institutions include transport museums, such as the National Railway Museum in York, Eng., or the Swiss Transport Museum on the shores of Lake Lucerne. Of more recent establishment are industrial museums, which often include a large technical component.

Museums devoted to modern science, such as the Palace of Discovery in Paris, also provide demonstrations of scientific theory. In India, where museums of science and technology are seen as having an important role in education, the National Council for Science Museums has established a network of such museums across the country.



Figure 3: The Air Transportation gallery at the National Air and Space Museum, Washington, D.C.
© Richard T. Nowitz

Performing a similar function are science centres where science is demonstrated but where there is not normally a responsibility for collecting and conserving historical apparatus. A pioneer in this field is the Ontario Science Centre in Toronto.

Some science and technology museums, such as the very popular Museum of Science and Industry in Chicago or the Technological Museum in Mexico City, are of a more technical nature. These museums are often sponsored directly or indirectly by industries, which occasionally found their own museums in order to preserve their heritage and promote their work.

HISTORY MUSEUMS

The term history museum is often used for a wide variety of museums where collections are amassed and, in most cases, are presented to give a chronological perspective. Because of the encompassing nature of history, museums of this type may well hold so many objects of art and science that they would more properly be called general museums (see above).

Museums dealing with specialized aspects of history may be found at the national, provincial, or local level, while museums of general history are rare at the national level. One example of the latter is the National Museum of History in Chapultepec Castle, Mexico City. Other national museums of history can be found particularly among newer states, where they have been used as a means of arousing national consciousness and providing historical perspective. At the local and regional level there are many examples, of which the Museum of London and the city museums of Amsterdam, Dresden, Luxembourg, New York City, Stockholm, and Warsaw are but a few. In many cases, if artifacts are not available or are inappropriate, curators use reconstructions, models, and graphics, sometimes with multimedia techniques, to maintain chronological continuity and to increase the opportunity for interpretation within their essentially didactic approach.

While history museums may include archaeological material, there is nevertheless a distinctive type that specializes in it: the antiquities museum. Collections of material of the ancient world can be found in national museums in a number of cities—for example, Amman, Jordan; Athens; Cairo; Copenhagen; Edinburgh; Madrid; and Mexico City (see Figure 4). The antiquities museum is particularly common in Europe and Asia. Specialized archaeology museums also are found in areas of rich antiquity or as on-site museums. The archaeology museum is concerned mainly with historical evidence recovered from the ground and in many cases provides information on a period for which the written record can make little or no contribution.

The ethnography museum

Another specialized form of the history museum collects and exhibits material from an ethnographic viewpoint. As the term suggests, emphasis is placed on culture rather than chronology in the presentation of the collections. The ethnography museum is common among newer nation-states of Africa and Oceania, where it is seen as a

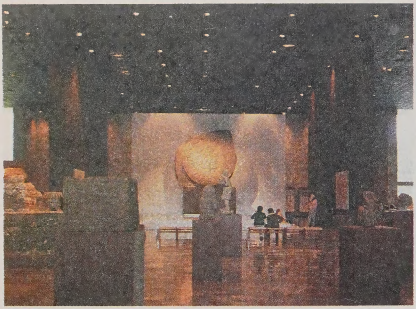


Figure 4: An Aztec calendar stone as the centrepiece of a gallery of archaeological artifacts, National Museum of Anthropology, Mexico City.
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means of contributing to national unity among different cultural groups. Among the industrialized nations, and particularly in countries that have been involved in colonization, the ethnography museum is a museum of the cultures of other peoples. Many of these institutions have been established in the capital cities, which at the height of colonization were the nation's window on a world otherwise distant and unknown. Thus were founded the Musée de l'Homme (Museum of Man), Paris; the extensive ethnographic collections of the British Museum, London; and the Tropenmuseum (Museum of the Royal Tropical Institute), Amsterdam. Specialized ethnography museums are also to be found in provincial cities. Normally these have arisen through personal associations, as with the Pitt Rivers Museum in Oxford, or because of trade connections, as with the Overseas Museum in Bremen or the National Museums and Galleries on Merseyside, Liverpool. The last two examples result from proximity to a major international port.

Many other forms of the cultural history museum exist. Particularly prolific are museums concerned with preserving urban and rural traditions; these have rapidly increased in number with the pace of technological progress. Indeed, some history museums are involved in documenting various material aspects of contemporary life and in the selective collection of artifacts. Work of this type was pioneered in Sweden, where in 1873 Artur Hazilius developed the first museum of traditional life at the Nordic Museum, Stockholm. This was followed 18 years later by the first open-air museum, at Skansen. Museums of both types soon appeared in other countries. Today the National Museum of Popular Arts and Traditions in Paris exemplifies a national approach within a museum building. Outdoor museums preserving traditional architecture, sometimes in situ, and often demonstrating the activities associated with them, are to be found in many parts of the world: the National Museum of Niamey, Niger, or the Museum of Traditional Architecture in Jos, Nigeria; the Village Museum of Bucharest, Rom.; Upper Canada Village, Morrisburg, Ont.; Colonial Williamsburg, Va., U.S. (see Figure 5); or the Novgorod State Museum Preserve in Russia.



Figure 5: A museum interpreter demonstrating the 18th-century art of wig making at the King's Arms Barber Shop, Colonial Williamsburg, Va., U.S.
© Richard T. Nowitz

Another form of history museum is the portrait gallery, in which pictures are collected and displayed less for aesthetic reasons than for the purpose of communicating the images of actual persons. Although the idea of a portrait gallery is of some antiquity—a large collection of portraits of the kings of France and their statesmen was exhibited in Paul Ardier's gallery at the Château de Beauregard near Blois in the 1620s, for example—the national portrait gallery as a public institution is a later development. In a similar vein, paintings and prints of people, as well as places and events, often constitute an important element in other types of history museums.

ART MUSEUMS

The art museum (called art gallery in some places) is concerned primarily with the object as a means of unaided communication with its visitors. Aesthetic value is therefore a major consideration in accepting items for the collection. Traditionally these collections have comprised paintings, sculpture, and the decorative arts. A number of art museums have included the industrial arts since the 19th century, when they were introduced, particularly to encourage good industrial design. The collection of so-called primitive art had a profound influence on certain forms of 20th-century art, but it can be argued that aesthetics have subordinated function and association to such an extent that objects often are presented in a totally alien context. In some countries this criticism applies to archaeological material as well.

The display of works of art presents the curator with certain problems. Works of art are exhibited to convey a visual message. While other disciplines tend to adopt didactic methods of display, the art curator is concerned particularly with unimpeded presentation of a given work. The ambience of the work is enhanced by highlighting its form and colour with proper lighting and background. At one time artificial light was preferred for paintings, both to create an effect and to prevent exposure to harmful elements in natural light, but it sometimes provides an unnecessarily theatrical presentation or creates an artificiality that can inhibit the visitor's appreciation and enjoyment of the work. Much greater use is now made of indirect natural light or—as at the Tate Gallery, London, for example—a controlled mixture of daylight and simulated daylight. Some art museums have returned to the earlier custom of hanging paintings in a tiered arrangement in order to exhibit more of their works.

The display of works of art

The search for context has led to the design of period settings in which to present certain art objects, to the development of furnished period-house museums, and to the preservation of country houses and other appropriate properties, together with their contents, in situ. In a specialized context, the restoration of the Moscow Kremlin, particularly the Great Palace and the churches with their fine murals and icons, provides an example of this approach. Some of the churches are open to the public as museums.

In many cases modern art is displayed in a separate institution. The role of such museums is to confront the public with art in the process of development, and there is a considerable experimental component in their exhibits. This is particularly so at the Pompidou Centre in Paris, the Stedelijk Museum in Amsterdam, or the museums of modern art in Stockholm and New York City, where other contemporary art forms besides painting also are presented. Because of the experimental nature of modern

art and the high cost involved in purchases, temporary exhibitions normally play a major role in such museums and in some cases are their principal activity. Contemporary sculpture is often exhibited outdoors, as at the Hirshhorn Museum and Sculpture Garden in Washington, D.C., the Open-Air Museum in Hakone, Japan, or the Billy Rose Art Garden in Jerusalem.

The operation of museums

ADMINISTRATION

There is no consistent pattern for the general administration of museums throughout the world. In part, the lack of such a pattern reflects the diversity of museums' collections, but it also reflects an ambivalence in the understanding of the role of museums in society—*i.e.,* whether museums are guardians and interpreters of the cultural heritage, repositories for the study of primary evidence relating to human and natural history, social instruments in community development, or facilities for leisure and recreation.

Private and public administration

On the most general level, museums may be either privately or publicly administered. Since 1970 there has been a marked increase in the number of private-sector museums, yet even some of these have corporate standing under general legislation and receive public moneys. In addition, private patronage also has become important for public museums, which often find themselves competing with private museums for additional funding from individual and corporate sources. In the public sector, national museums may be overseen by such diverse ministries as education, tourism, defense, environment, national heritage, culture, and leisure. The situation can be even more complicated at the local level.

The level of state control varies from country to country. In France, for instance, the state has traditionally exercised greater control over museums. A number of the national museums in Paris operate under a semiautonomous administrative council, with an executive chairman who has a dual responsibility for policy and executive matters. In addition, there are a number of national museums located outside Paris, and some technical control over the country's municipal museums is exercised by the central administration. In the United Kingdom, on the other hand, public museums have traditionally enjoyed greater autonomy. Britain's national museums—located mainly in the capital cities of London, Edinburgh, Cardiff, and Belfast—receive funds from the national government, but each museum has been established by its own specific legislation, which empowers a board of trustees (nominally independent of the government) to administer and raise funds and to guide the museum's policies. British municipal museums, however, are provided under general legislation, and representatives from local government form the management committees by law. The British model can be found in other European and English-speaking countries. In the United States only the dependent museums of the Smithsonian Institution and the National Park Service have national status and are financed by the federal government.

MANAGEMENT

Most museums operate under some form of governing body. This body defines the general policy of the museum and provides and controls the necessary resources to deliver it. The appointment of the director and perhaps of other staff members usually is among its responsibilities. The director of a museum governed by this type of body is responsible for the formulation and implementation of policy and for the day-to-day running of the institution and generally provides the link between the governing body, the staff, and the museum's clientele.

The operation of a museum involves a wide variety of skills. These involve specialists in subjects relevant to museum collections (normally designated curators or keepers), information scientists involved in the documentation of collections and related scientific information (sometimes known as registrars), and conservators concerned with the scientific examination and treatment of collections to prevent deterioration. Another group is involved more actively with the public functioning of the museum. These include specialists in education, communication, and interpretation, designers, the security staff, and marketing and public relations personnel as well as administrative, maintenance, and other support workers. Such diversity can lead to complex staff structures. Many of the larger, older established museums with encyclopaedic collections have a large number of senior specialized personnel. In museums where the emphasis is on providing services for the general public and the collections are less wide-ranging, there are likely to be fewer curatorial and more service personnel. Nevertheless, museums are labour-intensive, and the extent to which new technologies can alleviate the need for labour is limited. In all types of museums, operation is based on teamwork, and this has important implications for the management structures adopted as well as for the training of museum staffs.

Staff structures

It was not until about 1965 that university faculties or departments of museology—museum studies, as it is more commonly known in English-speaking countries—were created with a specific emphasis on the theory and practice of museums, as opposed to an emphasis on the subjects represented in their collections. In certain countries, notably Japan and some Latin-American nations, curators are required by law to have graduated in museology before they can practice. Such courses, where available, normally provide some training in museum management. Although some museum studies are taught at the undergraduate level, postgraduate training is the generally recognized requirement.

FUNDING

Public and private sources. Until the mid-1970s, public funds constituted the major income source for public museums and in many cases contributed a considerable percentage of the income of those operated privately. With increasing restrictions on expenditure of public moneys, however, funding from multiple sources has become far more commonplace. In both developed and developing countries this can be crucial to the formation and continued maintenance of a museum service.

The main source of funds for museums in the public sector remains the local or national government. This can result in a lack of flexibility in the use of such moneys, because the funds usually are subject to government policies that have little bearing on the particular requirements of museums. In addition, these museums are required to compete for funds against such traditional public expenditures as education, social services, defense, and law and order, and in consequence museums often are given low priority.

Private benefactors

Many museums were founded through private benefaction, and a few have endowments that help to support their routine operation. Others may have received bequests, many of which are designated to be used only for the purchase of objects. Such sources, although they may seem appropriate when secured, can suffer from changes in economic circumstances and may have attached to them conditions that are incompatible with requirements of the modern museum.

Today museums are becoming increasingly involved in fund-raising, in seeking commercial sponsorship, and in their own trading activities. Fund-raising may be undertaken by the museum, by a commissioned organization, or by a support body such as the many "friends of the museum" organizations now in existence. Fund-raising and sponsorship are normally directed toward a specific project or development.

Entrance fees. Many museums charge entrance fees to help finance operations—even in some countries, such as the United Kingdom, that previously had a strong tradition of free entry to museums. Some museums charge admission fees only for major exhibitions. Others have introduced a system of voluntary donations by visitors on entry to supplement their income, but the results of this approach generally have been disappointing.

Commercial activities. Commercial activities have become a significant feature of many museums. These may

take the form of restaurants or shops that provide a service to visitors as well as income to the museum. Some museums have separate trading companies that act as publishers or engage in mail-order business, the profits from which are directed to the museum for general purposes. In this way the museum retains its charitable status, is not exposed to the direct dangers that would follow commercial failure, and also circumnavigates any requirements that direct income be returned to the public purse.

MUSEUM COOPERATION

The first organized cooperation among museums at the international level arose through the League of Nations' Committee of Intellectual Cooperation. In 1922 the Committee established an International Museums Office, which initiated a number of studies and publications until it went out of existence in 1946. In that year the International Council of Museums (ICOM) was created, and today this nongovernmental organization provides a world forum for museum professionals through regular meetings and through continuous communication over the Internet. In some countries where there are no separate associations for museum personnel, the national committees of ICOM fill the role of professional association. ICOM is also the recognized adviser on museum matters to the Social and Economic Council of the United Nations as well as the United Nations Educational, Scientific, and Cultural Organization (UNESCO).

The International Council of Museums

Since its inception in 1946, UNESCO has been responsible for a growing body of legislation to protect the world's cultural heritage, has been active in promoting the return and restitution of cultural property to its country of origin, has initiated campaigns to ensure the protection of major world heritage sites, and has provided financial assistance for the renovation of older museums and the establishment of new ones, particularly in developing countries. Some of its member states were responsible for the creation in 1956 of the International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM).

COLLECTION

Acquisition policies. The history of museums and their precursors indicates the influence that the existence of a collection has had on the founding of museums and therefore on the nature of their original holdings. Relatively few museums have been established with the goal of making a collection; instead, most have been created to receive an existing collection. With the existing collection as its base, the museum has proceeded to collect to fill gaps or to extend its activity into other, usually related, fields. For this reason many museums have heterogeneous collections, at best accumulated under an "encyclopaedic" philosophy (which has rarely been successful unless major resources were available to achieve it) and at worst continuing a "cabinet of curiosities" approach (which may amuse and entertain the clientele but has little scientific validity). Often the collections made depended on the expertise or whim of the curator and were sure to change when that curator was succeeded by someone with different interests. This method has produced some outstanding special collections, but these have resulted from circumstance rather than long-term planning.

Explicit collection policies are now more common. Indeed, where national codes of practice exist, a strong recommendation is normally to be found on the need for a clear statement of collecting activity. This has arisen for a number of reasons. Not only should a public institution's policies be available for scrutiny, but the cost of maintaining collections of ever-increasing size must be justified, a factor highlighted at times of economic pressure. Further, although a museum may have arisen from circumstance, an assessment of its available resources, the clientele it attracts or intends to attract, and the role it can serve in society generally must be matched against its primary resource, its collections.

Legality. Every museum is responsible for ensuring the legality of its acquisitions. Laws regulating collection vary from country to country, but, whether or not a state has enacted its own legislation or ratified relevant international conventions, museum staff are expected to conform to generally recognized professional codes of ethics. Most regulation of collecting activity embodies principles established in the 1954 Convention for the Protection of Cultural Property in the Event of Armed Conflict and the 1970 Convention on the Means of Prohibiting and Preventing the Illicit Import, Export, and Transfer of Ownership of Cultural Property, both approved by member states of UNESCO. However, a number of countries involved in international trade found it difficult to ratify the 1970 convention, and certain difficulties arose over the definition of cultural property. The 1995 Unidroit Convention on Stolen or Illegally Exported Cultural Objects was intended to resolve these issues. Similar conventions exist on the regional level as well.

International conventions

Given the number and variety of legal regulations and professional codes, it is unlikely that a museum with clearly stated academic objectives will acquire illicit material. Indeed, methods of collection reflect the fact that a museum is concerned not only with collections per se but also with the information inherent in or associated with them. Where applicable, direct acquisition through fieldwork is much preferred. This involves collecting material through archaeological excavation, ethnological expeditions, or natural science fieldwork, and the collecting either is undertaken by the staff of the museum or is sponsored by it. Indirect acquisition is handled through purchases, gifts, bequests, and loans of objects.

Protection of cultural property. Conventions such as those cited above reflect the fact that the collecting activities of the industrialized world are markedly different from those available to the developing nations. In some instances the significant cultural property of entire nations has been dispersed to private collections and museums in different parts of the world, leaving the developing museums to rely on casts and replicas to convey the area's cultural achievements. The international community has had only limited success in encouraging the return, through exchange or loan, of such material to its country of origin.

The true significance of cultural property, collectively the universal heritage of humankind, places on museums a considerable responsibility. The acceptance of objects or collections into their care implies a permanence not associated with the acceptance of other types of property. Some museum legislation acknowledges this, declaring such collections inalienable. The disposal of museum collections in part or in full therefore normally only occurs in cases where items no longer serve a useful scholarly or interpretative purpose. The case for deaccessioning, as it is known in North America, can only otherwise have any validity where it is done to correct the imbalances of earlier indiscriminate collecting, and in that case the material concerned should first be made available to other suitable museums before disposal.

CONSERVATION

A museum's prime responsibility must be to maintain its collections and to do everything possible to delay the natural laws of deterioration. The acquisition of an item almost certainly brings it into a new and potentially alien environment. Material that has been recovered from the ground through archaeological excavation may need immediate treatment to stabilize it. Many of the materials from which objects are made are inherently unstable and undergo chemical or structural change as they age. A new or shifting environment can accelerate these changes, and temperature, light, humidity, and human and other biological factors all need to be controlled. In addition, conservation involves the treatment and, where feasible and acceptable, the restoration of objects as nearly as possible to their former condition.

Most large museums have their own laboratories where preservation and restoration work is carried out (see Figure 6), and some take on projects for other museums as well. In some cases, as at the British Museum, a separate department of scientific research supports the museum's academic and conservation work, providing advanced scientific equipment for the analysis, dating, and identi-

fication of materials. Some museums are served by independent conservation laboratories, an example of which is the Canadian Conservation Institute, in Ottawa, which uses a fleet of mobile laboratories to attend to museum collections in many parts of the country.

DOCUMENTATION

Documentation is a significant function of any museum, whether it holds only a few hundred objects or many millions of items. Quite apart from the need for records to maintain adequate control of its collections, a museum's documentation system provides an indispensable record of the information associated with the objects for research. The documentation system also may include records to facilitate the museum's interpretative and other work.

The form of a museum's documentation system may vary considerably, but to meet these requirements it should provide the fullest possible information about each item and its history. There are no generally accepted classification schemes for museum objects, although certain subjects have developed schemes with numeric or alphanumeric notations to facilitate the ordering and retrieval of information. For the natural sciences, taxonomic names are normally used.

Computerized documentation system

A number of museums have developed computerized documentation systems, some on-line but others relying on machine-generated indexes, periodically updated, to meet most of their information requirements. The advantages of computerized documentation are being exploited in a number of ways—for instance, in exchanging data between museums to facilitate study and research or in making collection information available for public use in the museum gallery or over the Internet.

RESEARCH

Because they hold the primary material evidence for a number of subjects concerned with an understanding of humans and their environment, museums clearly have an important role in research. The museum's research program is related to its objectives as an institution. A program may be concerned directly with the public services provided, in preparing exhibitions, catalogs, and other publications; or with promoting a better understanding of the discipline or region that it serves. In large museums, and in university museums in particular, pure and applied research may be of national or international significance and may be associated with fieldwork or study visits. Active research and publication on a given topic, apart from contributing to the academic standing of the institution, may attract further collections relevant to the topic.

Many museums provide facilities, apart from those used by casual visitors, for researchers to study collections and associated documentation. Such facilities may include study rooms with a supporting library and equipment to assist in the examination of collections. Certain museums have accommodations for visiting foreign scholars; this feature is particularly helpful at site museums that are difficult to reach.

EXHIBITION

Many museums have abandoned the traditional view of exhibition, by which storage and display are ends in themselves, in favour of an approach that enhances the setting of the object or collection. To this end museums use the expertise of a number of specialists—designers, educators, sociologists, and interpreters as well as curators—to improve communication through objects. The result has been a remarkable transformation in the presentation of museum displays. Far greater use is made of colour and light (within the bounds prescribed by conservation requirements), in the way material is interpreted through a variety of mediums (sound, video, interaction between visitor and exhibit, virtual reality, as well as more traditional methods), and in the provision of a more relaxing environment in which to enjoy the exhibits. A result of museums' increased awareness of the needs of their visitors has been a considerable increase in museum attendance.

As the museum's cultural role has developed, so its exhibition work has diversified. Large international exhibitions have been organized by cooperating nations and have been shown in the major museums of the participating countries. Exhibitions organized for national circulation are also increasingly common. Museums concerned with a particular region have arranged topical exhibitions to tour the area, and, in places without suitable premises for display or in sparsely populated areas, exhibitions have toured in specially adapted buses or trains. Some countries have developed multipurpose cultural centres, and collaboration with museums has resulted in exhibition programs successfully reaching a wide audience.



Figure 6: Textile artifacts under examination in the conservation studios of the Victoria and Albert Museum, London.
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Interest in the historic and natural environment globally has involved museums in the preservation and interpretation of sites, monuments, and landscapes (as in the Slave House museum at Gorée Island, Senegal; see Figure 7). Here the conflict inherent in imposing an interpretive medium into a natural or historical context has to be resolved. In its simplest form, interpretation may be conveyed through nature or history trails in which information is provided in written or recorded form. With a historic property there are also opportunities to reenact events associated with the property, such as period battle scenes and banquets, to demonstrate industrial or craft techniques, or to use theatre and son et lumière performances to interpret the site.

EDUCATIONAL SERVICES

The contribution that museums can make to education is widely acknowledged. The majority of their clientele learn by looking at exhibitions and displays. There has been, however, a long association with schools, and many museums provide services specifically designed to meet schools' needs. Services include facilities for use both in the museum and at the school, many of which are administered by separate departments of museum education employing teachers for the purpose.

Facilities for education

Special rooms equipped for teaching and for handling specimens are provided in many museums. By allowing the study and handling of objects from its collections, the museum can give substance and form to the bare facts of art, history, and science. Some museums build special collections for this purpose. Teaching may be undertaken by the museum's educational staff or, more often, by the schoolteacher, who will have been advised and instructed by the staff. For advanced studies, particularly in subjects

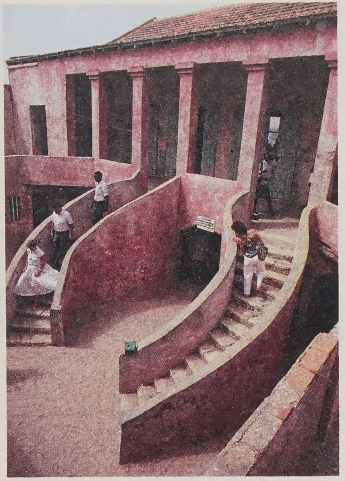


Figure 7: Visitors tour the Slave House, a historic site restored as a museum, Gorée Island, Senegal.
© Christine Burton/Robert Harding Picture Library

like archaeology and geology, the availability of museum collections can be indispensable.

Although opinion differs as to the value of school loan collections, many museums do provide small exhibit cases or kits that may be borrowed by the school for a limited period for classroom teaching. Unlike libraries, museums are not able to provide extensive loan services (which would conflict with their prime purpose), but, for rural schools unable to visit the museum, such a facility, albeit limited, meets a need. In some areas museums include the larger community schools within their traveling exhibition schedules.

As a better-educated adult population with increased leisure time seeks purposeful outlets, museums are well placed to provide activities. Many museums have adult programs such as lectures, courses, demonstrations, and field excursions, some of which are planned as family events.

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The Art of Music

The word music comes from the Greek *mousike* by way of the Latin adaptation *musica.* The Greek word is itself derived from *mousa,* "muse," and hence was applied to all branches of art over which the Muses were supposed to preside. In the instruction of the young, *mousike* was roughly equivalent to what in modern times would be called a liberal education, as opposed to *gymnastike,* which was concerned with the development of the body (the modern "gymnastics"). This conception survived in the Roman world, so that *ars musica* could mean either music or poetry; but it did not prevent "music" from being used in the specific sense now given to it. The use of a comprehensive term of this kind implied particularly a close connection between music and poetry that has survived to the present day. It is characteristic that St. Augustine's treatise *De musica,* in the form in which it has come down, is concerned almost entirely with metrics.

This article is divided into four main sections. Music's nature and significance includes the philosophical and theoretical basis and is followed by the elements of musical sound. Composition is discussed in sections on rhythm, scale, mode, harmony, and counterpoint as well as those on notation, the history of compositional technique, and instrumentation. Modern recording covers types of mechanical and electronic reproduction and their effects on composition, criticism, and music appreciation.

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The nature and significance of music

HISTORICAL CONCEPTIONS

Music is everywhere to be heard. But what *is* music? Commentators have spoken of "the relationship of music to the human senses and intellect," thus affirming a world of human discourse as the necessary setting for the art. A definition of music itself will take longer. As Aristotle said, "It is not easy to determine the nature of music or why anyone should have a knowledge of it."

Early in the 20th century, it was regarded as a commonplace that a musical tone was characterized by the regularity of its vibrations; this uniformity gave it a fixed pitch and distinguished its sounds from "noise." Although the view may be supported by traditional music, it would be an unacceptable yardstick in the latter half of the 20th

century, when "noise" itself may be treated as an element in composition, to say nothing of the random sounds incorporated (without prior knowledge of what they will be) by modern composers, such as the American John Cage, and others in works having aleatory (chance) or impromptu features. Tone, moreover, is only one component in music, others being rhythm, timbre (tone colour), and texture. Electronic machinery has enabled some composers to create works in which the traditional role of the interpreter is abolished and to record, directly on tape, sounds that were formerly beyond human ability to produce, if not to imagine.

The non-Western world. From historical accounts, it is clear that the power to move men has always been attributed to music; its ecstatic possibilities have been recognized in all cultures and have usually been admitted in practice under particular conditions, sometimes stringent ones. In the civilization of India, music was put into the service of religion from earliest times; Vedic hymns stand at the beginning of the record. As the art developed over many centuries into a music of profound melodic and rhythmic intricacy, the discipline of a religious text or the guideline of a story determined the structure. Even today the narrator is central in most performances of Indian music, and the virtuosity of a skillful singer rivals that of the instrumentalists. There is very little concept of vocal or instrumental idiom in the Western sense. The vertical dimension of chord structure—that is, the effects created by sounding tones simultaneously—has never been developed in South Asian music; the divisions of an octave (intervals) are more numerous than in Western music, and melodic complexity in Oriental music goes far beyond that of Western practice. Moreover, an element of improvisation is retained that is vital to the success of a performance. The spontaneous imitation carried on between an instrumentalist and narrator, against the insistent rhythmic subtleties of the drums, can be a source of the greatest excitement, which in large measure is because of the faithful adherence to the rigid rules that govern the rendition of ragas—the ancient melodic patterns of Indian music.

Indian music in religion

Chinese music, like the music of India, has traditionally been an adjunct to ceremony or narrative. Confucius (551–479 BC) assigned an important place to music in the service of a well-ordered moral universe. He saw music and government as reflecting one another and believed that only the superior man who can understand music is equipped to govern. Music, he thought, reveals character through the six emotions that it can portray: sorrow, satisfaction, joy, anger, piety, love. According to Confucius, great music is in harmony with the universe, restoring order to the physical world through that harmony. Music, as a true mirror of character, makes pretense or deception impossible.

Confucius and music in China

Ancient Greek ideas. Although music was important in the life of ancient Greece, it is not now known how that music actually sounded. Only a few notated fragments have survived, and no key exists for restoring even these. The Greeks were given to theoretical speculation about music; they had a system of notation, and they "practiced music," as Socrates himself, in a vision, had been enjoined to do. But the Greek term from which the word music is derived was a generic one, referring to any art or science practiced under the aegis of the Muses. Music, therefore, as distinct from gymnastics, was all encompassing. (Much speculation, however, was clearly directed toward that more restricted meaning with which we are familiar.) Music was virtually a department of mathematics for the philosopher Pythagoras (*c.* 550 BC), who was the first musical numerologist and who laid the foundations for acoustics. In acoustics, the Greeks discovered the correspondence between the pitch of a note and the length of a string. But they did not progress to a calculation of pitch on the basis of vibrations, though an attempt was made to connect sounds with underlying motions.

Plato (428–348/347 BC), like Confucius, looked on music as a department of ethics. And like Confucius he was anxious to regulate the use of particular modes (*i.e.*, arrangements of notes, like scales) because of their supposed effects on men. Plato was a stern musical disciplinarian; he saw a correspondence between the character of a man and the music that represented him. Straightforward simplicity was best. In the *Laws*, Plato declared that rhythmic and melodic complexities were to be avoided because they led to depression and disorder. Music echoes divine harmony; rhythm and melody imitate the movements of heavenly bodies, thus delineating the music of the spheres and reflecting the moral order of the universe. Earthly music, however, is suspect; Plato distrusted its emotional power. Music must therefore be of the right sort; the sensuous qualities of certain modes are dangerous, and a strong censorship must be imposed. Music and gymnastics in the correct balance would constitute the desirable curriculum in education. Plato admitted and valued music in its ethically approved forms; his concern was primarily with the effects of music, and he therefore regarded it as a psychosociological phenomenon.

Yet Plato, in treating earthly music as a shadow of the Ideal, saw a symbolic significance in the art. Aristotle carried forward the concept of the art as imitation, but music could express the universal as well. His idea that works of art could contain a measure of truth in themselves—an idea voiced more explicitly by Plotinus in the third century AD—gave added strength to the symbolic view. Aristotle, following Plato, thought that music has power to mold human character, but he would admit all the modes, recognizing happiness and pleasure as values to both the individual and the state. He advocated a rich musical diet. Aristotle made a distinction between those who have only theoretical knowledge and those who produce music, maintaining that persons who do not perform cannot be good judges of the performances of others.

Aristotle's view

Aristoxenus, a pupil of Aristotle, gave considerable credit to the human listener, his importance and his powers of perception. He denigrated the dominance of mathematical and acoustical considerations. For Aristoxenus, music was emotional and fulfilled a functional role, for which both the hearing and the intellect of the listener were essential. Individual tones were to be understood in their relations to one another and in the context of larger formal units. The Epicureans and Stoics adopted a more naturalistic view of music and its function, which they accepted as an adjunct to the good life. They gave more emphasis to sensation than did Plato, but they nevertheless placed music in the service of moderation and virtue. A dissenting 3rd-century voice was that of Empiricus, who said that music was an art of tones and rhythms only that meant nothing outside itself.

The Platonic influence in musical thought was to be dominant for at least a millennium. Following that period of unquestioned philosophic allegiance, there were times of rededication to Greek concepts, accompanied by reverent and insistent homage (*e.g.*, the group of late 16th-century Florentines, known as the Camerata, who were instrumental in the development of opera). Such returns to simplicity, directness, and the primacy of the word have been made periodically, out of loyalty to Platonic imperatives, however much these "neo" practices may have differed from those of the Greeks themselves.

In the 20th century, the effects of Greek thought are still strongly evident in the belief that music influences the ethical life; in the idea that music can be explained in terms of some component such as number (that may itself be only a reflection of another, higher source); in the view that music has specific effects and functions that can be appropriately labelled; and in the recurrent observation that music is connected with human emotion. In every historical period there have been defectors from one or more of these views, and there are, of course, differences of emphasis.

Music in Christianity. Much of the Platonic–Aristotelian teaching, as restated by the Roman philosopher Boethius (*c.* 480–524), was well suited to the needs of the church; the conservative aspects of that philosophy, with its fear of innovation, were conducive to the maintenance of order. The role of music as accessory to words is nowhere more clearly illustrated than in the history of Christianity, where the primacy of the text has always

been emphasized and sometimes, as in Roman Catholic doctrine, made an article of faith. In the varieties of plainchant, melody was used for textual illumination; the configurations of sound took their cue from the words. St. Augustine (AD 354–430), who was attracted by music and valued its utility to religion, was fearful of its sensuous element and anxious that the melody never take precedence over the words. These had been Plato's concerns also. Still echoing the Greeks, Augustine, whose beliefs were reiterated by St. Thomas Aquinas (*c.* 1225–74), held the basis of music to be mathematical; music reflects celestial movement and order.

Martin Luther (1483–1546) was a musical liberal and reformer. But the uses he envisioned for music, despite his innovations, were in the mainstream of tradition; Luther insisted that music must be simple, direct, accessible, an aid to piety. His assignment of particular qualities to a given mode is reminiscent of Plato and Confucius. John Calvin (1509–64) took a more cautious and fearful view of music than did Luther, warning against voluptuous, effeminate, or disorderly music and insisting upon the supremacy of the text.

Music as mathematics

17th- and 18th-century Western conceptions. In reviewing the accounts of music that have characterized musical and intellectual history, it is clear that the Pythagoreans are reborn from age to age. The German astronomer Johannes Kepler (1571–1630) perpetuated, in effect, the idea of the harmony of the spheres, attempting to relate music to planetary movement. Renê Descartes (1596–1650), too, saw the basis of music as mathematical. He was a faithful Platonist in his prescription of temperate rhythms and simple melodies so that music would not produce imaginative, exciting, and hence immoral, effects. For another philosopher–mathematician, the German Gottfried von Leibniz (1646–1716), music reflected a universal rhythm and mirrored a reality that was fundamentally mathematical, to be experienced in the mind as a subconscious apprehension of numerical relationships.

Immanuel Kant (1724–1804) ranked music as lowest in his hierarchy of the arts. What he distrusted most about music was its wordlessness; he considered it useful for enjoyment but negligible in the service of culture. Allied with poetry, however, it may acquire conceptual value. Georg Wilhelm Friedrich Hegel (1770–1831) also extolled the discursive faculties, saying that art, though it expresses the divine, must yield to philosophy. He acknowledged the peculiar power of music to express many nuances of the emotions. Like Kant, Hegel preferred vocal music to instrumental, deprecating wordless music as subjective and indefinite. The essence of music he held to be rhythm, which finds its counterpart in man's innermost self. What is original in Hegel's view is his claim that music, unlike the other arts, has no independent existence in space, is not "objective" in that sense; the fundamental rhythm of music (again an aspect of number) is experienced within the hearer.

Subjectivism in Hegel

After the 18th century, speculations upon the intrinsic nature of music became more numerous and profound. The elements necessary for a more comprehensive theory of its function and meaning became discernible. But philosophers whose views have been summarized thus far were not speaking as philosophers of music. Music interested them in terms extrinsic to itself, in its observable effects; in its connections with dance, religious ritual, or festive rites; because of its alliance with words; or for some other extramusical consideration. The only common denominator to be found, aside from the recognition of different types of music, is the acknowledgment of its connection with the emotional life; and here, to be sure, is that problematic power of the art to move men. Various extramusical preoccupations are today the raison d'être of "contextualist" explanations of music, which are concerned with its relation to the human environment. The history of music itself is largely an account of its adjunctive function in rituals and ceremonies of all kinds—religious, military, courtly—and in musical theatre. The protean character of music that enables it to form such easy alliances with literature and drama (as in folk song, art song, opera, "background" music) and with the dance (tribal, ethnic, "social," ballet) appears to confirm the wide range and influence that the Greeks assigned to it.

MODERN THEORIES OF MUSICAL MEANING

Musical theorists

Before the 19th century, musicians themselves seldom were theorists, if theorist is defined as one who explicates meaning. Musical theory, when it was something other than the exposition of a prevalent or emerging style, was likely to be a technical manual guiding vocal or instrumental performance, a set of directions for meeting current exigencies in church or theatre practice, or a missive advocating reforms. Prolific masters, such as Johann Sebastian Bach, produced not learned treatises but monuments of art.

The 19th century saw the emergence of composer–critics (Carl Maria von Weber, Robert Schumann, Hector Berlioz, Franz Liszt), versatile artists with literary proclivities who were not, to be sure, propounding comprehensive theories or systems of thought. Richard Wagner, an active theorizer, presaged a new species, the composer–author. But he did little to advance musical theory. He proposed a unity of music and drama (*Gesamtkunstwerk*)—a reflection of the "programmatic" preoccupations of 19th-century composers—but its multiplicity of musical and extramusical elements only added to the confusion of musical thought. The distinctly musical character of Wagner's genius, clearly discernible in *The Ring,* is in no way explained by his discursive credos. Igor Stravinsky, Arnold Schoenberg, and other composer–authors of the 20th century were to be somewhat more successful in elucidating their techniques and aims.

The concept of dynamism. Present-day ideas of music as a symbolism owe much to two German philosophers, Arthur Schopenhauer (1788–1860) and Friedrich Nietzsche (1844–1900), who brought to the theory of music a new concept, articulated by each in different ways and in divergent terms but faithful to the same principle—dynamism. Both saw in music an art that is not "spatialized" (hence not "objective") in the way that other arts are by the very conditions of their manifestation. Music is closer to the inner dynamism of process; there are fewer technical (and no concrete) impediments to immediate apprehension, for an entire dimension of the empirical world has been bypassed.

Schopenhauer looked upon Platonic Ideas as objectifying will, but music is

> by no means like the other arts, the copy of the Ideas, but the *copy of the will itself.* This is why the effect of music is so much more powerful and penetrating than that of the other arts, for they speak only of shadows, but it speaks of the thing itself.

In contrast to Kant he accords a special efficacy to music:

> The effect of music is stronger, quicker, more necessary and infallible. Men have practiced music in all ages without being able to account for this; content to understand it directly, they renounce all claim to an abstract conception of this direct understanding itself.

Schopenhauer acknowledged a connection between human feeling and music, which "restores to us all the emotions of our inmost nature, but entirely without reality and far removed from their pain." Music, which he is presenting an as analogue of the emotional life, is a copy or symbol of the will.

Nietzsche posed an Apollonian–Dionysian dichotomy, the former representing form and rationality and the latter drunkenness and ecstasy. For Nietzsche, music was the Dionysian art *par excellence.* In *The Birth of Tragedy from the Spirit of Music,* Nietzsche anticipated the 20th-century discovery that symbol making (whether in dreams, myth, or art) is a necessary and to some extent even automatic human activity. The rich suggestiveness and prescience of his insights embraced the concept of the "symbolical analogue"—the artistic function of ordering and heightening the ingredients of the actual world—and the polarities of experience symbolized in the Apollonian–Dionysian conflict itself, which Igor Stravinsky also explored. Nietzsche gave short shrift to mathematical aspects of music, and like Schopenhauer he deprecated blatantly programmatic music that abounds in obvious imitations of natural

sounds. Discerning a power in music to create myths, he looked upon mere "tone painting" as the antithesis of its essential character.

Efforts of theorists to account for the universal appeal of music and to explain its effects have, since the 19th century, been various, contradictory, and highly controversial. In pointing out the chief points of view that have emerged, it must be emphasized that there are no completely isolated categories, and there is usually considerable overlapping; a single spokesman, the 19th-century English psychologist Edmund Gurney, for example, may incorporate formalist, symbolist, expressionist, and psychological elements, in varying proportions, to explain the phenomenon of music. Although some disagreements are more apparent than real because of the inherent problems of terminology and definition, diametrically opposing views are also held and tenaciously defended.

Referentialists and Nonreferentialists. Among those who seek and propound theories of musical meaning, the most persistent disagreement is between the referentialists (or "heteronomists"), who hold that music can and does refer to meanings outside itself, and the nonreferentialists (who are sometimes called formalists or absolutists), who maintain that the art is autonomous and "means itself." The Austrian critic Eduard Hanslick, in his *The Beautiful in Music* (German edition published 1854), was a strong proponent of music as an art of intrinsic principles and ideas; yet even Hanslick, ardent formalist though he was, struggled with the problem of emotion in music. Hanslick's views have been classified as a modified heteronomous theory.

One looks in vain for an extremist of either persuasion, referentialist or nonreferentialist. Igor Stravinsky first achieved fame as a composer of ballet music, and his works throughout his career were rich in extramusical associations. It would be a comfortable simplification to ally referentialism with "program" music and nonreferentialism with "absolute" music. But the problem cannot be resolved by such a choice, if only, first of all, because extramusical referents can vary in complexity from a mere descriptive title to the convolutions of the Wagnerian leitmotiv, in which a particular musical phrase is consistently associated with a particular person, place, or thing. The referentialist does not require an explicit program (which may, when present, be altogether too meagre by his canons), and the nonreferentialist does not necessarily denigrate program music, though he makes a point of distinguishing between the extramusical program and the musical meaning. The contemporary U.S. theorist Leonard Meyer, in his *Emotion and Meaning in Music* (1956), speaks of "designative" and "embodied" meanings; he recognizes both kinds in music but appears to give equal weight to the extrinsic and intrinsic.

If there is intrinsic, or embodied, meaning, one may well ask what meaning is embodied and how it is to be apprehended. An extreme formalist would say that the acoustic pattern itself and nothing more is the sense of music; Hanslick, indeed, said this, though he did not hold consistently to the view. But most nonreferentialists regard music as, in one way or another, emotionally meaningful or expressive. Referentialists, too, find expressive content in music, though this emotional content may be extramusical (even if not explicit) in origin, according to the American theorists John Hospers in *Meaning and Truth in the Arts* (1946) and Donald Ferguson in *Music as Metaphor* (1960). Meyer has made the observation that while most referentialists are expressionists, not all expressionists are referentialists. He makes the useful distinction between absolute expressionists and referential expressionists and identifies his own position as "formalist–absolute expressionist." In acknowledging that music can and does express referential (designative) meanings as well as nonreferential ones, Meyer exhibits an eclectic and certainly permissive view. But he has been criticized for failing to make clear the *modus operandi* of this referential meaning in music.

Intuition and intellect. Most theorists agree that music is an auditory phenomenon and that hearing is the beginning of understanding. Beyond this there is little agreement. There is bad blood especially between proponents of intuition, like Benedetto Croce, and champions of intellectual cognition, like Hospers. Gurney was constrained to postulate a special musical faculty that need not reside exclusively either in the mind or the heart. The main problem for theorists arises from the inveterate tendency to dichotomize thought and feeling. Henri Bergson (1859–1941) broke with this tradition when he spoke for "an intellectual act of intuition." Recently, a reawakened philosophic and artistic concern for the concept of organic unity has revealed strong affinities among such disparate works as Gurney's *The Power of Sound* (1880); the U.S. philosopher Susanne K. Langer's *Philosophy in a New Key* (1942) and her later works; John Dewey's classic *Art as Experience* (1934); and the U.S. composer Roger Sessions' *The Musical Experience* (1950).

It is apparent that music is connected in some way with the emotional life of man, but the "how" continues to be elusive. Sessions (echoing Aristotle) states the problem fairly:

> No one denies that music arouses emotions, nor do most people deny that the values of music are both qualitatively and quantitatively connected with the emotions it arouses. Yet it is not easy to say just what this connection is.

The language analogy

It was long fashionable to speak of the "language" of music, or of music as the "language of the emotions," but since a precise semantics is wanting in music, the analogy breaks down. Two or more listeners may derive very different "meanings" from the same piece of music, and since written and spoken language cannot render these musical "meanings," whatever they may be, in consistent and commonly recognizable terms, verbal explication often seems to raise more questions than it settles. Philosophic analysts who hold that all meaning is capable of rendition in language therefore pronounce music—unless it can be saved by the referentialists—without meaning, confronting the thoughtful listener, thereby, with a proposition that seems clearly to contradict (and trivialize) his own experience. The difficulty, of course, is a semantic one and explains why some theorists substitute such terms as import, significance, pattern, or gestalt for meaning. Recognizing an incompatibility between the modalities of nonverbal arts and their treatment by discursive thought, it is hardly surprising that musical aestheticians have been few.

Symbolist contributions. Significant contributions to musical theory have been made in the 20th century by several investigators who may be classified as symbolists, though most of them exhibit formalist, expressionist, and psychological elements as well. The most influential (and controversial) work has been done by Langer. Her most adamant critics (such as John Hospers) have objected to her use of the term symbol that must, in their lexica, stand for something definite; she takes pains to ascribe this more limited usage to the term signal. The more general use of the term symbol that she endorses has a long history, notably in such 19th-century figures as Goethe, Carlyle, and the French Symbolist poets. Langer is accused of having somewhat weakened her argument through a vacillating terminology, and she has described the musical symbol as "unconsummated" because of its ambiguity. But the validity of her theory does not depend upon the term symbol; her thought, indeed, has much in common with that of Edmund Gurney, who does not employ the term and whose "ideal motion," if substituted for symbol, would remove most of her critics' objections. Her use of symbol is nevertheless defensible; she construes art as a "symbolic analogue of emotive life," rendering the "forms of sentient being" into intelligible configurations. She is a naturalist; she sees art as organic in origin, and she echoes the view, long held among symbolists, that artistic form and content compose an indissoluble unity that each art manifests according to its peculiar conditions. The symbolism of music is therefore tonal (or, at its broadest, auditory) in character and can be realized only in time; in psychological experience, time assumes an ideal guise. (Painting and sculpture, in their distinctive modalities, embody ideal space.) Langer embraces all the arts in her purview. The U.S. musical theorist Gordon

Epperson's *The Musical Symbol* (1967) is an application of her concepts, with modifications, intensively to music.

Contextualist theories. In moving from symbolic to contextualist explanations of music, it is well to note that a source of great confusion, in the former, is the fact that tone painting (with explicit signals that yield, when the code is understood, designative meanings) is widely regarded as musical symbolism. An example of such tone painting is Bach's introduction of musical notes, corresponding to the letters of his own name, as a theme in the unfinished final fugue of the *Art of the Fugue.* And surely it may be argued that this qualifies on one level. But the contention that there is an intrinsic symbolism in the musical meaning itself is a claim that referentialists are generally unwilling to honour. Yet many theorists, whose concern is with the sociological or psychological effects of music, are not so much opposed to the idea of inner or profound meaning as indifferent to such meaning per se. Even an absolutist, however, is unable to examine music in isolation from its human environment. Meyer deliberately eschews logical and philosophical problems of music and makes "no attempt to decide whether music is a language or whether musical stimuli are signs or symbols." (He does not defend the inference that such concerns are irrelevant to meaning.) Musical meaning and communication, he maintains, cannot exist in the absence of the cultural context. The statement is hardly open to dispute; a theorist is classified according to his proximity to the referential or nonreferential pole. If a referentialist emphasizes explicit aims and associations of a particular work (as in varieties of *Gebrauchsmusik*, or "utility" music, written for specific social or educational purposes), the formalist can maintain that there is also an intrinsic, or embodied, meaning to which he attaches the greater aesthetic value.

Among contextualists, however, a simple referential view is the exception rather than the rule. Any theorist who examines musical perception is making a study of a complex human activity. He is dealing with the psychology of music, in which certain elements—*e.g.,* music, listener, mode of apprehension, cultural context—are indispensable and in which characteristic processes recur. Specialists will emphasize one element or another: formalists the music itself, sociologists the listener and his milieu, psychologists the how of perception. Though psychology could survey the whole field, in practice psychologists, according to their persuasions, investigate the perception of measurable acoustic phenomena, the physical-mental effects of musical sound, or—more rarely—the functional role of music in human experience; and pragmatists and analysts alike may leave something out of account. But it remains for the comprehensive theorist, probably one who, like Langer, is equipped to discern relationships among many departments of thought, to construct a valid hierarchical structure of musical meaning in all its ramifications.

Psychological approaches

Deryck Cooke, the British musicologist and the author of *The Language of Music* (1959), who may be classified as a referential expressionist, has offered a sophisticated argument for the notion of music as language. Concepts, however, may not be rendered by this language, only feelings. Cooke reaffirms the possibility, long disputed by many theorists, that such feelings may be recognized, identified, and even classified. But he confines his investigation to the last few hundred years of the Western tradition.

Information theory. The French theorist Abraham Moles's *Information Theory and Esthetic Perception* (1966) brings the new science of information theory to bear on musical perception, emphasizing that the concept of form is the essential thing; the "sonic message," whose dimensions vary from one composition to another, is a whole. Information theory thus proves to be a novel ally for organicists. The message, which is subjected to "atomistic" study of its components, is (thanks to recording) concrete; there is a temporal sonic material, a *materia musica.* Moles gives reinforcement to the aesthetic theory of distance:

> The esthetic procedure of isolating sonic objects is analogous to the sculptor's or decorator's isolating a marble work against a black velvet draping: This procedure directs attention to it, alone and not as one element among many in a complex framework.

Information theory, which Leonard Meyer also discusses, begins its investigations without the help of traditional theory, which it finds to be untenable for its procedures. Musical messages discerned through information theory are not referential, yet Moles chooses to term the measurable elements in the sonic repertoire symbols: "each definable temporal stage represents a 'symbol' analogous to a phoneme in language." According to Moles, music must, as an art, obey rules; the role of aesthetics is to enumerate universally valid rules, not to perpetuate the arbitrary or merely traditional. He foresees experimentation with a much richer repertoire of sounds, transcending musical instruments and drawing on whatever sources—certainly electronic ones—are available for realizing the "most general orchestra." A host of composers have set out to fulfill this desideratum. In order to increase the compass of possible sounds, various electronic synthesizers were constructed. In electronically synthesized music, the medium itself is indistinguishable from its message.

The quest for some distillation of musical meaning may be foredoomed to failure. Meanings, intrinsic and extrinsic, abound; meanings of all kinds, moreover, are revealed in and through the social setting. Church, theatre, and broadcasting affect music in characteristic ways. The modern concert is a device whereby formal, autonomous meanings are emphasized; further, the scope and available repertoire of the concert have been enormously increased through recordings, for any suitably equipped room may become, at the turn of a switch, a recital hall.

Considerations related to performance practice. Listening to music for its own sake, apart from ritual or storytelling, is a recent historical development. There have always been impromptu song and dance; and performances of music in home, church, and theatrical productions have a long history. But there was no public opera house until 1637 when the first one opened in Venice; the first public concerts for which admission was charged appeared in London in 1672. During the next 50 years there were beginnings in Germany and France also, but the modern concert was not a significant feature of musical life until the late 18th century.

Of the forms that have characterized distinct periods of musical history, it is sufficient to remark here that the chief Renaissance forms—mass, motet, the polyphonic chanson, and madrigal—were allied to texts that strongly influenced their structure. Instrumental music was for the most part in the service of the voice, though instrumental church compositions, dances, and chansons arranged for organ were not uncommon. A strong alliance between voices and instruments has continued into the present, with musical theatre, the art song, and religious music. Instrumental music as a separate genre emerged in the 16th century, gaining considerable momentum in the 17th through a variety of idiomatic pieces. Increased attention to technical fluency was accompanied by greater complexity and sophistication in the instruments themselves. In response to stylistic demands for greater resonance and power, the modern forms of the violin appeared in the late 16th century, only gradually supplanting the earlier viols. The harpsichord did not finally yield to the pianoforte until the 18th century. The once-prevalent idea that early stringed and keyboard instruments were primitive precursors of their modern counterparts has been effectually demolished by research in medieval and Renaissance music and by dedicated performers, who seek to restore the sounds and spirit of those eras.

The development of opera, oratorio, and the cantata gave a prominence to vocal music throughout the Baroque era (*c.* 1600–1750) that made it equal in importance to instrumental music, with which these forms were closely allied. But instrumental chamber and independent orchestral ensembles, as they exist today, also had their beginnings during this period. A highly significant development of the late 18th century was the definitive appearance of the modern sonata (whether in the form of the solo and duo sonata, piano trio, string quartet, concerto, or symphony) with the Viennese classicists Haydn and Mozart and, later, Beethoven.

Since a vocal text is likely to be confused with intrinsic

musical meaning, or at least to divert attention from a preoccupation with it, it is not surprising that modern aesthetic theory followed on the emergence of an autonomous instrumental music requiring greater concentration on the sound itself, its colour and intensity, and the intelligibility (in terms of tonal organization alone) of a composition. Moreover, the very concept of listening as an attentive (and sometimes rigorous), serious, and necessary activity of the music lover gained acceptance only slowly, following the inauguration of public concerts, and is still vigorously resisted. The expectation that the art should provide enjoyment without effort is, indeed, widespread and accounts for much of the opposition to new and demanding idioms. But even for the well-disciplined and eager listener there is the problem of quantity: he must cope as best he can with what Langer has called "the madhouse of too much art." If more effort is required, more discrimination is also needed. In music education, articulate voices ask that teaching be centred more upon qualitative aspects of the art ("aesthetic education"), less upon music making as an activity. This concern for musical value appears to reflect a more intensive search for meaning, which is not likely to be the exclusive property of a particular style or era; nor is it to be sought in an indiscriminate acceptance or rejection of novelty per se. A pronounced pedagogical interest developed in such contemporary popular music as "rock," "soul," and similar folk idioms with great numbers of followers, especially among the young, whose gigantic festivals generated feelings of religious exaltation. The texts of the songs are highly emotional and often deal with "protest" themes; accompaniments are provided by guitars, keyboard and percussion instruments, and are electronically amplified. Music educators became attracted by the intrinsic structural values of this music, especially its distinctive rhythmic and modal characteristics, its texts, and the qualitative levels that may be distinguished. A music so vital and widespread, moreover, was deemed by many to be worth studying in school. The "rock" movement became a musical-sociological phenomenon of large proportions.

Music and world view. Again, music proves its protean susceptibilities in the service of disparate world views. Among humanist psychologists (such as the Americans Gordon Allport and Abraham Maslow) music may be one among other means toward self-fulfillment, integration, self-actualization; for aesthetic Existentialists (such as the philosopher Jean-Paul Sartre) it is yet another crucial department of choice and freedom; for spiritual Existentialists (such as the philosophers Karl Jaspers and Martin Buber) it transmits transcendent overtones. For expressionists (such as the composers Schoenberg, Ernst Krenek, and René Leibowitz) music carries austere, and sometimes doctrinaire, moral imperatives. Theodor Adorno, a composer–philosopher and pupil of Alban Berg, writes powerfully of these and speaks for an awareness of dazzling lucidity, but the tone, notwithstanding his humour, is one of obligation. Only the expressionists, among those mentioned here, are committed primarily to music, though Adorno, in particular, considers music and musicians always in interaction with their environments. The aesthetic concept of play is virtually absent, except among such humanists as Maslow. With Sartre, no less a humanist, the tone is one of responsibility. Many educators long held the explicit aim (at least in part because of a misinterpretation of John Dewey) of presenting the content of a discipline as "fun"; the present concern for aesthetic education, an area of great interest to Dewey himself, eschews this trivial view. But play, in the aesthetic sense, follows rules, as information theory has demonstrated; even "controlled aleatory" composition observes some limits. And the play may be very serious indeed, as in the important 20th-century atonal style known as "12-tone technique," practiced by the Viennese expressionists and their successors.

Tonality and meaning. The most troublesome problem not only for the untutored listener but also for the professional musician has been, in much contemporary work, the loss of explicit tonality; and this accounts for the tardy popular response to Schoenberg and his school: the vocabulary is esoteric. Nineteenth-century compositions did, indeed, stretch the tonal system to its outer limits; but it is now clear that Wagner and Richard Strauss, and even the early Schoenberg, had not broken from it. As for Debussy, his use of "exoticisms" was filigree upon a secure tonal base. So were such practices as the juxtaposition of keys by Stravinsky. This is not to say that the tonality of the Western world, fecund though it has been, is superior or more natural than other systems. Ethnomusicology and comparative musicology have proved this to be a parochial view, though there are still those who champion harmonic practices based on the physical laws governing overtones—as Western tonality is—as the only "natural" source of development. It should not be irrelevant, however, to inquire if any folk music has been discovered that exhibits atonal characteristics.

Tonality in Western music, though a significant aspect, cannot be considered the crux of musical meaning. The tone rows that are used in the 12-tone compositions of Schoenberg, like major–minor tonality in earlier music, are a technical substratum and must be no more explicit in the finished work than the chemical makeup of pigments in the "Mona Lisa." The devices selected may affect the comprehensibility or accessibility of the work, but they are not, per se, the determinants of its worth or quality. Similarly with musical colour, or timbre; the 19th century produced a great profusion of compositions, particularly in the orchestral repertoire (*e.g.*, works by Liszt and Berlioz) that exploited the unique sonorities of instruments; control of volume was, in itself, a rich source of colour. Works with literary or other extramusical associations were excellent vehicles for sonorous effects, but colour, like tonality, must be evaluated in musical context. Langer, among present-day aestheticians, regards words themselves as musical, rather than discursive, ingredients; they are "assimilated" by the song. (G.E./Ed.)

CRITICISM

Musical criticism, properly considered, is a branch of philosophy—more exactly, of aesthetics. It is chiefly concerned with making value judgments, either about composition or about performance, or both. This section reviews the history and fundamental issues of music criticism.

Unfortunately, it is difficult to show that a value judgment can stand for anything that is even remotely true about music, as opposed to standing for something that is merely a personal whim on the part of the critic, since there is, as yet, no such thing as an organized body of knowledge called "musical criticism." The entire history of musical criticism can be summed up as a vain struggle to forge itself into a suitable tool for coming to grips with the art of music.

Historical development. The criticism of music first gained serious hold in the 17th and 18th centuries. Among the first writer-musicians to make systematic contributions to criticism were Jean-Jacques Rousseau in France, Johann Mattheson in Germany, and Charles Avison and Charles Burney in England. Their work coincided with the emergence of periodicals and newspapers all over Europe. The first journal devoted entirely to music criticism was *Critica Musica*, founded by Johann Mattheson in 1722. Mattheson had a number of successors, notably the Leipzig composer Johann Adolph Scheibe, who brought out his weekly *Der critische Musicus* between the years 1737 and 1740 and whose chief claim to notoriety was his scurrilous attack on Bach. Generally speaking, the criticism of the time was characterized by an obsessive interest in the rules of music, and it tended to judge practice in the light of theory—a fatal philosophy. Mattheson, for instance, castigated Bach for ignoring certain rules of word setting in his cantatas.

Mattheson's contribution to musical criticism

At the turn of the century, the age of academicism dissolved into the age of description. Schumann, Liszt, and Berlioz, the leaders of the Romantic era, frequently saw in music the embodiment of some poetic or literary idea. They composed program symphonies, symphonic poems, and lesser pieces bearing such titles as "novellette," "ballade," and "romance." Their literary outlook naturally influenced criticism, the more so as they themselves frequently wrote it. In his pamphlet *On John Field's Noc-*

turnes (1859), Liszt wrote, in the purple prose of the time, of their "balmy freshness, seeming to exhale copious perfumes; soothing as the slow, measured rocking of a boat or the swinging of a hammock, amid whose smoothly placid oscillations we seem to hear the dying murmur of melting caresses." Most of the Romantics were guilty of this type of descriptive criticism. Its weakness is that, unless the music is already known, the criticism is meaningless; and once the music is known, the criticism is redundant, since the music itself says it all far more effectively.

Schumann and Hanslick

The most influential critic of the age was Schumann. In 1834 he founded the periodical *Neue Zeitschrift für Musik* ("New Journal for Music") and remained its editor in chief for 10 years. Its pages are full of the most perceptive insights into music and music makers. The first major article Schumann wrote was a laudatory essay on the young Chopin, "Hats off, gentlemen, a genius" (1834), and the last, called "New Paths" (1853), introduced to the world the young Brahms.

During the second half of the 19th century, the critical scene was dominated by the Viennese critic Eduard Hanslick, who is rightly regarded as the father of modern musical criticism. He was a prolific writer, and his book *Vom Musikalisch-Schönen* (1854: *The Beautiful in Music*) is a milestone in the history of criticism. It took an anti-Romantic stand, stressing the autonomy of music and its basic independence of the other arts, and it encouraged a more analytical, less descriptive approach toward criticism. The book was continually reprinted until 1895, appearing in many languages.

Inspired by Hanslick's example, critics in the 20th century rejected the age of description for the age of analysis. Scientific materialism created a climate of rationalism from which music did not remain immune. Critics spoke of "structure," "thematicism," "tonality"—a far cry from Liszt's "dying murmur of melting caresses." A group of musician–thinkers arose who questioned the very basis of musical aesthetics. They included Hugo Riemann, Heinrich Schenker, Sir Henry Hadow, Sir Donald Tovey, Ernest Newman, and, above all, Arnold Schoenberg, whose theoretical writings show him to be one of the most radical thinkers of the age. Criticism itself was criticized, its basic weakness clearly diagnosed. The search was on to discover the criteria for the evaluation of music. This quest—made ever more urgent by the rapidly changing language of music in the late 20th century—has dominated the work of serious critics ever since.

Criticism always seems to founder on the same small handful of basic problems. These problems are essentially philosophical. They appear to be insoluble. They are aggravated not only by the esoteric nature of music but also by the psychological mystery surrounding the very act of criticism. Are there any "standards" in criticism? If so, can they be defined? Are they objective or subjective? If the latter, can they possibly be true? These questions are fundamental. They disclose the full range of the philosophy of criticism.

The practice of criticism. Musical criticism has a primary aim: the evaluation of music. How does the critic set about this difficult task? The scientific school of criticism holds that he apply certain standards to the work in question. His evaluation is the result of testing music against his critical yardsticks and observing how far short it falls. According to this view, a value judgment is like a prize to be won by careful, objective, intelligent effort. This is an attractive notion, particularly among critics. It fosters the view that the critic is in a position of authority, and that he possesses the means to arbitrate over the creative artist. Unfortunately for criticism, there is nothing to suggest that this is anything but an illusion.

The intuitive nature of value judgments

If one reflects on the way in which one listens to music, a basic fact is apparent. Music's value is inherent; it resides in the work of art itself. A value judgment is something that comes across as part of musical communication. Paradoxically, a value judgment appears to be necessary before the critical process can start. The consequences of this observation are far-reaching. Rather than critics with standards, there appear to be only works with standards, which critics observe. It is not necessary to prove that Mozart's *Jupiter Symphony* is a masterpiece in order to be certain that it *is* a masterpiece. Its mastery is self-evident. Critics did not bestow value on Mozart; they perceived it in him.

Music as an autonomous communication. Music is autonomous. It refers to nothing outside itself. This sets it apart from the other arts, which rely upon the outside world for their images. A hat, a man, or an apple tree may all turn up in a painting, a sculpture, or a play. Indeed, they may be part of the very language of visual art and therefore essential to its understanding. Music has no such aids toward comprehension. It is completely lacking in conceptual crutches. It develops according to its own laws. It is a purely musical truth that is comprehended on a purely musical level. The purity of musical communication is what the German philosopher Arthur Schopenhauer was admiring when he said that all of art aspires toward the condition of music.

The inexplicability of musical experience

The totally musical nature of musical experience raises a difficulty for the critic. Such experience is virtually impossible for him to describe. Consequently, the critic can hardly be called "the man in the middle," a role frequently assigned to him. Music is not like a foreign language that requires an expert to translate it for a lay audience. It is a universal tongue. It either speaks to each listener directly, or it does not speak to him at all. If it speaks, the critic's words are already redundant. If it does not speak, a problem exists that his words cannot solve.

Two important consequences flow from these views. They are among the axioms of criticism. First: since music is autonomous, all knowledge about it must spring from experience of it; practice, in short, precedes theory. Second: because of the purely private and personal nature of musical communication, a work's mastery can only be demonstrated to those listeners who already know about it, who have already experienced it—and they hardly require the demonstration. To those listeners who have not experienced it, a work's mastery is not demonstrable. If it were demonstrable, it goes without saying that critical differences would cease to exist: there would be nothing to prevent those who had experienced it from converting those who had not. Yet critical differences remain.

Objectivity versus subjectivity. A difficulty confronting all critics concerns the subjectivity of their observations. Since music is perceived subjectively, so the argument runs, does this not reduce criticism to mere personal opinion? And if this is so, what makes one critic's opinions any truer than another's? This objection can be disposed of, first, on the broadest philosophical level. Since all things perceivable are perceived subjectively, the charge of subjectivity must either be levelled against every other human endeavour, or it must be withdrawn from criticism. Second, and more to the point, what would be said of a performer who proclaimed to all the world his objectivity, his noninvolvement with music? As for the composer, he would be thought strange indeed if he managed to avoid subjective entanglement with his creations. Why is it considered virtuous for performers and composers to enjoy an inner participation with music and not critics? Quite clearly, there is a contradiction here.

The crucial question facing every critic is how to demonstrate the truth of his reaction. Yet all critics cannot be right; many are diametrically opposed to one another. It is no wonder that musical criticism has been described as stuck at the litmus paper stage: critics take a dip into music, and one sees what colour they turn. Plainly, criticism remains indistinguishable from mere speculation until the critic develops the means of confirming the truth of his views. If he wishes to develop such means, it is to the theory of criticism that he must turn.

A definition of criticism

Meanwhile, a definition of musical criticism emerges: Criticism is the rationalization of intuitive musical understanding.

Issues in the theory of criticism. If the practice of criticism, as has been noted, can be reduced to one thing—expressing value judgments—the theory of criticism is essentially one thing, too—explaining them. It is not enough for critics to assert that one work is a masterpiece, another a mediocrity. An attempt must be made to explain why,

and this may lead to a central discovery. A masterpiece is not a matter of chance, nor is a mediocrity. Both are symptomatic of deep, far-reaching principles.

Unity. When Rudolph Reti, the Viennese critic, was a young man studying music at the Vienna Conservatory, he once stood up in the middle of a composition class and put the following question to his professor: "Why can't we take the themes of one work and substitute the themes of another?" Reti did not receive a very convincing reply and was therefore stimulated to think about the problem for himself. Forty years later, he worked out an answer in his book *The Thematic Process in Music* (1951). Briefly, it was that masterpieces diversify a unity. They grow from an all-embracing idea. Their contrasting themes hang together because each of them represents a different aspect of a single basic thought. This observation was not new. Schoenberg had made it years earlier. So, too, had Heinrich Schenker, who used it as the basis for a major theory of aesthetics in his monumental *Das Meisterwerk in der Musik*, 3 vol. (1926–29; "The Masterpiece in Music"). Reti sharpened the concept. He made the critics think again about what, precisely, they mean when they talk about the integrity of a musical structure.

Diversity in unity

Reti's thesis can be vividly demonstrated by taking an existing masterpiece and substituting random themes from another. Even if such themes preserve a semblance of continuity (matching the key, metre, and mood of the themes they displace), they lose the deep sense of unity communicated by the original.

Not all musicians accept this theory. They argue that many composers, notably Bach, have put together works by borrowing materials from other sources. They fail to realize, however, that the act of borrowing is so highly selective that it, too, must be regarded as part of the creative process. The question then becomes: Why was that particular theme or movement borrowed?

Medium. Another question is why a composition expresses itself through its particular medium? Why that medium rather than another?

If a masterpiece is transferred from the instrumental medium for which it was conceived to some other, alien medium, it undergoes a curious distortion. Such distortion offers the clearest proof that a musical law is operating in the original: an identity of the idea with its medium. A master's inner inspiration adapts to his outer terms of reference. Individual instruments lay down individual limitations. If a composer ignores this fact, he can never be certain that his creative aims will ever coincide with the musical results.

Collision of idea and medium

Occasionally, a great composer deliberately engineers a collision between the idea and the medium for a special musical purpose. The fugue in Beethoven's *Hammerklavier Sonata*, for example, is one of the most physically awkward works to play in the entire piano repertoire. It has been composed against, rather than for, the instrument. Some bars are strictly unplayable, and Beethoven knew it; they contribute to the sense of struggle that is an essential part of musical communication, which is present even in the greatest performance. The orchestration of this fugue by the Austrian composer and conductor Felix Weingartner does a major service to musical aesthetics by providing an alternative musical experience of the same work; but by rendering the difficult easy, his orchestral version robs the music of its basic characteristics. It is a splendid illustration of the way in which, in Beethoven's original, a creative aim has been identified with a physical limitation.

Thematic chronology. A further question is why the chronology of the themes of a masterpiece cannot be changed. Why does one thematic chronology sound good, another bad? If the movements of a great sonata or a symphony are switched around, the result will be musically inferior. If the themes of one movement are mixed with those from the same work's companion movements, the result may even be an artistic disaster.

An illuminating exercise in criticism is to "reconstruct" a masterpiece so that its thematic running order is altered; that is, to transfer the first movement's second subject to the position occupied by the finale's second subject, and vice versa. Any musician can carry out this simple experiment for himself. Nothing is better calculated to reveal to him the presence of a creative principle of contrast distribution in the original. Given the thousands of different directions in which the material of a work could be unfolded, a master chooses the "right" one, the one that maintains structural tension—and, hence, musical interest. The themes of a masterpiece cannot assume one another's functions. They are born to fulfill specific roles. They develop out of each other because they create a musical need for each other.

The creative principle of contrast distribution

Economy. Composers through the ages have hinted at a law of economy toward which all great music strives. Brahms, in a characteristic piece of understatement, once said of composing that "the essential thing is that every note should be in its place." Beethoven expressed the same truth another way. Once, after he had heard the "Funeral March" from the opera *Achille* by the Italian composer Ferdinand Paer, he observed: "I must compose that!" To "fix" the idea, to define it, to pin it down—both composers felt that this was of the essence. Notes are redundant that do not stand for precisely those musical thoughts they are supposed to express. To have more notes, or less, than are actually required to communicate musical meaning must render such meaning correspondingly obscure. This law may be divided into three subsidiary principles.

First is the principle of identity between the idea and its utterance. There is a concrete musical difference between what a composer intends (the idea) and what he actually says (the utterance). Some musicians contend that the distinction is merely theoretical, that in practice it cannot be made. Fortunately, composers have left ample evidence to the contrary. Consider the act of revision. Revision is an acknowledgment by the composer himself that what he actually wrote was not, on reflection, what he actually meant. Revision is self-criticism. The very word implies that a composer has a re-vision of the work, that he returns to the utterance and modifies it in order to be truer to the idea. Revision can sometimes result in criticism on a grand, creative level. Composers occasionally revise the work of other composers with such effective results that the original composition may be eclipsed by the new version, the "criticism," often succeeding where the original work failed. Bach's arrangement (in A minor) for four harpsichords of Vivaldi's *Violin Concerto in B Minor,* for example, is more than an adaptation from one medium to another. It is an act of musical criticism *par excellence.* Vivaldi created the idea. But it was left to Bach to give it complete utterance.

Revision as self-criticism

Second is the relation of form and content. Why does music unfold a particular structure? Why that kind of structure rather than another? The textbooks on form remain silent. Yet this is a profound question. It is surely of paramount interest to know why music unrolls in one direction rather than another. Inspired music appears to carry within itself its own blueprint, according to which it propels itself across precise distances and in precise directions. If it is prematurely halted, diverted, or too long continued—all hallmarks of creative immaturity—it loses the sense of punctuality, the feeling of arriving "on time," the knowledge of being in the right place at the right moment, which characterizes each stage of an emerging structure masterfully handled.

The importance of structure

Some musicians have observed that the distinction between form and content is a false one. They rightly argue that no one hears one without the other, that the one is an organic result of the other. Therefore, why not abolish the distinction? They are right in regard to good forms, forms that arise inevitably from the musical material, in which case there is indeed no distinction to abolish. But bad forms, those that are not true to their content, produce a symptomatic division between the inner direction the music was born to follow and the outer direction it was made to follow.

The third subsidiary principle is audibility. The objective of all compositions is to make a total aural impact. There have been some famous miscalculations, intrinsically inaudible passages, which even the most illustrious performance could not render audible. A striking case of inaudibility occurs toward the end of Grieg's *Piano Con-*

certo in A Minor, in which the "big tune" of the finale returns in full orchestral splendour and obliterates the part of the solo pianist. In the concert hall, it is an extraordinary sight to see the soloist racing up and down the keyboard, fortissimo, without producing any sound. The observation is beyond all question and may be checked every time the work is played in public.

In 1937 Schoenberg completed an orchestration of Brahms's *Piano Quartet in G Minor*, Opus 25. As a young man, he had regularly participated in performances of the quartet. Time and again, he was bothered by its intermittent inaudibility: the piano tended to swamp the strings. Schoenberg's orchestration, as he himself claimed, attempted to put matters right. It remains an exercise in musical audibility—one master helping another to communicate. It constitutes an act of criticism on the highest creative level.

Other principles could be formulated to show that a theory of criticism is also a theory of composition. A search for these principles is really a search for the ultimate justification of the feelings of value inspired by great music.

Criticism and performance. Since music does not exist until it is brought to life by the player, two basic requirements are demanded of the critic: a knowledge of the work and a knowledge of the instrument. Many critics talk loosely about "the work" and "the performance" as though they were separate aspects of musical experience. They are, in fact, different aspects of a total musical experience, and it can be misleading to split them. Much bad criticism results from trying to do so. The Polish-American pianist Leopold Godowsky used to survey his audience before commencing his recitals in an endeavour to discover how many "detectives" there were in the house. Being such a superb pianist, he attracted all those critics exclusively interested in keyboard gymnastics. On the other hand, those interested exclusively in the composition may be equally biassed. In this age of authenticity, when the urtext is the thing, many a promising career has been blighted through what, in the profession, is called a "departure from the text." It is not always appreciated that at least a part of the total musical experience is created by the performer, who has a twofold artistic duty: first, to the fundamental character of the work he interprets; and, second, to his own artistic conscience, which tells him how the work should unfold. The two are not necessarily mutually exclusive.

The performer's duty

The criticism of performance is the most public, and publicized, aspect of a critic's function. It is also the least important. Unfortunately, what particular critics think of particular artists accounts for most contemporary music criticism. This is due rather to arbitrary factors than to the critic's sense of priority. Most newspapers insist that a musical event be reported the following day. The critic, consequently, is forced to telephone his review to his newspaper immediately after the concert, limiting himself to a strictly prescribed number of words. Under these conditions, it is not surprising that most criticism consists of predictable accounts of what was played, who played it, and how it was played. Nevertheless, performing artists are obliged to rely on these critical notices if they are to secure further work, even though neither critics nor artists like it. The box-office economics of performance are so delicate that bad publicity, or no publicity, can wreck artists and management alike.

(A.W./Ed.)

PERFORMANCE

Musical performance is that step in the musical process during which musical ideas are realized and transmitted to a listener. In Western music, performance is most commonly viewed as an interpretive art, though it is not always merely that. A performer to some degree determines aspects of any music he plays. Issues of tempo, phrasing, dynamics, and, in some types of music, pitches and instrumentation are subject to a performer's discretion. In this section, the various aspects and traditions of musical performance in Western and non-Western civilization are treated and their development traced.

Because the pleasure people derive from sounds has always been closely related to the pleasure they derive from making the sounds themselves, it is difficult to conceive of the origin of music as separate from an act of musical performance. Models for the establishment of rhythm may be found in heartbeat and breathing, and in the inflections of speech and cries of grief, pleasure, and desire are found the source of what became song.

The earliest visual manifestations of musical performance are found in rock paintings and excavated objects. While the interrelationship of music and ritual is clear, there is evidence that music was performed for dancing, in various work activities, and primitive games as well. Flutelike instruments of many sizes, made from bones and wood, and elaborate percussion instruments figure prominently in all primitive cultures, in which these instruments often were assigned symbolic significance associated with forces of the supernatural.

Singing is most probably the oldest musical activity. Even in the most primitive cultures the singer has had a special, defined position. In primitive singing there are three classes of sound: the first is called logogenic, in which words form the basis for the wavering musical incantation; the second, called pathogenic, consists of harsh, forceful, percussive, nonverbal sounds emitted to express strong feeling; in the third category, called melogenic, the sounds of the two previous categories combine to form a contour of pitches that pursue a course seemingly dictated by the weight of tensions inherent in the sequence of pitches and hence melodic in effect.

Primitive societies evolved several means to relieve the monotony of one person's singing. A principle device is called antiphony, which involved two groups that sang in alternation or a leader who sang and was answered by a group of singers. In the latter may be seen the origin of responsorial singing, which continues today and which may be the point of origin for several types of musical phrase structures. Polyphony was also anticipated in primitive musical performance. It appeared through haphazard rather than intentional manifestations, such as the singing of the same melody with the parts starting on different pitches or at different times.

Primitive antiphony

This section deals primarily with Western musical performance and its history but also deals briefly with non-Western traditions.

Aspects of Western musical performance. *The performer as interpreter.* Music as an interpretive art is a relatively recent phenomenon. In primitive societies, music plays a ritual role based on an oral tradition, and each performer in a sense interprets the tradition, but, more importantly, he renews it and transforms it through his own performance.

The development of the performer's role as interpreter coincided with the development of musical notation. Because composers for so many centuries were in a position to supervise the performances of their music, certain aspects of performance were not notated. Notation has grown increasingly complex as the dissemination of printed music has become more widespread. Ultimately, the degree of judgment a performer may exercise is determined by the period in which the music was composed. For music of certain periods, even though their notational systems are incomplete and give few indications of how the music should sound beyond pitch and rhythm, musical scholarship has amassed much information concerning proper instrumentation, ornamentation, improvisation, and other traditional performing practices that determine to a large degree the sound and stylistic character of the music. A performer as interpreter operates within a range of limitations imposed upon him by his understanding of the printed page, whatever knowledge may be available concerning the tradition that surrounds the music he is playing, and the extent to which his personal tastes coincide with this information. Certain aspects of the musical taste of the past sometimes cease to be expressive and gradually disappear from usage. Just as often, with the passage of time, performers tend to reassess the literature of previous ages and find renewed interest in practices that an earlier generation may have set aside. In any case, the performer as interpreter speaks to and with the tastes of his own

time. And his task, no different from that of the performer in primitive music, is to renew, to refine, and to enrich the materials and traditions he inherits.

Mediums of performance. The mediums for musical performance are extraordinarily various. Western technology has had a tremendous impact on the development of musical instruments and has thereby greatly expanded the means whereby music is made. Performance may be vocal, instrumental, or electronic. Vocal performance is the oldest and the primary influence for the development of all subsequent musical gestures and materials. Instrumental music began with the development of percussion instruments and crude horns; stringed instruments came later. Electronic music is a 20th-century development involving the reproduction of traditional performance mediums through electronic means, at the same time that it is also evolving composition and performance of its own. At first it reproduced natural sounds by electronic means; later, composers and technicians began to invent electronic sounds and to discover new sound relationships.

Vocal, instrumental, and electronic performance

In all musical mediums the solo performance is the most spectacular. The power of music to compel attention and to stir emotions lends to the solo performer an especially fascinating aura. This is the domain of the virtuoso, that musical performing phenomenon of prodigious technical mastery, invention, and charisma. Most solo literature includes another instrument or group of instruments, and the literature varies from one medium to another according to the expressive range and technical capabilities of the solo instrument.

The largest solo literature for a single instrument is for keyboard instruments. Vocal solo literature is very important and extensive, and the stringed instruments also have a distinguished solo repertoire. The wind, brass, and percussion solo literature is more restricted.

In vocal and instrumental chamber ensemble performance, the performing groups are divided into duets, trios, quartets, quintets, sextets, septets, and octets, which exist for every medium and combination. Of particular importance is a string quartet consisting of two violins, viola, and violoncello. Dating from the 18th century, this instrumental ensemble is analogous to the vocal ensemble consisting of soprano, alto, tenor, and bass.

Beginning of symphonic music

Symphonic music dates from the 17th century. With the rise of the middle class and its aspirations for culture, music as an art required performing situations that would accommodate more people. Larger halls required ensembles acoustically suited to the expanded performing areas. The primary result of this development was the symphony orchestra with its multiple stringed, wind, brass, and percussion instruments.

Ensemble performance places a special responsibility on the concentration of the performer, who must attend not only to his own playing but also to that of all the others in the ensemble. All aspects of the performance depend on this mutual awareness. The leader of most small ensembles is one of the performers, the first violinist, a keyboard player, or one of the singers who indicates tempi, entrances, and musical character and supervises rehearsals. As ensembles grew in size and complexity and their problems of coordination increased, the leader set aside his instrument and devoted his efforts to the beating of time and the communication through clear hand signals of his indications for entrances, tempo changes, dynamic accents, and the shaping of phrases. This leader is called a conductor. The conductor often occupies a position analogous to that of a soloist in the attention of an audience, though the conductor himself makes no musical sound. As they are chiefly responsible for the music orchestras play, both in terms of choice and execution, conductors have had considerable impact on the development of music.

Opera, the marriage of music and drama, is the most complex performance situation. It entails much more than a single performer or group of performers, their instruments, and a hall in which to play. Text, decor, costumes, histrionic projection, preparation time, as well as singers, instrumentalists, and a bevy of extramusical technicians, must all be brought together and coordinated into the final production.

Artistic temperament. Many forces interact in developing those traits that distinguish various performing traditions and individual performers. Personality and temperament fundamentally affect the manner in which a performer works, as does his cultural milieu. There are performers who use music as a vehicle for display and others for whom performance is only a means to illuminate the music. Nor does performance necessarily mean public performance. For some people musical performance is essentially private, requiring no confirmation in the form of audience approval. The musical pleasure of such people rests solely on performing, either alone or with other musicians. Much chamber music is played under these private circumstances, and much music has been written for such situations. This used to be the primary realm of the musical amateur, that skilled but nonprofessional music lover whose ranks are diminishing in the era of the phonograph.

The type of performing situation at the opposite end of the spectrum is one directed to securing audience attention and affection. The need for audience approval has led to innovations as well as some decadence in its impact on the musical scene: innovation, if the performer is led to discover imaginative and fresh means of attracting public acclaim; decadence, if the devices for audience attraction become cheap and thinly spectacular, when the performer may distract the audience from more deserving work and debase its taste.

Intuition versus intellect

Intuition and intellect figure prominently in the temperament of a musical performer. Intuition is the capacity to do the musically "right" thing without instruction or special consideration of the alternatives. Intellect is the means whereby a musician enlarges the range of his instincts through the pursuit of new information, reflection, and analysis of the musical material at hand. Each element informs and completes the other.

Many musicians depend heavily on intuition in solving performance problems. Their solutions are often imaginative and fresh and their performances exciting. Others pursue a methodical path as they examine minutely relevant musical details. They analyze thoroughly the scores they perform, comparing manuscript facsimiles and various printed editions, and attempt to discover new musical relationships, new ways of delineating these relationships in performance, and, in short, new ideas as to how the music might best be played and how it should sound. Art, poetry, biography, cultural history, and any material relating to the period of the piece of music being studied for performance may be sources of musical insight for the performer.

National characteristics. At various times in history, national origin has been considered an important delineating characteristic in musical performance. This is partly the result of certain consistent emphases and features in the music written by composers of different nationalities. The Italians' interest in the voice has evolved a special singing (bel canto) quality in their music, which has carried over into their music for instruments (the stringed instruments especially), and into the general texture of Italian music, which has always given melody special prominence.

The English have had a highly developed and sophisticated musical performance tradition. Amateur improvisation figured importantly in its early history. While this has perhaps tended toward a conservative musical atmosphere, it has also produced a high standard for performance. The French have maintained a strong sense of national identity in their performing arts. In music their concerns for orderly design, delicate expressiveness, simplicity, naturalness, and beauty of sound extend back for centuries. Articulate philosophical and structural considerations have played important roles in developing nationalistic traits in the German tradition of musical performance.

The rich folklorist traditions of Spain, Hungary, and Russia have influenced rhythm, melody, and sonority in Western musical performing traditions. The Russian schools of string and piano technique have greatly advanced the performance resources of these instruments in the past 100 years. The United States, younger and more heterogeneous, has had a shorter musical history but an

abundance of great symphony orchestras and solo artists, who are in demand because of their precise execution, versatility, and breadth of repertoire.

Historical stylistic developments. In antiquity the Sumerians, Egyptians, Greeks, and Romans evolved the first aesthetic theories and musical systems relevant to the music of the modern Western world. Unfortunately, few actual musical examples survive because of primitive notational practices and the gradual erosion of oral traditions. What is known is derived from the writings of the period and iconography—depictions of performing musicians, instruments, and musical events in sculpture and in wall and vase paintings.

In the Middle Ages traditions of musical performance were kept alive by the church and in the music sung and played by wandering minstrels.

In the Renaissance, polyphony (combining several simultaneous voice parts) and the early precursors of modern tonality (organization of music around a focal tone) were developed. The smooth flow of Renaissance liturgical counterpoint (polyphony) and the perky rhythms of secular Renaissance dance music remain as models of taste and musical technique even into the 20th century.

Developments in the Baroque

The performer emerged as a central figure in the focus of musical attention and purpose during the Baroque period. The heightening of the role of the individual performing artist and the invention of increasingly dramatic gestures to demonstrate performers' skills combined with a steady refinement in the construction of musical instruments. The reduction of musical materials to two modes (scale and melody patterns), in this case the major and minor scales, and the initial efforts to compose with large musical forms (opera, oratorio, sonata, and concerto) took place in this period. It is notable that in the Baroque era the equal-temperament system for tuning the strings or pipes of keyboard instruments evolved—a development that has had profound effect on the nature of musical language.

In the Rococo or Classical period that followed, the elaborate contrapuntal texture of Baroque music gave way to music of subtle dynamic differentiation, often based on simple folk materials (rhythms and melodies). The relationships between tonal materials and large musical forms achieved their highest state in the sonata and in opera.

The Romantic age was a period of refinement and intensification of Rococo principles with heavy literary overtones. It was the true age of the star virtuoso; that is, the age in which the role, person, and effect of the virtuoso was most dramatized and glamourized. The symphony orchestra in this period achieved its maximum development. Italian opera under Verdi found its noblest expression and German opera with Wagner expanded into the *Gesamtkunstwerk* ("complete art work").

Modern music dates from an era beginning roughly around World War I. Concert life has remained more or less what the 19th century established; the virtuoso conductor and performer dominate the musical establishment. More chamber, symphony, and opera programs are performed in more parts of the world than ever before, but musical progress has ceased to occur in established organizations and is found instead in the combo: jazz, rock, improvisational, experimental, live electronic, and multimedia groups that have sprung up in the 20th century.

The development of Western musical performance. *Antiquity.* The civilizations of antiquity expanded the role assigned to music in primitive cultures. The Sumerians established the foundations for the tradition of liturgical music. Some of the prayers that they sang have survived. From various artifacts of this civilization something is known about Sumerian musical instruments and some of the situations in which music was played. Such instruments as the lyre, harp, sistra, pipes, timbrels, and various drums figured importantly. Particular instruments were identified as accompaniment with specific types of religious poetry, and indeed the development of different poetic genres seems to have been considerably influenced by the nature of these instruments. While its primary purpose was religious, music also had something of a secular role in Sumerian culture and was played in processions, at banquets, and during primitive sporting events. Music as a profession first developed in Sumerian culture. Both men and women participated as singers and instrumentalists and held priestlike positions with specific functions and ranks of authority.

The musical culture of ancient Egypt, which apparently emerged from the same primitive sources as Sumer, resembles that earlier culture in many aspects: the close relationship between music and religion, the presence of a musical profession, some secular musical activity, and similar musical instruments. Of special interest in Egyptian music is the development of chironomy, the use of hand signals to indicate to instrumentalists what they should play. The singer in this manner guided instrumentalists through melodies with which the singer was seemingly more familiar than the players.

In these ancient cultures there was no notational system or codified theory of musical practice. Different musical traditions were exchanged in the process of trade, migration, military conquest, and intermarriage to form that common body of practices that is the basis of Western music.

Importance of Greek music

Of the early civilizations, Greece provided the musical culture of greatest significance for the development of Western music. The system of scales and modes, as well as a large part of the general philosophy concerning the nature and effect of musical sounds, has been inherited from the Greeks. It was also the Greeks who developed the theory of ethos, which defines the character of psychological and emotional response to different musical stimuli. Building on the ancient religions and magical accoutrements of music, the Greeks assigned specific mental and emotional states to specific pitch arrangements and instrumental combinations. Music infused with this motivating power stood at the centre of the social order.

Though a major part of Western musical terminology, basic music theory and philosophy, basic notational practices, and the foundations of acoustical physics derive from the ancient Greeks, very little of their music has survived. The great ethical significance of music in Greek society caused performing mastery to be an essential aspect of education. Everyone was taught to sing and to play instruments. For a major part of the period all music was a setting of words with instrumental accompaniment, for the most part doubling the voice at the interval of octaves, fourths, or fifths. It was only in the later part of the period, after the age of Pericles (late 5th century BC), that instruments began to play independently of singers.

Music, in the later stages of the Hellenic period, became an increasingly important part of public spectacles. As musical performance became increasingly secularized and became the property of the masses, the upper classes withdrew to esoteric considerations of the art and reflections on its past. It was perhaps at this point that music was divided into two fairly artificial categories: the contemplation of music's nature and history and practical musical performance.

Assuming the artistic mantle of ancient Greece, the Romans disseminated Greek music throughout the known world. The essential role of music in the Roman Empire remained unchanged. Rome's principal contribution consisted in serving as a catalyst for the mixing of Hebraic and Hellenic traditions of musical performance, which, preserved by the Christian Church for a thousand years, emerged again in the Renaissance into the first flowering of modern musical practices in the West.

Although not in the mainstream of Western musical performance, Islāmic (North African and Near Eastern) classical music closely approaches the orchestral tradition of European music in one respect: large choruses and orchestras—consisting of tambourines, pot drums, recorder-flutes, *'ūds* (plucked lutes), bowed lutes, and dulcimers—are assembled to perform "suites" consisting of a series of instrumental solos and orchestral selections interspersed with unison choral songs or solo recitatives based on classical poetry. But while these suites are perfectly suited to performance in formal concert halls, they may also be heard in much less regulated settings, such as cafés. Here the listener is free either to concentrate intellectually on the progress and development of the musical ideas or to

"Oriental" side of Islâmic musical performance

converse and eat, relaxing in the beauty of the general musical design. The more "oriental" side of Islâmic musical performance is more improvisatory, either in solo performance on a recorder-flute, fiddle, *'iúd,* or dulcimer or by any of these in combination with the voice—the instrumentalist then elaborating on the singer's improvisation. Here, too, the relationship of audience to performer is much less formal than in the performance of European music.

The Middle Ages. The tradition of sung prayers and psalms extends into the shadows of early civilization. Such sacred singing was often accompanied by instruments, and its rhythmic character was marked. In the synagogue, however, the sung prayers were often unaccompanied. Ritual dance was excluded from the synagogue as the rhythmic character of sacred music surrendered its more sensual aspects. Even in the prayers themselves, rhythmic verse gave way to prose. The exclusion of women, the elevation of unison singing, and the exclusion of instruments served to establish a clear differentiation between musical performance in the synagogue and that of the street.

The musical performance tradition of the Christian Church grew out of the liturgical tradition of Judaism. The melodic formulas for the singing of psalms and the sung recitation of other scriptural passages are clearly based on Hebraic models.

Music in the Roman Catholic liturgy was performed mainly for the mass. Originally, the music was performed by the priest and the congregation, until, in time, there emerged from the congregation a special group of singers, called the choir, who assumed the musical role of answering and contrasting the solo singing of the priest. Women participated actively in musical performances in the ancient Christian Church until 578, when older Hebraic practices excluding them were restored. From that time until the 20th century, Roman Catholic Church choirs were composed solely of men and boys.

First codification of church music

The first codification of early church music was reputedly made by Pope Gregory I during his reign (590–604). Gregory's collection was selected from chants already in use. His codification assigned these chants to particular services in the liturgical calendar. In general it reinforced the simple, spiritual, aesthetic quality of liturgical music. The music in this collection serves as a model of melodic design even in the 20th century and is regarded as one of the monuments of Western musical literature. This school of unison liturgical singing is called plainchant, plainsong, or Gregorian chant. Specific details concerning the manner in which chant was performed have been lost. There are speculations that the quality of sound the singers employed was somewhat thinner and more nasal than that used by contemporary singers. The authentic rhythmic style of chant cannot be ascertained. There is a theory, however, that the basic rhythmic units had the same durational value and were grouped in irregularly alternating groups of twos and threes. Pitch levels and tempos apparently varied somewhat according to the occasion. There are preserved manuscript notations reminding singers to be careful and modest in their work, indicating that temptations of inattention and excessive vocal display existed for even the earliest liturgical musicians.

While modern musical traditions in the West are based to a large extent on the principles of antiquity preserved in the notated music of the early church, a secular musical practice did exist; but because of the pervasive influence of the church, the dividing line between sacred and secular aspects was thin throughout a good part of the medieval period.

Several types of later secular song have survived. The musical notations are for the most part inadequate to give an accurate impression of the music, but it is known that it retained the essential monophonic character of liturgical music. One curious type of secular song, conductus, originated in the church itself. This song did not use traditional liturgical melodies or texts but was composed to be sung in the liturgical dramas or for processions. For this reason it dealt occasionally with subjects not religious in character. The goliard songs dating from the 11th century are among the oldest examples of secular music. They were the often bawdy Latin songs of itinerant theological students who roamed rather disreputably from school to school in the period preceding the founding of the great university centres in the 13th century.

Several other groups of medieval performers developed literary and musical genres based on vernacular texts: the jongleurs, a group of travelling entertainers in western Europe who sang, did tricks, and danced to earn their living; the troubadours in the south of France and the trouvères in the north; and the minnesingers, a class of artist-knights who wrote and sang love songs tinged with religious fervour.

Instruments, such as the *vielle,* harp, psaltery, flute, shawm, bagpipe, and drums were all used during the Middle Ages to accompany dances and singing. Trumpets and horns were used by nobility, and organs, both portative (movable) and positive (stationary), appeared in the larger churches. In general, little is known of secular instrumental music before the 13th century. It is doubtful that it had a role of any importance apart from accompaniment. Yet the possibility of accompanied liturgical music has not been eliminated by modern scholars.

Medieval polyphony

The medieval musical development with the furthest-reaching consequences for musical performance was that of polyphony, a development directly related, as indicated above, to the experience of performing liturgical chant. For performers and performance, perhaps the most important developments in the wake of polyphony were refinements of rhythmic notation necessary to keep independent melodic lines synchronous. At first the obvious visual method of vertical alignment was used; later, as upper voices became more elaborate in comparison with the (chant-derived) lower ones, and writing in score thus wasted space, more symbolic methods of notating rhythm developed, most importantly in and around the new cathedral of Notre-Dame in Paris.

In the 14th century, partly because of the declining political strength of the church, the setting for new developments in music shifted from the sacred field to the secular, from the church to the court. This shift led in turn to a new emphasis on instrumental music and performance. Already the lower voices began to be performed on instruments—both because their long notes made them difficult to sing and because their texts (of only a few syllables) became senseless outside their original liturgical positions. Now, as secular princes became increasingly important patrons of composers and performers—a situation that would continue well into the 18th century—secular and instrumental music flourished. The polyphonic music of the church merged with the poetic art of the troubadours, and the two most important composers of the age were the blind Florentine organist Francesco Landini and the French poet Guillaume de Machaut, canon of Reims.

Most of the music of these composers seems to have been intended for combined vocal-instrumental performance, although this is seldom expressly indicated in the manuscripts. Medieval composers probably had no rigid expectations about performance media. Until the 17th century, and even through the 19th in the case of domestic performance, choice of instruments was likely to be dependent as much on available performers as on anything else. Many sources do, however, indicate that medieval musicians tended to separate instruments into two groups, loud and soft (*haut* and *bas,* or, very generally, wind and string), and to prefer contrasting sonorities within those groups for maximum differentiation of the individual parts. Outdoor or ceremonial music would be performed with loud instruments (shawm, bombard, trombone, organ); room music, with soft ones (lute, viol, recorder, harp). Paintings and manuscript illuminations of the period show that much secular performance included both a wide variety of bells, drums, and other percussion instruments and instruments with drones—bagpipes, fiddles, double recorders, hurdy-gurdies. The parts for these instruments are never found in the musical sources and must be reconstructed for modern performance.

The notation of medieval music often is misleading for the modern performer. Accidentals (sharps and flats, called then musica ficta) were often omitted as being understood.

Notation of medieval music

Further, it seems likely that variation, embellishment, and improvisation were very important elements of medieval performance. It is known that sections of some 15th-century two-part vocal music were enhanced by an extempore third part, in a technique called fauxbourdon; the notation of the 15th-century *basse danse* consisted of only a single line of unmeasured long notes, evidently used by the performing group of three instrumentalists for improvisation, much as a modern jazz combo's chart.

The Renaissance. The very concept of improvisation as a mere subcategory within performance practice could arise only after the invention of music printing, which had at first little discernible effect on performance. Extemporized ornamentation of polyphonic music continued and increased during the 16th century in instrumental, vocal, and combined performance, both secular and sacred. Later in the century, liturgical music again became less extravagant in the wake of the Council of Trent (1545–63), which ordered that masses be sung "clearly and at the right speed" and that singing "be constituted not to give empty pleasure to the ear, but in such a way that the words may be clearly understood by all." Music printing was at first too expensive to alter seriously the social structure of musical performance; the traditions of ostentation and exclusiveness embodied in music written by Guillaume Dufay for the early 15th-century Burgundian court were continued in the magnificent musical establishments of the Italian Renaissance princes and popes. Detailed records exist of the elaborate musical festivities arranged for weddings and baptisms of the powerful Florentine family, the Medici. Printing increased the dissemination as well as the survival of these works; but, like the earlier Burgundian chanson and unlike the contemporary Parisian chanson, which was cast in a more popular mould, they were nonetheless primarily intended for a select group of discriminating performers.

Printing, both of music and of books, does document the ever increasing development and sophistication of instrumental music during the 16th century. Printed descriptions of instruments date from the 16th century. Their discussions of tuning and technique supplied the needs of professional and nonprofessional musicians alike. There was a growing tendency to construct instruments in families (whole consorts of homogeneous timbre, high, middle, and low), a tendency perhaps related to recent expansion at both ends of the musical scale: with more space available, contrapuntal parts no longer crossed so frequently and no longer needed the differentiation provided by the markedly contrasting timbres of the medieval "broken consort."

The 17th and 18th centuries. After printing, the next significant influence on music performance was the gradual emergence of the audience, for the relationship between participants in the musical experience—between performer and listener—became polarized. The first evidence for this shift was the rise of the professional vocal virtuoso about the last quarter of the 16th century, and this development soon had a profound influence on musical style. Italian composer-singers, such as Giulio Caccini and Jacopo Peri, reacted quickly to their audiences' desire for more expressive and passionate vocalism, and the music they wrote for themselves eventually was imitated and refined by other composers, such as the Italian Claudio Monteverdi, whose nine successive books of madrigals document the changes in style from music composed for four to six essentially equal voices to music in which the interest lay primarily at the extremes of the texture. The technical underpinning for this new monodic style was the basso continuo, or thorough bass, played by one or more polyphonic solo instruments "realizing" a "figured bass": that is to say, improvising chords above a single line of music provided with numbers and other symbols to indicate the other notes of the chords. In the 17th century a wide variety of continuo instruments was used, including lute, theorbo, harp, harpsichord, and organ. By the 18th century the practice was more standardized: the bass line would be realized on a keyboard instrument and reinforced by a monophonic bass instrument, such as a lute, viola da gamba, violoncello, or bassoon. The continuo player not only completed the harmony but could also control rhythm and tempo to suit the particular conditions of a performance.

Rise of the vocal virtuoso

The development of monody was itself a necessary precondition for that most expensive of all performance institutions, opera. Beginning in Florence at the very end of the 16th century, opera soon spread over Italy: through Rome, where its initially pastoral nature matured into full-blown spectacle, to Venice, where the first public opera theatre opened in 1637. There, although audiences were still aristocratic, opera was dependent upon the sale of admissions rather than royal patronage, and musical performance began to find an entirely new method of economic support.

In the realm of purely instrumental music, the new economy of performance was slower to emerge, but there were many other new developments. By far the most popular Renaissance instrument had been the versatile lute; it served all levels from the merchant's daughter learning the simplest dance melody to the virtuoso. In the 17th century the lute began to yield to keyboard instruments, but the intimate music of the French *clavecinistes* (harpsichordists) was still a clear outgrowth of the precious and evanescent performance style of the lutenist Denis Gaultier (1597/1603–1672). Later, keyboard ornamentation began to be codified in tables of agrément-symbols published with each new collection of music. In Italy composers also were attempting to provide performers with more explicit directions. Contemporary keyboard fingering systems, which used the thumb much less than modern ones, also served contemporary preference for subtlety and unevenness of rhythm. As the century progressed and national styles drew further apart, there evolved a specifically French tradition of *inégalité:* performing certain evenly written notes unequally, with alternately longer and shorter values.

Predominance of keyboard instruments

A more lasting French development was the first instance of instrumental music consistently performed by more than one player to a part. In 1656, Jean-Baptiste Lully made his orchestra, the Petits Violons ("Little Violins"), abandon the old tradition of free embellishment and drilled them in a disciplined and rhythmically pointed precision that was widely imitated. Simultaneously, the violin and its family, because of their passionate brilliance and versatility, replaced viols as the standard ensemble instruments—especially quickly in Italy, where performance was less sophisticated, less mannered, and less restrained than in France.

In the 18th century, national performance styles tended again to merge, except in the case of opera. French opera, which had reached its first height under Lully and had counted among its star performers Louis XIV himself, continued to emphasize ballet and correct declamation more than pure vocalism. In other areas, standardization and codification were the trend. The place of improvised embellishment and variation was further circumscribed, limited in general to such recognized spots as repeated sections in binary and da capo forms, slow movements of sonatas and concertos, and cadences. Instrumental tutors by famous performers were important and widespread.

Foundation of public concerts

The foundation of public concerts increased, and orchestras all over Europe followed the pattern set by the famous ensemble maintained by the Elector of the Palatine at Mannheim, with its standard size (about 25) and new style of performance with dramatic dynamic effects and orchestral devices (*e.g.,* crescendos, tremolos, grand pauses). The Mannheim composers also hastened the decline of the improvised thorough bass by writing out harmonic filler parts for the violas; conducting from the keyboard nevertheless remained standard practice into the 19th century. Meanwhile, entrepreneurial speculation was finally supplanting aristocratic patronage as the economic base for concert activity. Haydn, who had already spent one full career in Austria, in the service of the House of Esterházy, in 1791 began another and more lucrative one in association with the concert manager Johann Peter Salomon—conducting his London symphonies from the piano.

The 19th century. The heyday of the concert artist began before Haydn's first journey to London, and it still shows few signs of ending. It reached its zenith and was the

primary factor in all music performance in the 19th century. Mozart and Beethoven were famous concert pianists before they were famous composers, and succeeding generations saw a large number of piano virtuosos travelling over Europe and, later, North and South America. Some were composers of works for themselves; others were more important as interpreters of other composers' works. The tradition of the star singer was of course much older, and it continued; one new development was that of the claquer, paid by the star for his applause. The independent conductor, as distinct from the first violinist or the continuo player, emerged from the body of the orchestra during the first half of the 19th century, and his development toward the lionized figures of the 20th century was swift. Parallel with this rise came the establishment of many of today's major orchestras: New York Philharmonic (1842), Vienna Philharmonic (1842), Boston Symphony (1881), Berlin Philharmonic (1882), Amsterdam Concertgebouw (1883), Chicago Symphony (1891), and London Symphony (1904).

Establishment of major orchestras

The result of the enormous widening of concert activity and of the increasingly international reputations of performers was an even further standardization of performance practice. Eighteenth-century concern with appropriateness and taste in embellishment yielded to emphasis on clarity and evenness of touch, purity of intonation, and accuracy of execution. As composers' scores became increasingly precise, the performers' interpretative decisions were increasingly limited to matters of technique, tempo, rhythmic and dynamic nuance and personality—a subjectivism justified by the cult of Romantic genius prevalent in 19th-century artistic life. Real improvisation in music would not re-emerge until the 20th century—in jazz. The addition of such mechanical aids and improvements as chin rests and end pins to stringed instruments (which permitted a wider and more constant vibrato without tiring); valves and extra keys to brass and woodwind instruments (making scales more even and intonation more secure); and double-escapement action, iron frames, and cross-stringing to the piano (which facilitated crisper and surer attack and made both tone and tuning last longer) all had profound influence not only on performance techniques but also on the very sound of the instruments. The most successful new instrumental and vocal teaching methods emphasized virtuosity, brilliance, evenness, and wide range, reflecting a desire to make music more effective for large audiences.

Technical advances in instruments

The rise of the concert artist was seconded by the appearance of the professional music critic, whose influence on performance has been, and is, difficult to assess. At first critics tended to be primarily practicing musicians; later this was less the case. A more tangible residue of 19th-century music performance and one that illustrates how little its basic social structures have changed since then is the large number of concert halls and opera theatres that were built and are still used today.

One final development, the import of which would not be fully realized until the present century, was that of historicism: the active revival of old music. This incipient recognition of the validity of other styles of composition and performance is dated conventionally from the German composer Felix Mendelssohn's 1829 performance of parts of Bach's *St. Matthew Passion,* but it was preceded in a sense by the Concerts of Antient Music (1776–1848) in London. The stated policy of this musical group was not to perform music less than 20 years old (but they often updated the compositions with added brass parts). The revival of interest in the music of Palestrina and Bach, while at first expressed only in terms of 19th-century Romanticism, would pave the way for 20th-century advances and retrenchments in both style and performance.

The 20th century. The major performing institutions of the 19th century have continued into the 20th century with only minimum structural change, except for a rather belated movement toward unionization of personnel; this development has of course improved the performers' lot greatly, while increasing the costs of performance. Unquestionably, the major new influence on 20th-century music performance has been electronics. Broadcasting and recording have widened even further the potential audience for concert artists, at the same time as they have tended to decrease the physical necessity for large new public performance arenas. Electronic instruments have appeared, both amplified versions of older ones (guitar, piano, and even some woodwinds) and instruments with fundamentally electronic means of tone production (electronic pianos and organs, the theremin and Ondes Martenot, and sound synthesizers). Other new compositional and performance possibilities have also developed; for example, film, tape, stereophonism, and computers. Even before the phonograph (invented *c.* 1875) had begun to be regarded as more than a toy, serious research into the authentic performance of older music had produced an awareness of possibilities that pointed the way out of the seeming dead end of late Romantic gigantism and subjectivism. From the very beginning of the century, the chamber concerts given by Arnold Dolmetsch and his family, on reconstructions of old gambas and recorders, attracted attention to small ensembles and different sonorities and encouraged the activities of other artists.

Appearance of electronic instruments

The true end of the Romantic era and the beginning of the modern era can be dated from the second decade of the 20th century, the time of the composition of two masterpieces that more than any others mark the departure from 19th-century performance ideas: the German composer Arnold Schoenberg's *Pierrot Lunaire* (1912) and the Russian composer Igor Stravinsky's *Histoire du soldat* (*The Soldier's Tale,* 1918). These are chamber works, but their instrumental makeup is a unique mixture of instruments that do not necessarily blend and that seem further to repudiate the orchestra as a performing medium. *Pierrot* is a series of songs which repudiate the 19th-century lied: the voice does not sing but produces a kind of pitched speech (*Sprechstimme*). *Histoire* repudiates both orchestra and opera as previously understood: it is specifically (and inexpensively) designed for performance on a portable stage by three dancers, a narrator, and seven instrumentalists. For these works a new kind of performer is required, and these works in turn have helped to train the new performer—who might be called the group-virtuoso. Teams or groups of such performers have sprung up everywhere. Often they are centred on a living composer or the university where he teaches, where they function as partners to his composition, realizing the work rather than interpreting it. The performer is very much involved in the creative act, the product of which reflects his particular skills and personality, and the dynamics of the working situation.

In the second half of the 20th century the established performance situation moved from the formal, ritualized event of the past to a more informal and spontaneous type of gathering. The interaction of various media has led to new art forms and circumstances. Many artists attempt to create performance situations that actively involve as participants all those in attendance. The roles of composer, performer, and listener are consolidated in a single participant, who in interaction with others arrives at an art work, which all have invented, realized and perceived, and which can never take place again. On the other hand, the growing use of technology intensifies the problem of evaluating the meaning and effect of electronically produced and assembled performances that, in their totality, never took place at all and possibly never could.

Increasing spontaneity of performance situations

The electronic media continue to improve so that anyone may be able to select chamber, concert, opera, and other new types of performance from anywhere in the world, experiencing them through nearly lifelike reproduction facilities. Vast numbers of people may study performance skills via two-way transmission with great artists. The number of actual public performing events may decrease as private musical performance increases. Already there is the phenomenon of the widespread dissemination of great performers' recordings, which has forced the standards of quality for a live performance to almost inhuman heights and has increased interest in the performance of older as well as contemporary music.

Non-Western musical performance traditions. *South Asia.* Although the classical South Asian or Indian musician usually performs in a concert situation quite analogous to that of a typical Western artist, his audience

responds to him quite differently: he is not judged on how faithfully he reproduces the music the composer imagined but on how well he creates his own music within certain wide bounds set by the composer and by the general practice of Indian music. Since Indian musical performance is based on improvisation, Indian musical pedagogy is therefore a more personal procedure, in which an aspiring musician will "apprentice" himself to a guru, with whom he thereafter identifies himself; in the West this kind of organization is reflected in the rise of the group-virtuoso discussed above. Similarly, Western development away from large performing groups such as the full orchestra reflects—or at least parallels—the more intimate character of Indian music, the basic texture of which usually involves a quite small group of performers: one player to provide rhythm on a drum such as the double-headed, pitched tabla; one to provide a basic drone, often on the lute-like tamboura; and a central performer on the sitar (technically also a plucked lute but one with melodic capability, unlike the tamboura). The players often engage in a kind of competition not unlike that of Western jazz groups. If there is singing, the style of performance is low and soft, in contrast to that of Indonesian classical vocalism.

Intimate character of Indian music

Southeast Asia. The gamelan is at the center of the art-music tradition of Indonesia. It may range in size from a few to over 75 instruments. The basic melodic instrument is the *saron* (bronze xylophone), accompanied by various gongs, a kind of violin, a recorder-flute and/or a zither; the group is led by a drummer. As in medieval Western music, there are two kinds of gamelan playing, one emphasizing the bronze instruments (comparable to medieval *haut*, or loud, consorts) and the other the wind and stringed instruments (*bas*, or soft, groups). A similar differentiation exists in Indochinese music in the contrast between the percussion-dominated *pi phat* band of Thailand and the string-dominated *mahori* bands of Thailand and Cambodia. Gamelan playing, particularly of the softer type, often accompanies solo and unison choral singing of classical poetry (music is connected with most of Indonesian literature). Southeast Asian vocal performance—like that of a great deal of non-Western art music—is characterized by tense, high, often nasal voice production; this is one of many alternatives being explored by the more experimental 20th-century Western composers and performers.

China and Japan. The most extensively developed and most important Chinese and Japanese traditions of musical performance are closely tied to theatrical styles and traditions. Perhaps the most spectacular of non-Western performance traditions is Chinese opera, in which singers, acrobats, costumes, scenery, and instruments are combined in the creation of a highly varied work of art. Peking opera uses two basic kinds of instrumentation: for military scenes a battery of drums, gongs, and cymbals with a kind of oboe playing the melody; for the more frequent domestic scenes a wider variety based on a drum (*pan ku*) with a peculiarly sharp, cracking sound for keeping time, and a number of two-stringed, bowed lutes played with the bow passing between the strings. Plucked lutes and flutes also appear at times. All of the melody instruments play heterophonically with the singers, whose vocal style, as in the West, is highly artificial. Heroines are usually portrayed (sometimes by female impersonators) in a high, thin voice; heroes use a raucous, rasping tone quite foreign to traditionally oriented Western ears—but, again, not unlike some of the vocal techniques required by 20th-century Western avant-garde composers.

A performance tradition peculiarly Japanese is the emphasis on the visual aspects of making music: custom directs that *gagaku* (court orchestra) instruments must be played as gracefully as possible. (L.Fo./J.Th./B.A.C.)

Musical sound

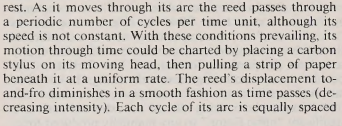
That some sounds are intrinsically musical, while others are not, is an oversimplification. From the tinkle of a bell to the slam of a door, any sound is a potential ingredient for the kinds of sound organization called music. The choices of sounds for music making have been severely limited in all places and periods by a diversity of physical, aesthetic, and cultural considerations. This section will analyze those involved in Western musical traditions.

General characteristics. The fundamental distinction usually made has been between tone and noise, a distinction best clarified by referring to the physical characteristics of sound. Tone differs from noise mainly in that it possesses features that enable it to be regarded as autonomous. Noises are most readily identified, not by their character but by their sources; *e.g.*, the noise of the dripping faucet, the grating chalk, or the squeaking gate. Although tones too are commonly linked with their sources (violin tone, flute tone, etc.), they more readily achieve autonomy because they possess controlled pitch, loudness, timbre, and duration, attributes that make them amenable to musical organization. Instruments that yield musical sounds, or tones, are those that produce periodic vibrations. Their periodicity is their controllable (*i.e.*, musical) basis.

The strings of the violin, the lips of the trumpet player, the reed of a saxophone, and the wooden slabs of a xylophone are all, in their unique ways, producers of periodic vibrations. The pitch, or high-low aspect, created by each of these vibrating bodies is most directly a product of vibrational frequency. Timbre (tone colour) is a product of the total complement of simultaneous motions enacted by any medium during its vibration. Loudness is a product of the intensity of that motion. Duration is the length of time that a tone persists.

The vibrating reed

Each of these attributes is revealed in the wave form of a tone. The pattern may be visualized as an elastic reed—like that of a clarinet—fixed at one end, moving like a pendulum in a to-and-fro pattern when set into motion. Clearly, this reed's motion will be in proportion to the applied force. Its arc of movement will be lesser or greater depending upon the degree of pressure used to set it into motion. Once moving, it will oscillate until friction and its own inertia cause it to return to its original state of rest. As it moves through its arc the reed passes through a periodic number of cycles per time unit, although its speed is not constant. With these conditions prevailing, its motion through time could be charted by placing a carbon stylus on its moving head, then pulling a strip of paper beneath it at a uniform rate. The reed's displacement to-and-fro diminishes in a smooth fashion as time passes (decreasing intensity). Each cycle of its arc is equally spaced



Visual representation of a reed's vibration.

(uniform frequency). Each period of the motion forms the same arc pattern (uniform wave content). If this vibratory motion were audible, it could be described as follows: it grows weaker from the beginning (diminishing loudness) until it becomes inaudible; it remains at a stable level of highness (steady pitch); and it is of unvarying tonal quality (uniform timbre). If the reed were a part of a clarinet and the player continued blowing it with unvaried pressure, loudness, pitch, and timbre would appear as constants.

TONE

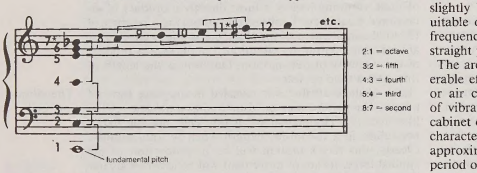
Most musical tones differ from the demonstration tone (above) in that they consist of more than a single wave form. Any material undergoing vibratory motion imposes its own characteristic oscillations on the fundamental vibration. The reed probably would vibrate in parts as well as a whole, thus creating partial wave forms in addition to the fundamental wave form. These partials are not fortuitous. They bear harmonic relationships to the fundamental motion that are expressible as frequency ratios of 1:2, 3:4, etc. This means that the reed (or string or

air column as well) is vibrating in halves and thirds and fourths as well as a whole. Another way of expressing this is that half the body is vibrating at a frequency twice as great as the whole; a third is vibrating at a frequency three times greater; etc.

Overtone series

These numerical relationships also are expressible by pitch relationships as the harmonic, or overtone, series, which is merely a representation of numerical ratios in terms of pitch equivalents. Depending upon its shape and substance, a vibrating mass performs motions that are the equivalents of these partial vibrations, whether it be the mass of a string, reed, woodblock, or air column. This means that most tones are composites: they consist of partial vibrations of the vibrating body as well as the vibrations of the whole mass. Although one can develop the acuity required to hear some of these overtones within a musical tone, the ear normally ignores them as separate parts, recognizing only a more or less rich tone quality within the fundamental pitch.

Although pure tones, or tones lacking other than a fundamental frequency, sometimes occur in music, most musical tones are composites. A typical violin tone is

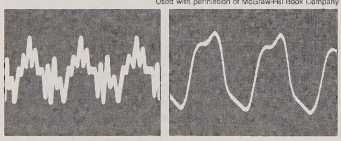


* Actual pitch slightly lower than standard notation shows.

Overtone series.

relatively rich in overtones while a flute tone sometimes approaches a pure tone. What the listener recognizes as "a violin tone" or "a trumpet tone" also is a product of the noise content that accompanies the articulation of any sound on the particular instrument. The friction of the bow as it is set into motion across the string, the eddies of air pressure within a horn's mouthpiece, or the hammer's impact on a piano string all add an extra dimension, a significant "noise factor," to any manually produced tone. After articulation, however, it is the presence or absence of overtones and their relative intensities that determine the timbre of any tone. The violin and flute tones are distinguishable because their articulatory "noises" are quite different and their overtone contents are dissimilar, even when they produce the same pitch.

From C. Culver, *Musical Acoustics*. Copyright 1956. Used with permission of McGraw-Hill Book Company



Comparison of (left) violin wave form, d', and flute wave form, d'.

Electronic sound

Musical tones of determined harmonic content can be produced by electronic vacuum tubes or transistors as well as by traditional manual instruments. Some electronic organs, for example, use single vacuum tubes whose frequency output can be varied through control of an adjustable transformer. Through ingenious mixing circuits a compound tone consisting of any predetermined overtone content can be produced, thereby imitating the sound of any traditional instrument. Composers of electronic music have utilized this capability to synthesize tones quite different from any available on traditional instruments, as well as tones similar to natural sounds. Electronic computers are capable of complete imitation of such sounds; the tone is broken down into its component parts, then synthesized through an auditory output circuit.

MOVEMENT

Once an audible oscillation is produced by a vibrating body, it moves away from its source as a spherical pressure wave. Its rate of passage through any medium is determined by the medium's density and elasticity; the denser the medium, the slower the transmission; the greater the elasticity, the faster. In air at around 60° F, sound moves at approximately 1,120 feet per second, the rate increasing by 1.1 feet per second per degree of rise in temperature.

Sound waves move as a succession of compressions through the air. The wavelength is determined by frequency; the higher the pitch, the shorter the wavelength. A pitch of 263 cycles per second (middle C of the piano) is borne as a wavelength of around 4.3 feet (speed of sound ÷ frequency = wavelength).

By the time a wave has moved some distance, it has changed in some of its characteristics. The journey has robbed it of intensity, which is inversely proportional to the square of the distance. Its timbre has been altered slightly by objects within its path that disrupted an equitable distribution of frequencies, particularly the high-frequency waves, which, unlike the low, move in relatively straight paths from their sources.

Resonance

The area within which a sound occurs can have considerable effect upon what is heard. Just as a string or reed or air column has a natural resonance period (or rate of vibration), any enclosure—whether an audio speaker cabinet or the nave of a cathedral—imposes its resonance characteristics on a sound wave within it. Any tone that approximates in frequency the characteristic resonance period of an enclosure will be reinforced through the sympathetic response, or natural resonance, of the air within the enclosure. This means that tones of frequencies differing from the resonance of the enclosure will be less intense than those that agree, thereby creating an inequity of sound intensities.

Fortunately, most rooms where music is performed are large enough (wall lengths greater than about 30 feet) so that their natural resonance periods are too slow to fall within the range of pitches of the lowest musical tones (usually no lower than 27 cycles per second, although some organs have pipes that extend to 15 cycles per second). Smaller rooms can produce disturbing sympathetic resonance unless obstructions or absorbent materials are added to minimize that effect. (Bathroom singers revel in this phenomenon because the band of resonance sometimes lies close enough to the pitches of the male voice to support it, making it appear richer and more powerful.)

Reverberation period

In addition to resonance, any enclosure possesses a reverberation period, a unit of time measured from the instant a sound fills the enclosure (steady state) until that sound has decayed to one-millionth of its initial intensity. Anyone who has spoken or clapped his hands inside a large, empty room has experienced prolonged reverberation. There are two reasons for such protracted reverberation: first, the space between the surfaces of the enclosure is so great that reflected sound waves travel extended distances before decaying; and, second, the absence of highly absorbent materials precludes appreciable loss of intensity of the wave during its movement.

The reverberation period is a crucial factor in rooms where sounds must be heard with considerable fidelity. If the period is too long in a room where speech must be understood, spoken syllables will blend into each other and the words will be mumbled confusion. If, on the other hand, the reverberation period is too brief in a room where human "presence" and music each contribute to the acoustics, only a "cold" and "dull" feeling will persist, because no reverberative support of the prevailing sounds can be provided by the enclosure itself. (See also ENGINEERING: *Acoustical engineering*.)

Although all sound waves, regardless of their pitch, travel at the same rate of speed through a particular medium, low tones mushroom out in a broad trajectory while high tones move in straight paths. For this reason listeners in any room should be within a direct path of sound

propagation. Seats far to the side at the front of an auditorium offer occupants a potentially distorted version of sound from its source. Thus the high-frequency speakers (tweeters) in good audio reproduction systems are angled toward the sides of the room, ensuring wider coverage for high-frequency components of all sounds.

Sites of musical performance in the open demand quite different acoustical arrangements, of course, since sound reflection from ceilings and walls cannot occur and reverberation cannot provide the desirable support that would be available within a room. A reflective shell placed behind the sound source can provide a boost in transmission of sounds toward listeners. Such a reflector must be designed so that relatively uniform wave propagation will reach all locations where listening will occur. The shell form serves that purpose admirably since its curved shape avoids the right angles that might set up continuous reflections, or echoing. Furthermore, sound waves are reflected more uniformly over a wide area than with any other shape, diffusing them equally over the path of propagations. (The needs here are similar to those of the photographer who wishes to flood a scene uniformly with flat light rather than focus with a spotlight on a small area.)

PITCH AND TIMBRE

Just as various denominations of coins combine to form the larger units of a monetary system, so musical tones combine to form larger units of musical experience. Although pitch, loudness, duration, and timbre act as fourfold coordinates in the structuring of these units, pitch has been favoured as the dominating attribute by most Western theorists. The history of music theory has to a great degree consisted of a commentary on the ways pitches are combined to make musical patterns, leaving loudness and timbre more as the "understood" parameters of the musical palette.

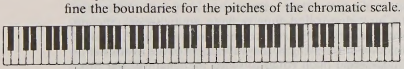
Music terminology, for example, recognizes loudnesses in music in terms of an eight-level continuum of nuances from "extremely soft" (ppp, or pianississimo) to "extremely loud" (fff or fortississimo). (The musical dominance of Italy from the late 16th to the 18th century—when these Italian terms first were applied—explains their retention today.)

The timbres of music enjoy an even less explicit and formalized ranking; other than the vague classifications "shrill," "mellow," "full," and so on, there is no standard taxonomy of tone quality. Musicians for the most part are content to denote a particular timbre by the name of the instrument that produced it.

Divisions of the pitch spectrum

Pitch is another matter. A highly developed musical culture demands a precise standardization of pitch, and Western theory has been occupied with this task from as early as Aristoxenus (4th century BC). Especially since the Renaissance, when instruments emerged as the principal vehicles of the musical impulse, problems of pitch location (tuning) and representation (notation) have challenged the practicing musician. When at least two instrumentalists sit down to play a duet, there must be some agreement about pitch, or only frustration will result. Although the standardization of the pitch name *a'* (within the middle of the piano keyboard) at 440 cycles per second has been adopted by most of the professional music world, there was a day—even during the mid-18th century of Bach—when pitch uniformity was unknown.

Man's perception of pitch is confined within a span of roughly 15 to 18,000 cycles per second. This upper limit varies with the age and ear structure of the individual, the upper limit normally attenuating with advancing age. The pitch spectrum is divided into octaves, a name derived from the scale theories of earlier times when only eight (Latin *octo*) notes within this breadth were codified. Today the octave is considered in Western music to define the boundaries for the pitches of the chromatic scale.



Piano keyboard.

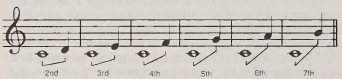
The piano keyboard is a useful visual representation of this 12-unit division of the octave. Beginning on any key, there are 12 different keys (and thus 12 different pitches), counting the beginning key, before a key occupying the same position in the pattern recurs.

One must keep in mind that the chromatic scale, within the various octave registers of man's hearing, is merely a conventional standard of pitch tuning. Performers like singers, trombone and string players, who can alter the pitches they produce, frequently make use of pitches that do not correspond precisely to this set of norms. The music of many non-Western cultures also utilizes distinct divisions of the octave. Furthermore, some contemporary music makes use of pitch placements that divide the octave into units smaller than the half-step. This music, called microtonal, has not become standard fare in Western cultures, in spite of its advocates (Alois Hába, Julian Carillo, Karlheinz Stockhausen) and even its special instruments that provide a means for consistent performance.

Western music history is dotted with systems formulated for the precise tuning of pitches within the octave. From a modern viewpoint all suffer from one of two mutually exclusive faults: either they lack relationships (intervals) of uniform size, or they are incapable of providing chords that are acceptable to the ear. Pythagorean tuning provides uniformity but not the chords. Just tuning, based on the simpler ratios of the overtone series, provides the chords but suffers from inequality of intervals. Meantone tuning provides equal intervals but gives rise to several objectionable chords, even in simple music. All three of these systems fail to provide the pitch wherewithal for the 12 musical keys found in the standard repertoire (see below *Tuning and temperament*).

The compromise tuning system most widely accepted since the mid-19th century is called "equal temperament." Based on the division of the octave into 12 equal half-steps, or semitones, this method provides precisely equal intervals and a full set of chords that, although not as euphonious as those of the overtone series, are not offensive to the listener.

The semitone is the smallest acknowledged interval of the Western pitch system. The sizes of all remaining intervals can be calculated by determining how many semitones each contains. The names of these intervals are derived from musical notation through a simple counting of lines



Generic names of pitch intervals.

and spaces of the staff. Just as the overtone content of a single tone determines timbre, the relationship of the constituent pitches of an interval determines its quality, or sonance. There is a long history of speculations in this area, but the subjectivity of the data indicates that little verifiable fact can be sorted from it.

Consonance and dissonance

Until the 20th century, music theorists were prone to concoct tables that showed an "objective" classification of intervals into the two opposing camps of consonant and dissonant. But only the person who utters these terms can know with assurance what he means by them, although many attempts have been made to link consonant with pleasant, smooth, stable, beautiful and dissonant with unpleasant, grating, unstable, and ugly. These adjectives may be reasonably meaningful in musical contexts, but difficulty arises if one attempts to pin a singular evaluation on a particular interval per se.

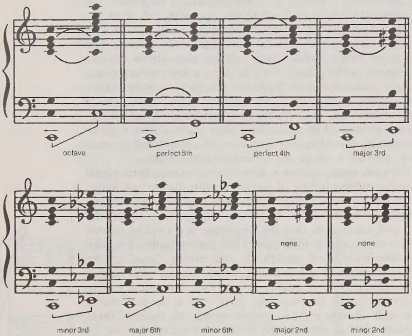
Theorists have noted that the character of an interval is altered considerably by the sounds that surround it. Thus the naked interval that sounds "grating," "unstable," and lacking in fusion might within a particular context create an altogether different effect, and vice versa.

Recognition of the power of context in shaping a response to the individual pitch interval has led some music theorists to think more in terms of a continuum of sonance that extends from more consonant to more disso-

nant, tearing down the artificial fence once presumed to separate the two in experience.

Helmholtz theory

The explanation of consonance and dissonance offered by Hermann von Helmholtz in *On the Sensations of Tone* (1863) is perhaps as helpful as any. An initial theory was based on the notion that dissonance is a product of beats, which result from simultaneous tones or their upper



Common overtones (incomplete series, excluding the seventh) at various pitch intervals.

overtones of slightly differing frequencies. Another explanation, offered later by Helmholtz, held that two tones are consonant if they have one or more overtones (excluding the seventh and ninth) in common.

Music in which a high degree of dissonance occurs has rekindled interest in this old problem of psychoacoustics. The German composer Paul Hindemith (1895–1963) provided one explanation of harmonic tension and relaxation that depends upon the intervals found within chords. According to his view a chord is more dissonant than another if it contains a greater number of intervals that, as separate entities, are dissonant. Although Hindemith's reasonings and conclusions have not been widely accepted, the absence of any more convincing explanation and classification often leads musicians to use his ideas implicitly.

Although the complete pitch spectrum can be tuned in a way that provides 12 pitches per octave (as the chromatic scale), pitch organization in music usually is discussed in terms of less inclusive kinds of scale patterns. The most important scales in traditional Western theory are seventone (heptatonic), which, like the chromatic, operate within the octave. These scales are different from one another only in the intervals formed by their constituent pitches. The major scale, for instance, consists of seven pitches arranged in the intervallic order: tone–tone–semitone–tone–tone–tone–semitone.

Called major because of the large (or major) third that separates the first and third pitches, this scale differs from the minor scale mainly in that the latter contains a small (or minor) third in this location. Since three variants of the minor scale are recognized in the music of the Western repertoire, it is important to note that they share this small interval between their first and third pitches.

Scales and modes

Major and minor scales formed the primary pitch ingredients of music written between 1650 and 1900, although this is a sweeping generalization for which exceptions are not rare. Other scales, called modes, possess greater representational power for music of earlier times and for much of the repertoire of Western folk music. These too are heptatonic patterns, their uniqueness produced solely by the differing pitch relationships formed by their members. Each of the modes can most easily be reproduced by playing successive white keys at the piano.

The modes and the major and minor scales best represent the pitch structure of Western music, though they do not utilize the total complement of 12 chromatic pitches per octave. They are abstractions that are meaningful for tonal music; *i.e.*, music in which a particular pitch acts as a focal point of perception, establishing a sense of repose or tonality to which the remaining six pitches relate. Major and minor scale tonality was basic to Western music until it began to disintegrate in the art music of the late 19th century. It was replaced in part by the methods of Arnold Schoenberg (1874–1951), which used all 12 notes as basic material. Since that revolution of the early 1920s, the raw pitch materials of Western music have frequently been drawn from the complete chromatic potential. By contrast, the music of several Eastern cultures, a number of children's songs, and occasional Western folk songs incorporate pitch materials best classified as *pentatonic* (a five-pitch scale).

SOUND PRODUCTION OF MUSICAL INSTRUMENTS

Classification of musical instruments

Excluding electronic tone synthesizers, which employ vacuum tubes or transistors to produce tones, musical instruments can be classified within three groups: (1) chordophones, or strings; (2) aerophones, or winds; and (3) idiophones and membranophones, nearly all of which are percussion instruments. Each category is further divisible into groups according to the way the vibrating medium is set into motion.

Chordophones. Three means of eliciting sounds determine three categories within the family of chordophones. They are bowing, plucking, and striking. Most common of the first category are the violin, viola, violoncello, and double bass of the orchestra, all of which use a horsehair bow for setting their strings into motion. Essentially a resonant box bearing strings of four different fundamental frequencies, members of this group have not changed appreciably in construction since the 17th century, except for the 20th-century advent of the electrified bass, which is in fact a close cousin of the amplified guitar.

Violins and the larger members of its group are sounded by plucking (pizzicato) on occasion, which provides a brittle tone of extremely brief duration. The harp is the best known orchestral instrument whose tone depends upon the noise components added by plucking. Other plucked instruments are the guitar, banjo, mandolin, ukelele, zither, lyre, lute, and the harpsichord. The latter differs from the piano in that its strings are actuated by the plucking action of a tiny plectrum.

The piano is most notable of the struck stringed instruments, employing a hammer mechanism linked with the keyboard for producing its wide range of sounds. Other instruments of this group are the clavichord and the dulcimer.

For all chordophones pitch is proportional to string tension and inversely proportional to length, thickness, and density. Since string length is the most readily altered of these factors, all chordophones provide a means for altering the resonating length of strings (as with the violin and guitar) or a set of many string lengths and masses (as with the piano and harp) for producing a variety of pitches.

Aerophones. This category covers everything from the piccolo to the pipe organ and is best understood by consistent reference to the nature of the air column employed in the various types of instruments, as well as the way this air column is set into motion.

Brass instruments consist of a long tube whose cross section is proportionately small. Coupled with a mouthpiece that, in response to vibrations of the performer's lips, helps to create eddies of air pressure that set an enclosed air column into motion, these instruments produce a range of pitches corresponding to the overtone series. The bugle is a primitive kind of brass instrument in that it is limited to only one overtone series, while the modern trumpet, cornet, French horn, trombone, tuba, flügelhorn, and various kinds of euphoniums utilize valves or a slide to lengthen the air column and thus provide up to seven different overtone series. Pitch on these instruments is primarily a function of tube length, the wavelength of the instrument's fundamental pitch equal to twice the length of the tube, plus a so-called end correction that accommodates variations of bore. Timbre is a product of mouthpiece shape,

bore (whether cylindrical or conical), and material, aside from the important role performed by the player himself in obtaining desired overtones.

Woodwinds prior to the 20th century were made for the most part of wood. Today the flutes and clarinets are classified in this group only because of this heritage, while the saxophones, always built of metal, share only the reed mouthpiece and similar fingering technique with the clarinet. All are, nonetheless, called woodwinds, and they consist of an air column set into motion by one of two means: (1) through high pressure eddies produced by the wind of the performer blown directly into the instrument (as with a recorder or whistle) or over it (as with the flute and piccolo), or (2) by means of a vibrating reed that is set into motion by air pressure from the performer. The clarinets and saxophones utilize a single reed fixed at one end, while the oboe, English horn, and bassoon use two thin reeds that are connected laterally and vibrate jointly. For all of these instruments, either keys or the fingers of the performer directly open holes, with the effect of shortening the enclosed air column of the instrument and thereby producing higher fundamental pitches. Through overblowing and various fingering procedures, the overtone series provides the wealth of pitches available on these instruments.

Free reed instruments utilize a single, freely vibrating reed, different in nature from that of a woodwind. The category includes the accordion, harmonica, and harmonium and their relatives. In these instruments the reed vibrates, causing periodic vibrations in the air; but the reed's size, rather than the air enclosed by the instrument, determines the pitch.

Pipe organs are of the aerophone (wind) category, too, although their keyboard mechanism and literature link them closely with the piano and harpsichord. Like a grand synthesis of woodwinds and brasses, organs produce their tones by means of tuned air columns that are formed with pipes of varied length, cross section, and shape (called flue pipes) or by means of a vibrating brass reed actuated by forced air (called reed pipes). Flue pipes range in length from under an inch to 32 feet.

Idiophones and membranophones. Idiophones are instruments whose bodies vibrate to produce sound. The class contains most of the pitched percussion instruments. These include instruments made of wood or other organic material, such as xylophones. They also include pitched percussion instruments that are struck or plucked and are made of metal or other inorganic material (triangle, glockenspiel, vibraphone, celesta, tubular bell, gong, steel drum, cymbal, glass harmonica, etc.). Idiophones without pitch consist of such instruments as the percussion board, castanets, and rattles, all of which are made of wood or other organic material and are struck, scraped, rubbed, brushed, or shaken.

Membranophones produce sound by a vibrating membrane. The group consists most notably of the timpani, or kettledrums, which can be tuned by increasing or decreasing the tension of the membranes that form the heads of the enclosed cavities. Other membranophones consist of drums without fixed pitch, such as side drums, bongos, and various non-Western types of fixed and indefinite pitch. Tone quality and character are the result of the player's skill in controlling intensity and overtone character of the sound.

(W.E.T.)

TUNING AND TEMPERAMENT

Musical sound largely depends on the organization of pitch, the high or low quality of sound; and the determination of acceptable pitch plays a large part in both the theory and practice of music. The adjustment of one sound source—such as a voice, a string, or a column of air enclosed in a wind instrument—to produce a desired pitch in relation to a given pitch is called tuning. Two concepts fundamental to the theory of tuning are those of frequency ratio and of consonance and dissonance. A given musical pitch is determined by the frequency of vibration of the sound wave that produces it, as $a' = 440$ cycles per second. An interval, or distance between two pitches, can thus be mathematically described as the ratio of the frequency of the first pitch to the frequency of the second. Various frequency ratios can be reduced to the same basic relationship; for example, 440:220 and 30:15 and 750:375 can all be reduced to the ratio 2:1.

Consonance and dissonance

When two tones are sounded together the subjective reaction may be anything from one of perfect consonance to one of extreme dissonance. Dissonance is produced by beats (interference between pulsations of sound waves), and it is found that maximum dissonance occurs when the rate of beats between the two tones is about 33 per second. Consonance results from the absence of beats, which occurs only when the ratio between the frequencies of the two tones is numerically simple. When the two tones are tuned to the same pitch, they are said to be in unison (ratio 1:1) and their consonance is absolute. Next in order of consonance comes the octave (2:1), the interval between c and c′ (encompassing eight notes of the piano keyboard); another highly consonant interval is the fifth (3:2, as from c to g). When a unison, octave, or fifth is slightly mistuned, the resulting combination is markedly dissonant and is judged "out of tune." The slight mistunings that occur in systems of tempered tuning are necessary for reasons that will be discussed later in this article.

The problems of tuning. So long as music consists of melody without harmony, consonance plays little part in the determination of successive pitches in a scale. Many primitive scales are sung, not played, and are variable in the exact pitches of their notes. When instruments are made, it is often necessary to determine precise pitches. The tendency is either to make the steps in the scale sound equal in size or to place them in simple arithmetic relationship to one another. The fundamental unit is the octave, which has the unique property that its two notes are felt in some indefinable way to be the same, though in pitch level they are recognizably different. For this reason, high and low voices naturally sing the same tune an octave apart. In nearly all musical cultures the octave is subdivided into a number of steps, each a simple fraction of an octave. In the diatonic, or seven-note scale, for example, which is the basis of Western music and is represented by the white notes on the piano keyboard, there are five steps of one-sixth of an octave and two of one-twelfth. In contrast to these uncomplicated fractions, the frequency ratios of these intervals are actually the irrational numbers: $\sqrt[6]{2}$:1 and $\sqrt[12]{2}$:1. As has been noted, consonance is related to simple frequency ratios such as 2:1. Consequently, the arithmetic subdivision of the octave can never produce perfectly consonant intervals. This unavoidable fact underlies many of the problems in the history of tuning. Insignificant when notes are heard melodically, it becomes highly important when notes of different pitch are heard simultaneously. The complex development of harmony has been the most striking peculiarity of Western music, and it has brought with it a host of tuning problems.

Conflict of scale and consonance

Apart from the octave, which presents no problem, there are really only three distinct intervals in the diatonic scale the consonance of which is important. These are the fifth (3:2, as C–G), the major third (5:4, as C–E), and the major sixth (5:3, as C–A). The other three consonant intervals are the fourth (4:3, as C–F), the minor sixth (8:5, as C–Ab), and the minor third (6:5, as C–Eb). The intervals of this second group are not truly distinct, for they can be derived from the first three by inversion—*i.e.*, by transposing the lower note of the interval up an octave. Thus, inverting the fifth c–g yields the fourth g–c′. Inverting the major third c–e yields the minor sixth e–c′, and inverting the major sixth c–a yields the minor third a–c′. Because of the phenomenon of inversion, if the fifths in a scale are in tune, the fourths also will be in tune. For each of these six intervals the tuning expressed by the above simple frequency ratios sounds "right"; if modified slightly in either direction it sounds seriously out of tune. The same cannot be said of other intervals of the diatonic scale. The major and minor seventh (as c–b and d–c′) and the diminished fifth (as b–f′), with their inversions, sound dissonant in any case; they have no one tuning that is clearly more acceptable than another. Hence the harmonic merits of any tuning system depend on the way fifths, major thirds, and

Inversion of intervals

Table 1: Melodic Comparison of the Four Principal Tuning Systems*

		diatonic scale				chromatic scale			
		Pythagorean tuning	"just intonation"	mean-tone temperament	equal temperament	Pythagorean tuning	"just intonation"	mean-tone temperament	equal temperament
	C								
semitone		90	112	117	100	90	112	117	100
whole tone	B	204	204	193	200				
	B♭					114	92	76	100
whole tone	A	204	182	193	200				
	A					90	90	117	100
whole tone	G	204	204	193	200				
	G♯					114	92	76	100
semitone	F	90	112	117	100				
	G					90	112	117	100
whole tone	E	204	182	193	200				
	F♯					114	92	76	100
whole tone	D	204	204	193	200				
	F					90	112	117	100
	E					114	92	76	100
	E♭					90	90	117	100
	D					90	112	117	100
	C♯					114	92	76	100
	C								

semitones

*The sizes of successive steps in the diatonic and chromatic scales are shown for each of the four systems, in cents. Black notes of the chromatic scale are indicated by bold lines.

major sixths are tuned. In the diatonic scale (indefinitely extended through several octaves) there are six perfect fifths (F–C, C–G, G–D, D–A, A–E, E–B), three major thirds (F–A, C–E, G–B), and four major sixths (F–D, C–A, G–E, D–B). It is impossible to tune the seven notes of the scale so that each of these 13 intervals is maximally consonant. This is the second inescapable obstacle to perfection in the tuning of the diatonic scale.

The Pythagorean system

Classic tuning systems. Of the two ancient Greek systems that were used chiefly in the Middle Ages, one, Pythagorean tuning, makes all the fifths perfectly consonant. As a result, all the major thirds and major sixths are sharp (too wide) by 22 cents (a cent is 1/1200 of an octave) or by the ratio of 81:80. This amount is called a comma of Didymus, and it makes intervals severely dissonant when their notes are sounded simultaneously. Within the gamut, the pitch range in use during the Middle Ages, a major third or sixth mistuned by a comma beats between 6 and 32 times a second. Melodically, the Pythagorean system is satisfactory. (Table 1 compares whole tone and semitone sizes in the four main tuning systems.) Pythagorean tuning makes all five whole tones (the larger steps in the diatonic scale) equal at 9:8 (204 cents), and the two semitones (the smaller steps) equal at 256:243 (90 cents). The semitones are considerably less than half the whole tones in size, but this is not particularly objectionable in a melody.

Just intonation

Ptolemaic tuning, often misleadingly named just intonation, sacrifices one of the fifths (D–A), which is altered to 40:27 from the simpler ratio 3:2, making it flat (too narrow) by a comma. The advantage of this system is that all the major thirds are true, or "in tune," as are all the major sixths except F–D, which is tuned to the ratio 27:16, as in the Pythagorean tuning (instead of to 5:3). The triad D–F–A is quite unusable, although the other triads used are perfectly in tune. (A triad is a chord built of two thirds.) For melody the system has the drawback of employing two different sizes of whole tones: C–D, F–G, and A–B are major tones (9:8, or 204 cents), and D–E and G–A are minor tones (10:9, or 182 cents). The difference is noticeable without being great enough to suggest that they are two purposely distinct intervals. To sing the first phrase of "Three Blind Mice" with the middle note perceptibly too high can hardly have seemed satisfactory at any period.

Although just intonation occupied the attention of many theorists, its disadvantages are so great that it is doubtful whether the system was ever strictly applied to harmonized music. Some kind of temperament may have been practiced empirically long before it was described in writing. The addition over several centuries of the five chromatic notes (the black notes of the piano), giving the full chromatic scale, certainly does nothing to improve either the Pythagorean or the Ptolemaic tuning (see Table 2, which shows the deviation of the four main tuning systems from the ideal tuning of the principal intervals). To either system the use of the chromatic notes adds more true fifths but also more untrue thirds and sixths. The advantages of just intonation over Pythagorean tuning are experienced only

Table 2: Harmonic Comparison of the Four Principal Tuning Systems*

	diatonic scale						added black notes					enharmonic intervals			
Perfect fifths	F-C	C-G	G-D	D-A	A-E	E-B	E♭-B♭	B♭-F	B-F♯	F♯-C♯	C♯-G♯	G♯-E♭			
Pythagorean tuning	0	0	0	0	0	0	0	0	0	0	0	−24			
"just intonation"	0	0	0	−22	0	0	0	0	0	0	0	−2			
mean-tone temperament	−5	−5	−5	−5	−5	−5	−5	−5	−5	−5	−5	+35			
equal temperament	−2	−2	−2	−2	−2	−2	−2	−2	−2	−2	−2	−2			
Major thirds	F-A	C-E	G-B				E♭-G	B♭-D	D-F♯	A-C♯	E-G♯	B-E♭	F♯-B♭	C♯-F	G♯-C
Pythagorean tuning	+22	+22	+22				+22	+22	+22	+22	+22	−2	−2	−2	−2
"just intonation"	0	0	0				+22	+22	+22	+22	+22	+20	+20	+20	+20
mean-tone temperament	0	0	0				0	0	0	0	0	+42	+42	+42	+42
equal temperament	+14	+14	+14				+14	+14	+14	+14	+14	+14	+14	+14	+14
Major sixths	F-D	C-A	G-E	D-B			E♭-C	B♭-G	A-F♯	E-C♯	B-G♯	F♯-E♭	C♯-B♭	G♯-F	
Pythagorean tuning	+22	+22	+22	+22			+22	+22	+22	+22	+22	−2	−2	−2	
"just intonation"	+22	0	0	0			+22	+22	+22	+22	+22	+20	+20	+20	
mean-tone temperament	+6	+6	+6	+6			+6	+6	+6	+6	+6	+49	+49	+49	
equal temperament	+16	+16	+16	+16			+16	+16	+16	+16	+16	+16	+16	+16	

*The tuning of each of the three basic intervals is analyzed for each system. Deviations from the "true" intervals are given in cents. 100 cents = 1 equal-tempered semitone. The sizes of the "true" intervals are as follows: perfect fifth, 702 cents; major third, 386 cents; major sixth, 884 cents.

in chords made up of white notes. With the development of harmony and the increased use of chromatic notes, both tuning systems became increasingly unsatisfactory.

Temperament. The first mention of temperament is found in 1496 in the treatise *Practica musica* by the Italian theorist Franchino Gafori, who stated that organists flatten fifths by a small, indefinite amount. This practice tends to spread out the mistuning of the fifth D–A over several fifths, so that all are tolerable although none is perfect. This principle was systematized as mean-tone temperament, first described in 1523. Under this scheme, all the major thirds of the scale are made perfect (*i.e.*, are tuned in the simple ratio 5:4); it results in an imperfection in the tuning of fifths that is spread out evenly over the entire cycle. Specifically, the interval of two octaves and a major third is tuned perfectly and divided into four fifths (C–G–d–a–e′), each of which has the ratio $\sqrt[4]{5}$:1 (compared to 3:2 for a perfectly tuned fifth). The fifths are flat by a quarter of a comma, which is much less dissonant than a comma: it gives a beat rate of 0.9 to 4 per second for fifths that fall within the compass of the medieval gamut. All major sixths are sharp by the same amount. Melodically, the scale resulting from mean-tone temperament is superior to the Ptolemaic (just intonation) scale, for all the whole tones are equal in size, being exactly half a true major third, or 193 cents. This is the source of the system's name: the mean, or average, whole tone. The semitones of the diatonic scale are relatively large, at 117 cents.

Mean-tone temperament

Mean-tone temperament, which was specifically designed for keyboard instruments, was an acceptable compromise so long as the black notes used in a composition did not extend beyond E♭ and G♯. As soon as D♯ was needed as well as E♭, the system collapsed. The keyboard provided only one key for E♭ and D♯. This key was tuned as E♭ and with no reference to the G♯ below it. The enharmonic fifth G♯–E♭ (in which E♭ is treated as equal to D♯) is nearly two commas out of tune in the mean-tone system. Worse even than the mistuned fifth of just intonation, it was often given the name "the wolf." Organs were occasionally built with split black keys so that E♭ and D♯ could be differently tuned and also A♭ and G♯. This expedient slightly extended the range of usable harmonies, but a more drastic remedy was soon needed. By spreading out the mistuning of the "wolf" fifth among its neighbours, in the same way that their predecessors had spread out the mistuning of the fifth D–A, musicians of the 17th century moved imperceptibly away from mean-tone temperament, in which the fifths are tuned unequally, toward the system of equal temperament, in which all fifths are equally flat.

Equal-tempered tuning

In equal temperament, all intervals are made up of semitone units, each of which is set exactly at a 12th of an octave, or 100 cents. A fifth is built of seven semitones; in relation to a pure fifth, it is 2 cents flat. A major third is four semitones and is 14 cents sharp; a major sixth is nine semitones and is 16 cents sharp. Because in equal temperament the intervals are identical in all parts of the chromatic scale, the system is the only one that can accommodate the expanded range of harmonies of 19th- and 20th-century music. Melodically, it fulfills the ideal of equal steps. The price for these great advantages is the total disappearance of perfectly tuned intervals, save only the octave. For the piano and the harpsichord this is scarcely a drawback: the characteristic tone of these instruments is, in any case, rich in dissonant components. Indeed, it has been found that piano tuners systematically set octaves and even unison strings out of tune. But on the organ, with its purer and more sustained tone, the disadvantages of equal temperament are considered by many to outweigh its blessings. In England such musicians as the organist and composer Samuel Sebastian Wesley continued to oppose it even as late as the mid-19th century.

On fretted instruments—such as lutes, guitars, and viols—the frets extend across the fingerboard, producing at any one point divisions of equal lengths on strings of different pitch. Unless equal temperament is used, the positioning of the frets results in mistuned octaves and unisons when the same note is played on different strings. For this reason equal temperament was applied at least as early as the 16th century in the construction of fretted instruments.

It has often been stated that singers and players on instruments of undetermined tuning, such as violins and trombones, naturally use just intonation when performing together. Experimental evidence does not support this theory. In such circumstances musicians tend either to play in equal temperament, or, if anything, to distort intervals away from perfect consonance. Most probably this is the result of generations of conditioning. Moreover, it has been found that few musicians can distinguish melodically between just intonation and equal temperament and that those who can do so prefer the latter.

Tuning and musical history. It is seldom realized what an important effect tuning practices have had on the development of harmony and tonality. From the 10th to the 13th century thirds and sixths—now considered consonant—were treated as dissonances simply because, according to then-current tuning methods, they *were* dissonances. In Pythagorean tuning, only the bare fifth and octave could provide a tolerable point of repose in music accompanied by the organ. Although just intonation permitted some harmony based on triads, the use of sharpened leading notes (the last note of the scale, leading upward into the first), which by the 16th century had caused the older system of modes to disintegrate, was made acceptable only by the use of some kind of temperament. At a later date it was the existence of lutes tuned in equal temperament that made possible the more extreme experiments in chromaticism of composers such as Luca Marenzio and Don Carlo Gesualdo. The formation of a unified orchestra was probably delayed by the simultaneous practice of two incompatible tuning systems—mean-tone for keyboard instruments, equal temperament for lutes and viols. The decline of viols and their replacement by the violin family may have been hastened by the inability of viols to play with the organ. The modern orchestra began with the Vingt-quatre Violons du Roi (Twenty-four Violins of the King) of Louis XIV, and most later Baroque music is based on a keyboard instrument with from one to 30 members of the violin family playing in mean-tone temperament. The cycle of six related keys, established in the operas of Alessandro Scarlatti and the sonatas of Arcangelo Corelli and followed closely in most of the music of J.S. Bach and George Frideric Handel, is probably a direct outcome of mean-tone temperament. Within the limits of mean-tone temperament, the six keys exhaust the chromatic compass available. On the other hand, "wolf" chords may have been deliberately introduced by Domenico Scarlatti, François Couperin, and other composers to give an added piquancy to certain harpsichord passages. Many harpsichord players, including Bach, would retune a few notes of their instruments to prepare to play a piece in a new key, shifting the "wolf" fifth to part of the scale where it would do no harm. But in organ works such temporary retuning was hardly possible. Bach's organ tuning must have been as close to equal temperament as modern instruments are, although it is known that he was opposed to a strictly mathematical equality of intervals. By his title *Well-Tempered Clavier* he probably meant a kind of modified mean-tone temperament.

Enharmonic modulation, in which one note (say B♭) is treated as identical to another (say A♯) that actually has the same pitch only in equal temperament, was an exceptional device in Baroque music. But as orchestras became free of keyboard instruments and as keyboard instruments increasingly adopted equal temperament, it became a normal stock-in-trade, allowing the use of a series of key changes in one direction that eventually returns to the original key. Thus, it is not unusual for Mozart to complete the cycle of 12 keys in the course of a movement. Equal temperament permitted 19th-century composers to use the 12 notes of the chromatic scale with the utmost freedom. It also fixed those 12 notes so immutably in the Western musical consciousness that the revolutionary developments of 20th-century music, far from undermining them, have tended to perpetuate them.

Enharmonic modulation

(N.T.)

Elements of musical composition

At its most fundamental level the act of composition involves the ordering of pitched sounds in musical time and space. Pitch relationships are referred to as intervals; their specific occurrence in musical time is determined by rhythm, a concept that embraces all durational aspects of music. Rhythm in turn may or may not be regulated by metre. In metrically organized rhythm, recurring patterns of accented and unaccented "beats" furnish a durational substructure that necessarily affects all the other elements of composition, including the nature of melody, harmony, and texture. Metrical rhythm is nearly always present in dance music because its patterning is largely analogous to that of bodily motions and step figurations. But logogenic, or word-determined, music also often employs metrical patterns, corresponding as a rule to those of the poetic text. The first large corpus of logogenic compositions transmitted through the ages is that of medieval plainchant, consisting of monophonic settings (limited to a single melodic line) of liturgical texts for the entire year, based on a system of eight church modes, diatonic scales abstracted from the melodic motives utilized by medieval singers. Modality—whether referring to a melodic or a rhythmic framework—furnishes compositional frames of reference in a wide variety of essentially monophonic musical styles, especially in Asia. Asian influences upon early European music cannot be ruled out, whether by way of ancient Judaea, Greece, Byzantium, or the medieval Arab invasions. But unlike their Asian counterparts, Europeans at first limited modality to melody, through pitch arrangements. The rhythmic properties of plainchant have largely remained a matter of conjecture, for no systematic discussion of plainchant rhythm survives, and the notation used was noncommittal with respect to rhythm. By the same token, plainchant no doubt owed much of its amazing vitality to the absence of an all-encompassing notation, which made possible the flexibility of performance and regional variation inherent in a partly written, partly oral tradition.

Music like medieval plainchant, in which the lengths of individual tones tend to be rather uniform, is often referred to as nonrhythmic or rhythmless. Such careless terminology denies the very essence of music as a temporal art, which implies by definition the omnipresence of rhythm as "order in musical time." Actually, the relative presence or lack of rhythmic differentiation in the duration of tones can act as a decisive stylistic determinant. Thus the rhythmic equanimity of the monophonic plainchant, at least in the interpretation set forth by the 19th-century Benedictine monks of Solesmes, France, and recognized as authoritative by the Roman Catholic Church, effectively symbolizes an atmosphere of faith and inner peace. By contrast, the strictly metrical organization of rhythm in most 18th-century music reflects the thinking of an age of reason, favouring mathematically definable, hence "natural," structures in its music.

The smallest melodic-rhythmic unit (minimally two separately perceived sounds) is the motive. Pitched sounds are, however, not of the essence: drum motives are so effective rhythmically precisely because they lack pitch definition. By and large, rhythmic motives are used to endow pitch relationships with identifiable durational characteristics. And consequently rhythmic identity often serves to establish motive connections between different intervals. A famous case in point is the opening short–short–short–long motif of Beethoven's *Symphony No. 5 in C Minor*, Opus 67, which serves as an effective element of structural cohesion in this large-scale work.

Types of melody owe their aesthetic associations in many instances to their motivic peculiarities. In Western music motivic contrast has been identified with emotional conflict since at least the mid-16th century, when composers of madrigals (Italian polyphonic secular songs) began to set dramatic texts. The opening of Mozart's *Symphony No. 35 in D Major*, K 385 (the *Haffner Symphony*), offers an excellent example. Analogous in its motivic structure to a section of the first act of Mozart's opera *Don Giovanni*, the opening of the symphony engenders emotional contrasts similar to those inherent in the opera's dramatic action when Donna Anna, under the double impact of attempted rape and her father's violent death at the Don's hands, impulsively rejects Don Ottavio's sympathy until, realizing that she has no one else to rely on for help, she reverses herself and induces him to swear revenge. Conversely, melodic lyricism correlates with a high degree of motive affinity.

This section will examine the process of musical composition in the Western tradition from its basic elements to its history as an art.

RHYTHM

In its most general sense rhythm (Greek *rhythmos*, derived from *rhein*, "to flow") is an ordered alternation of contrasting elements. The notion of rhythm occurs in music and in other arts (*e.g.*, poetry, painting, sculpture, and architecture) as well as in nature (*e.g.*, biological rhythms).

Attempts to define rhythm in music have produced much disagreement, partly because rhythm has often been identified with one or more of its constituent, but not wholly separate, elements, such as accent, metre, and tempo. As in the closely related subjects of verse and metre, opinions differ widely, at least among poets and linguists, on the nature and movement of rhythm. Theories requiring "periodicity" as the *sine qua non* of rhythm are opposed by theories that include in it even nonrecurrent configurations of movement, as in prose or plainchant.

Elements of rhythm. Unlike a painting or a piece of sculpture, which are compositions in space, a musical work is a composition dependent upon time. Rhythm is music's pattern in time. Whatever other elements a given piece of music may have (*e.g.*, patterns in pitch or timbre), rhythm is the one indispensable element of all music. Rhythm can exist without melody, as in the drumbeats of primitive music, but melody cannot exist without rhythm. In music that has both harmony and melody, the rhythmic structure cannot be separated from them. Plato's observation that rhythm is "an order of movement" provides a convenient analytical starting point.

Beat. The unit division of musical time is called a beat. Just as one is aware of the body's steady pulse, or heartbeat, so in composing, performing, or listening to music one is aware of a periodic succession of beats.

Tempo. The pace of the fundamental beat is called tempo (Italian "time"). The expressions slow tempo and quick tempo suggest the existence of a tempo that is neither slow nor fast. his "moderate" tempo is often assumed to be that of a natural walking pace (76 to 80 paces per minute) or of a heartbeat (72 per minute). The tempo of a piece of music indicated by a composer is, however, neither absolute nor final. In performance it is likely to vary according to the performer's interpretative ideas or to such considerations as the size and reverberation of the hall, the size of the ensemble, and, to a lesser extent, the sonority of the instruments. A change within such limits does not affect the rhythmic structure of a work.

Rubato. The tempo of a work is never inflexibly mathematical. It is impossible to adhere in a musical manner to the metronomic beat for any length of time. In a loosely knit passage a tautening of tempo may be required; in a crowded passage a slackening may be needed. Such modifications of tempo, known as *tempo rubato*—*i.e.*, "robbed time"—are part of the music's character. Rubato needs the framework of an inflexible beat from which it can depart and to which it must return.

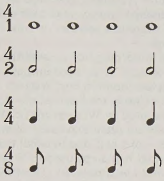
Time. The mind apparently seeks some organizing principle in the perception of music, and if a grouping of sounds is not objectively present it imposes one of its own. Experiments show that the mind instinctively groups regular and identical sounds into twos and threes, stressing every second or third beat, and thus creates from an otherwise monotonous series a succession of strong and weak beats.

In music such grouping is achieved by actual stress; *i.e.*, by periodically making one note stronger than the others. When the stress occurs at regular intervals, the beats fall into natural time measures. Although in European music the concept of time measures reaches back to a remote

age, only since the 15th century have they been indicated by means of bar lines. Thus, the terms measure and bar are often used interchangeably.

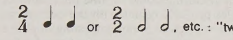
Time signatures

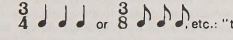
The time measure is indicated at the opening of a piece by a time signature; *e.g.*, $\frac{2}{4}$, $\frac{4}{4}$, $\frac{3}{4}$, $\frac{9}{8}$. The length of each beat in a measure may be a time unit of short or long duration:



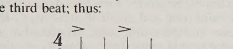
The signature $\frac{4}{1}$ (above) means that the whole note (1) is the unit in each measure, and there are four (4) of them to each measure. In the second illustration, $\frac{4}{2}$, the half note (2) is the unit of measurement, with four of them (4) to each measure, etc.

The two basic types of time measure have either two or three beats and admit of many different notations.

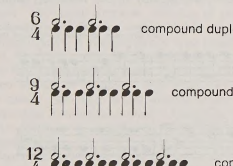




"Four time," or "common time," is really a species of duple time allied to "two time," as it can hardly be thought of without a subsidiary stress at the half measure; *i.e.*, on the third beat; thus:



Duple, triple, and quadruple time measures—*i.e.*, those in which there are two, three, and four beats to a measure—are known as simple time. The division of each of the component beats into three produces compound time:



More complex times, such as the quintuple, $\frac{5}{4}$, usually fall into groups of 3 + 2, as in "Mars" from Gustav Holst's suite *The Planets* and in the second movement of Tchaikovsky's *Sixth Symphony.* Rimsky-Korsakov, in *Sadko,* and Stravinsky, in *Le Sacre du printemps,* use 11 as a unit. Ravel's piano trio opens with a signature of $\frac{5}{8}$ with the internal organization 3 + 2 + 3. Folk song and folk dance, particularly from eastern Europe, influenced the use of asymmetrical time measures, as in the "Bulgarian Rhythm" pieces in $\frac{7}{8}$ and $\frac{5}{8}$ in Bartók's *Mikrokosmos.*

Prosody applied to music

Metre. The combinations of long (—) and short (∪) syllables are known in prosody as feet. The system of notating the musical equivalents of feet derives from the application of prosody to music. The foundations for European music were laid in ancient Greece, where classical music and poetry were regarded as parts of a single art. These principles were adopted by the Romans and were transmitted, by way of Latin poetry, to medieval Europe. The feet of classical poetry and their equivalents in music are shown in Table 3. And in late antiquity St. Augustine (354–430), in *De musica,* added more.

Table 3: Classical Poetic Metre

	metrical foot	poetic syllables	musical notation	groups of beats	equivalent time signatures
duple	dactyl	— ∪ ∪		2 + 2	$\frac{2}{4}$
	anapest	∪ ∪ —		2 + 2	$\frac{2}{4}$
triple	trochee	— ∪		2 + 1	$\frac{3}{8}$
	iamb	∪ —		1 + 2	$\frac{3}{8}$

Rhythmic metre. Until the 12th century, church music was virtually limited to unadorned plainchant. The early composers found that polyphony required a rhythmical organization to keep the parts together; so rhythmic metre was adopted (see Table 4). Compared with a hypothetical flow of beats equal in stress, metre adds significance to what was merely a forward flow in time—though the continuation of a metrical pattern may itself become monotonous. Thus, metre, though "rhythmic" by comparison with pulse, is not the whole of rhythm. The 13th-century musicians often varied the rhythmic modes by combining several of them simultaneously in different parts of polyphonic composition.

Table 4: Classification of Rhythmic Metre

poetry	metrical foot	musical notation
— ∪	trochee	
∪ —	iamb	
— ∪ ∪	dactyl	
∪ ∪ —	anapest	
— —	spondee	
∪ ∪ ∪	tribrach	

Polyphonic metre. Theoretically, metre appears to be without stress accent, and certainly much polyphonic music of a later period, such as the masses of Palestrina, has an almost stressless flow. Yet these works reveal a subtle rhythmical organization. At a later period metre and time measure cannot be wholly separated. In their "purest" forms they may be extremes, but in music predominantly of one type, the other element is rarely wholly absent, though on an instrument such as the organ, actual dynamic stress is impossible. After all, metres like the spondee, 𝅗𝅥 𝅗𝅥, and the dispondee, 𝅗𝅥. 𝅘𝅥𝅘𝅥, need an accent on the first beat to keep their identity. Notwithstanding the opposite tendencies of metrical organization and stress accent, however, some metre is obviously subject to stress, so that metre and time measure become very closely linked, as in the scherzo of Beethoven's *Ninth Symphony,* where a measure has a strong first beat and at the same time follows a metre.

Organic rhythm. In broad terms, the time framework of music is composed of tempo, time measure, metre, and period; and its rhythmical life hangs on rubato, musical motif (which may already include cross accent), and metrical variation, as well as on asymmetry and balance of phrase. Whereas the former are more or less measured and rational, the latter are organically inspired and numerically irrational—the very life of the music.

Rational and irrational features

Prose rhythms and plainsong. Rhythm is, therefore, not any one of these rational or formal features, nor is it composed solely of a combination of these factors. Yet rhythm requires the background of a rational framework in order that it may be fully perceived, but this framework need not embrace all the rational factors described above.

Thus plainchant, as it is known in modern times, makes no use at all of measure or of regular metre but is

supremely rhythmical in conception; its "free" rhythms are felt. Whereas so much music has for its framework a regular repetition of underlying accent, whether stress or durational, the framework of plainchant is irregular. Its rhythm belongs to the Latin tongue and springs from the correct accentuation of the text and the dynamic quality inherent in the word grouping.

Rhythm, melody, and harmony. Thus far, music's structure in time has been examined separately from its structure in tone, but no such separation is really possible. Melody and rhythm are intimately connected. Moreover, various styles of music tend to standardize their melodic cadences and, with them, their time divisions (*e.g.*, Mozart's melodic rhythm is much more regular than Prokofiev's).

In music employing harmony, the rhythmic structure is inseparable from harmonic considerations. The time pattern controlling the change of harmonies is called harmonic rhythm. In 17th- and 18th-century music, harmony tends to limit rhythmic subtleties and flexibility of the melodic elements (as well as determining the basic type of melody) in regard to stress accents. It is, therefore, no accident that the polyphonic music of Indonesia and Southeast Asia, like much European music, exhibits certain four-square melodic tendencies. By contrast, the music of India and the Perso-Arab world employs a melody instrument or voice performing in a given metre offset by a drum playing cross rhythms or (in the Arab world) a quite different metre; with no harmony (except a drone) to impede its flow, the rhythm can reach a structure of great subtlety and complexity.

Diversity from conceptual differences

Rhythm, structure, and style. In European music the great variety of styles derives its relation to melody from different concepts of rhythm. They include the strict rhythmic modes of the 13th century; the free oratorical speech-rhythms of the Renaissance; the almost stressless flow of Renaissance polyphony; the strong body rhythms of the Baroque; the freedom of the late Romantics; and the primitivistic rhythms of the 20th century with composite and ever changing time signatures.

Thus, study of musical history shows a varying attitude toward rhythm, sometimes closer to strict rule, sometimes to "freedom," as the temper of the times and the relative influence of poetry, dance, and folk music decree. Plato's definition of rhythm as "an order of movement" might, therefore, be expanded. As a determining factor in the vitality of music, rhythm may be described as "an inspired, organic order of movement," communicating intelligibly to the senses. From the analytical viewpoint, it operates in the rational framework described, which it varies in terms of rubato, motif, etc. Ultimately, rhythm is the organic process of music in time; it is music's direction in time. The quality of rhythm is the quality of life; however vitally the composer conceives his music, he must depend upon the performer to recreate it rhythmically. (P.C.-H.)

SCALE

A theoretical description of pitch relationships that exist in music is called a musical scale. The specific selection of different tones in any piece of music generally reveals a pattern of relationships among its pitches that can be expressed as a series of fixed distances (intervals) from one pitch to another within the span of an octave. The interval relationships among pitches of a scale are its essential feature, and a particular pattern of intervals defines every scale. Other aspects of pitch usage in music, such as range (distance from the highest pitch used to the lowest), emphasis placed on certain pitches, or the simultaneous (harmonic) and successive (melodic) occurrence of tones, do not alter the identity of the scale, although they may be essential in describing its function.

Although the number of different scales that can be formulated is theoretically nearly infinite, particular scales tend to become conventionalized within any given culture or musical tradition. The scale of a single piece of music may therefore be characteristic of the tone system of a whole culture. In general, the simplest scales can be found in very old music and in the music of nonliterate cultures, while the most complex scales occur in the world's most advanced cultures.

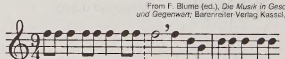
Scale and melody. Scales have proven to be important in the analysis of folk music and the music of nonliterate cultures, but scholars have been obliged to deduce the scales through a study of the actual music, since the creators of the music were not cognizant of scales as theoretical concepts. By contrast, music of the most highly developed cultures (variously described as classical music, art music, cultivated music, and high-culture music) is created in full awareness of rules or conventions pertaining to scale usage.

Non-explicit scales

In view of the wide range of possibilities, a surprisingly small number of scale types predominate throughout the world. The intervals found in non-Western music often approximate rather closely the basic whole-step and half-step intervals that are used in Western music. Variations from Western intervals are often expressed as measurements in cents (100 cents = one half step in equal temperament, the pattern of 12 equal half steps used in Western music; see above *Tuning and temperament*). The task of identifying scales in non-Western music is complicated further by the occasional appearance of highly variable intervals or by singing techniques that produce sounds whose pitches cannot be specified accurately through conventional notation, like the "tumbling strains" (falling melodies) described by musicologist Curt Sachs in the singing of Aboriginal Australians.

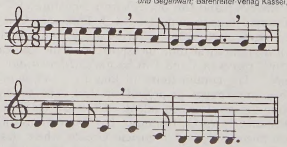
Although music performed only on one pitch does exist, the study of scales properly begins with the occurrence of at least two different pitches. Scales consisting of only one or two intervals (*i.e.*, two or three pitches) can be found throughout the world in monophonic music (that consisting of a single unharmonized melodic line), though they are perhaps most numerous in Ceylon, eastern Siberia, California Indian cultures, and in regions near the Ural Mountains. Such scales commonly display a narrow range in which the pitches are separated by a half step, a whole step, or a minor third (one and one-half steps, as, C–Eb). Larger skips in two- and three-note scales do occur but are less frequent. Some simple scales have probably acquired additional pitches through a tendency to fill in large skips with intervening pitches. Another process by which scales may have expanded is the transposition within a single melody of one characteristic melodic motive (identifiable fragment) to a different pitch level, thus creating additional scale degrees, as in the melody of the Makurap Indians shown below.

From F. Blume (ed.), *Die Musik in Geschichte und Gegenwart*; Bärenreiter-Verlag Kassel, Basel



Occasionally, primitive melodies apparently generated by motivic transposition also contain evidence of emphasis on particular pitches. As an example, the skips in the following Osage Indian melody are arranged so that the pitches G and C are consistently reiterated.

From F. Blume (ed.), *Die Musik in Geschichte und Gegenwart*; Bärenreiter-Verlag Kassel, Basel



The melodic "weight" given to those two pitches could not have been achieved by the simple transposition of motives. Further, weighted scales may also give prominence to certain pitches by using them as range limits or by placing a particular pitch at the ends of sections or the end of a piece.

Explicit scale systems

Scales function somewhat differently in the art-music traditions of highly sophisticated cultures, since they are not only a means of description and analysis but are also pre-existent assumptions for the composer or performer. Within those cultures, knowledge of the characteristics and requirements of various scales is often perpetuated by written treatises on music theory as well as by oral communication from generation to generation. The existence of professional composers and performers also encourages continuity in musical knowledge, even though some cultures, like those of the Western world, advocate continuous change in musical practices within acceptable limits. Through gradual evolutionary processes, the nature of scales and their functions may change radically over a period of several centuries.

Highly developed, complex systems governing the use of scales exist in a variety of cultures, principally in the Far East, India, Iran, the Muslim world, and the West. The differences in musical styles among those cultures are indeed great, yet there are some similarities in the manner in which scales function in each instance. Each culture has a number of basic scales (interval patterns), called *grāma* in India, *dastgah* in Iran, *maqām* in Muslim cultures. Generally, a basic scale is used to produce a number of different modes, or bases for melodic construction, in which the intervallic structure of the scale remains intact while primary and secondary melodic importance is attached to different pitch degrees (see below, *Mode*). This hierarchy in which modes are generated by basic scale types consequently produces a greater number of modes than there are basic scales. The terms *maqām* and *dastgah* also are used to refer to such modes; the corresponding Indian term is *jāti*. In some art-music traditions the modes serve as the basis for an even larger number of specific melody types, which may again be elaborated further by improvisation in performance. In India the basic melodies are called *rāgas*; in Iran they are *gusheh*. Although Western art music has a system of scales and modes, the melody types are not used as systematically or as consciously as they are in some of the non-Western traditions.

Common scale types. Pentatonic (five-note) scales are used more widely than any other scale formation. In fact, Western art music is one of the few traditions in which pentatonic scales do not predominate. Their frequency is especially notable in the Far East and in European folk music. The most common varieties of pentatonic scales use major seconds and minor thirds, with no half steps (anhemitonic). A representative type could be spelled C–D–E–G–A, for example. The pentatonic scale is so pervasive that melodies exhibiting tetratonic (four-note) scales often appear to be pentatonic with one pitch omitted. Hexatonic (six-note) scales appear rather rarely in folk music and nonliterate cultures. Examples that are known often seem to be fragments of the seven-note Western diatonic scale.

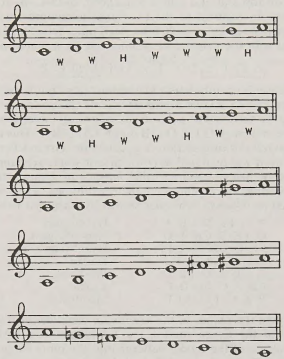
Heptatonic scales are especially prominent in the world's art-music traditions. The tone systems of India, Iran, and the West are entirely heptatonic, and seven-note scales are also present in the art music of some cultures that do not use such scales exclusively (*e.g.*, the *ritsu* scale in Japan and the *pelog* scale in Java).

The diatonic scale

With some exceptions in both the distant and the recent past, Western art music has been based largely on one heptatonic scale, known as the diatonic scale. The origins of this scale can be traced to ancient Greece, and it has been formulated to some extent according to acoustical principles. Since the octave in Western music is normally divided into 12 equal half steps, the characteristic intervals of the diatonic scale can be constructed upon any one of the 12 pitches. Such transpositions of the scale are known as keys.

Before the 17th century, as many as 12 different mode permutations of the diatonic scale were in common use (see below *Mode*), but only two modes—now called major and minor—have been in general use during most of the past 300 years. The diatonic scale itself consists of five whole steps (W) and two half steps (H), with the half steps dividing the whole steps into groups of two or three. The major scale uses the sequence W–W–H–W–W–W–H, as shown in the first of the following examples, while the intervals in the minor scale are W–H–W–W–H–W–W, as in the second.

In actual music the minor scale is usually altered in one of two ways to create greater emphasis on particular pitches. In the harmonic minor scale (the third example shown) the seventh note is raised one half step, and in the melodic minor scale (the fourth example) both the sixth and seventh notes are raised by one half step in ascending patterns while they are left unaltered in descending patterns (the fifth example).



Chromatic, whole-tone, and microtonal scales

In the 19th and 20th centuries, composers have made increasing use of pitches lying outside the diatonic scale, and that tendency has stimulated a variety of novel scale systems, developed as alternatives to the diatonic scale. Principles for composition within the chromatic scale (consisting of all of the 12 half steps within the octave) were first articulated by the Austrian-born composer Arnold Schoenberg early in the 20th century. Other scales have also been employed on an experimental basis. The whole-tone scale (comprising six whole steps) was used prominently by the French composer Claude Debussy and others, especially in France and England. Microtonal scales requiring intervals smaller than the conventional half step have also appeared sporadically in the 20th century. Among microtonal structures the most important, perhaps, have been scales calling for quarter tones (equal to half the distance of a half step).

Other uses of the term scale. The word scale is sometimes used to describe musical passages consisting of a succession of consecutive scale degrees in ascending or descending patterns. It is also used to describe scalelike exercises that are practiced for the development of technical proficiency on a musical instrument. "Scale" can refer in rare instances to the ordering of some musical element other than pitch. An example is the term *Klangfarbenmelodie* used in some recent music to denote a carefully arranged succession of different tone colours. (J.C.Gr.)

MODE

In musical theory and analysis, the word mode has been employed in a variety of more or less correlated meanings. Mode designates particular aspects of melodic construction; its meaning ranges from strictly defined scales whose identity stems from the position of given intervals (distances between notes) in the sequence of tones to broadly delineated melody types and constellations of motivic figures (brief, identifiable melodic fragments) that may serve as bases for improvised or written compositions.

Ancient Greek modes. The modes of Greek antiquity were placed by theorists in orderly fashion within a larger context. Although the modes were a series of seven-note diatonic scales (*i.e.*, containing five whole tones and two

semitones), the nucleus of the tone system was the tetrachord—a group of four consecutive notes (as, from C to F on the piano) comprising the interval of a fourth. Except in late antiquity, the notes were always arranged in a descending order, the basic tetrachord consisting of two whole tones and one semitone: E–D–C–B. Two such tetrachords, separated from one another by a whole tone, formed the so-called Greek Dorian mode: E–D–C–B A–G–F–E. The Dorian mode was taken as a basis for the construction of the larger system. Its single-octave range was extended by the addition of a third tetrachord, A–G–F–E, on top and of a fourth tetrachord, E–D–C–B, at the bottom. In contrast to the two inner tetrachords, which were separated by a whole tone, each outer tetrachord was linked with the neighbouring inner one by a shared note:

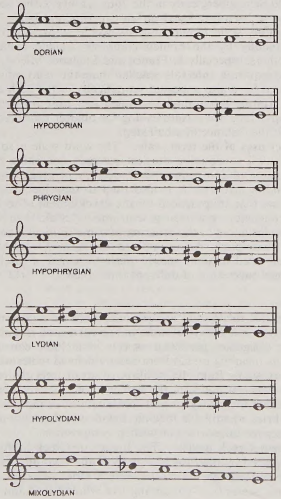
A G F E D C B A G F E D C B .

Because the combination of the four tetrachords yielded a range of two octaves minus one whole tone, a low A was added by theorists to achieve the following diatonic two-octave system: A G F E D C B A G F E D C B A. This two-octave row, or disdiapason, was called the Greater Perfect System. It was analyzed as consisting of seven overlapping scales, or octave species, called *harmoniai*, characterized by the different positions of their semitones. They were termed as follows (semitones shown by unspaced letters):

The Greater Perfect System

A G FE D CB A	Hypodorian
G FE D CB A G	Hypophrygian
FE D CB A G F	Hypolydian
E D CB A G FE	Dorian
D CB A G FE D	Phrygian
CB A G FE D C	Lydian
B A G FE D CB	Mixolydian

Although the names of the *harmoniai* were identical with those of the Greek modes, the *harmoniai* were instead projections of the modal patterns into the more extensive Greater Perfect System. The modes proper were termed *tonoi*, their essence being their interval pattern. On the kithara or *lyra* (the two basic plucked stringed instruments of ancient Greece) the *tonoi* were produced either by the basic tuning or by the raising or lowering of one or more of the strings by a semitone. Thus, the seven *tonoi* would sound within the octave E–E as follows (black notes indicate changes from the Dorian tuning):



Greek theory distinguished three different genera of tetrachords, producing an additional variety of modes. The previously described tetrachord (two descending whole tones plus one semitone) was called diatonic. There were also chromatic and enharmonic genera. The two tones bounding the tetrachord were fixed and always formed a perfect fourth; the two inner tones were movable. The chromatic tetrachord consisted of a minor third (encompassing 1½ whole tones) plus two semitones, the enharmonic tetrachord of a major third (encompassing two whole tones) plus two approximate quarter tones:



Also prominent in Greek music was the concept of ethos, which ascribed certain ethical characteristics to the different modes. The Dorian mode was preferred because of its strong and virile character; the Phrygian mode was ecstatic and emotional, the Lydian mode intimate and lascivious. In *The Republic* Plato stressed the educational values of the Dorian mode and warned against the softening influence of the Lydian ode.

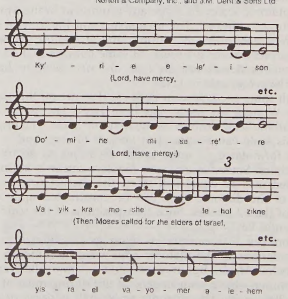
In early Greek antiquity a system of modal categories developed, referred to as *nomoi* (singular, *nomos*, "law"). The *nomoi* represented modes in that they were characterized by distinctive melodic formulas suited to different song types. The performers were free to improvise within the boundaries of these modal formulas.

Jewish and Eastern Christian chant. Ancient Hebrew music followed well-established modal patterns. According to Abraham Zevi Idelsohn, a musicologist whose comparative research conducted during the early decades of the 20th century established modern understanding of the Hebrew modes,

> A mode . . . is composed of a number of motives (*i.e.*, short music figures or groups of tones) within a certain scale. The motives have different functions. There are beginning and concluding motives, and motives of conjunctive and disjunctive [*i.e.*, convergent and divergent] character. The composer operates with the material of these traditional folk motives within a certain mode for his creations. His composition is nothing but his arrangement and combination of this limited number of motives. His "freedom" of creation consists further in embellishments and in modulations from one mode to the other.

The modal Hebrew music strongly influenced early Christian chant. This correlation can be illustrated by comparing a plainchant Kyrie, in the third mode, with a Babylonian Jewish melody for a phrase from Exodus:

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Syria played an important part in developing early Christian chant by integrating both Hellenistic and Hebrew

elements. The Syrians devised a musical system called *oktōēchos,* a term suggesting a classification into eight *ēchoi.* The Syrian *ēchoi* are modes, although there is no consensus on whether they represented modes in a specifically technical sense, comparable to the Greek *tonoi,* or melodic formulas, comparable to the Greek *nomoi.*

Byzantine chant molded the features of early Christianity with Hellenic and Oriental traits, including the Syrian *oktōēchos,* and achieved a brilliant and distinctive style that served as a prototype for the chant of the Greek Orthodox Church. The eight *ēchoi* of the Byzantine *oktōēchos* were divided into four authentic and four plagal (derived) forms. The most common classification of the Byzantine modes was in terms of typical initial and final notes of melodies in a given mode, with the characteristic distinctions as follows (the orderly progression of notes in each series should be observed).

	Ēchos	Initial Note	Terminal Note
Authentic	I	a′	a′ or d′
	II	b′ or g′	e′ or b′
	III	c″ or a′	f′ or c″
	IV	d″ or g′	g′ or d″
Plagal	I	d′ or g′	d′
	II	e′ or g′	e′
	III	f′ or a′	f′
	IV	g′, a′, or c″	g′

The above classification reflects only two of various characteristics (not all completely clarified by modern scholars) that gave the modes their identity.

Even before the foundation of the Byzantine Empire, Armenia adopted Christianity as a state religion (AD 303). Although the early Armenian chant did not survive, the arrangement of the hymns of the Armenian Church in the comprehensive collection, known as the *Sharakan,* indicates that Armenian chant used an *oktōēchos* classification the modal characteristics of which seem to have been defined by melodic formulas rather than by scalar distinctions.

Another variety of the *oktoëchos* occurs in Russian Church chant. Although a concept of eight *ēchoi* points to the Byzantine system, the Russian *ēchoi* show a different structure. The melodic motives characteristic of the *ēchoi* are called *popievki;* but similar *popievki* could be employed in more than one *ēchos.* The use of some *popievki* is limited to the beginning, the middle, or the end of a chant. Occasionally, two *popievki* are merged into a compound *popievka.*

Plainchant. Plainchant, or plainsong, is also known as Gregorian chant and forms the core of the musical repertoire of the Roman Catholic Church. It consists of about 3,000 melodies collected and organized during the reigns of several 6th- and 7th-century popes. Most instrumental in codifying these chants was Pope Gregory I.

Melodically, Gregorian chants are based on eight different modes, often called church modes. Seven of them were given names identical with those used in the musical theory of ancient Greece: Dorian, Hypodorian, Phrygian, Hypophrygian, Lydian, Hypolydian, and Mixolydian, while the name of the eighth mode, Hypomixolydian, was adapted from the Greek. Each mode comprises a diatonic scale with the compass of one octave. The modes are classified by their *finalis,* the usual final note of a melody in that mode. Each of the four notes of the tetrachord D–E–F–G serves as the *finalis* of an "authentic" mode (see chart below).

Structure of Gregorian modes

An authentic mode consists of a pentachord (a succession of five diatonic notes) followed by a conjunct tetrachord, for example:

D E F G | A B C D |.

But the tetrachord may be added below rather than above the pentachord, thus generating a "plagal" mode:

| A B C | D E F G A |.

In either case the *finalis* falls on the lowest note of its pentachord. Each authentic mode has a correlated plagal mode, which is identified by the prefix *Hypo.* In the following chart of the eight church modes, the *finalis* is marked by a capital letter:

1. Dorian			D	e	f	g	a	b	c	d
2. Hypodorian	a	b	c	D	e	f	g	a		
3. Phrygian			E	f	g	a	b	c	d	e
4. Hypophrygian	b	c	d	E	f	g	a	b		
5. Lydian			F	g	a	b	c	d	e	f
6. Hypolydian	c	d	e	F	g	a	b	c		
7. Mixolydian			G	a	b	c	d	e	f	g
8. Hypomixolydian	d	e	f	G	a	b	c	d		

The tones of the Hypomixolydian mode are identical with those of the Dorian, but the two modes differ in the location of their *finalis.* The character of the church modes was further determined by a number of distinctive melodic formulas, and sometimes a particular ethos was attributed to the different modes.

Contrary to the Byzantine classification, which lists first the four authentic and then the four plagal modes, the Roman classification alternates the authentic and plagal modes, so modes with the same *finalis* follow each other. This principle underlies the medieval fourfold system of the so-called *maneriae* (Latin: "manners"), a division of the modes into four pairs. The first pair, or *protus maneria,* includes the Dorian and Hypodorian modes; the second, or *deuterus,* the Phrygian and Hypophrygian; the third, or *tritus,* the Lydian and Hypolydian; and the fourth, or *tetrardus,* the Mixolydian and Hypomixolydian.

Although Greek names were sometimes applied to the church modes and the principle of diatonic octave scales is found in both systems, certain significant discrepancies seem to belie any direct historical connection. Most conspicuous is the different meaning attributed to the names of the Greek octave species and of the church modes. Comparing the two systems provides a plausible explanation: medieval theorists apparently assumed wrongly that the Greek octave species were named in ascending rather than descending order. The Greek octave species Dorian (E–E), Phrygian (D–D), Lydian (C–C), and Mixolydian (B–B) thus appeared in the church modes as Dorian (D–D), Phrygian (E–E), Lydian (F–F), and Mixolydian (G–G).

Gradual emergence of major and minor tonality

The strict consistency of the system of church modes was gradually weakened by the appearance of B♭ in addition to B♮, although the two notes never occurred in succession. The main reason for the use of a tone not included in the basic scale pattern was that medieval musicians sought to avoid the tritone F–B. The tritone (so called because it includes three whole tones) was considered an undesirable interval sharply contrasting with the perfect fourth F–B♭. The substitution of B♭ for B♮ changed the character of a mode. For example, the Lydian mode with a flattened B was identical with the modern major mode, specifically, with the F–major scale (F G A B♭ C D E F); and the Dorian mode with a flattened B generated a minor mode corresponding to the natural D minor scale (D E F G A B♭ C D).

Nevertheless, for centuries medieval theorists considered these alterations as special forms of the Lydian or Dorian mode rather than as new modes. The reluctance to acknowledge the existence of additional modes is reflected in the so-called musica ficta. According to this practice, musical notation appears to conform strictly to the system of church modes but presupposes that the performer makes certain adjustments by raising or lowering a note through the insertion of a sharp or flat.

Two different developments occurring between the 12th and the 16th centuries resulted in a radical change in modal theory: an infiltration of folk music into the ecclesiastical and secular art forms and the steadily evolving fabric of harmony destined to unify the growing complexity of polyphonic (many-voiced) musical texture. Finally, a theorist, Heinrich Loris, commonly known by his assumed name Henricus Glareanus, sanctioned the coexistence between the old church modes and the emerging major and minor modes. In his *Dodecachordon* (1547; from Greek *dōdeka,* "twelve," and *chordē,* "string"), perhaps the most significant musical treatise of the time, Glareanus enlarged the system of the eight church modes by adding the following four:

9. Aeolian			A	b	c	d	e	f	g	a
10. Hypoaeolian	e	f	g	A	b	c	d	e		
11. Ionian				C	d	e	f	g	a	b	c
12. Hypoionian	g	a	b	C	d	e	f	g		

The Ionian and Hypoionian modes correspond to the major mode, the Aeolian and Hypoaeolian modes to the "natural" minor mode. The 12 modes of the *Dodecachordon* comprise authentic and plagal structures with tonal centres on the notes C, D, E, F, G, and A, without recourse to sharpened or flatted tones. Glareanus mentions another two modes: the Locrian and the Hypolocrian, having B as their tonal centre. But because in these two modes B and the fifth degree above it, F, form a "false" (*i.e.*, diminished, or flattened) fifth (another form of the forbidden tritone), Glareanus states that for practical purposes only 12 modes are available.

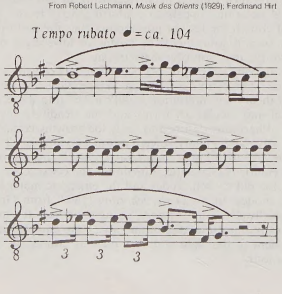
The growing complexity of polyphonic music caused the distinction between authentic and plagal modes to become more and more irrelevant, and, as a result, the number of modes was virtually reduced to only six. The further development of art music in the Western Hemisphere is characterized by the gradual abandonment of the old ecclesiastical modes in favour of the dual major-minor system that dominated 18th- and 19th-century harmony. This system is often termed tonal, in contradistinction to that of the church modes; in fact, some 20th-century works reviving the patterns of the old church modes, as well as folksongs that occasionally use them, are often termed modal. Nevertheless, major and minor scale patterns have all essential characteristics of modes and should therefore be evaluated as such.

Non-Western modes and melody types. Modal concepts permeate all manifestations of Oriental art music. They represent a synthesis of well-established systems both of scalar construction and of a variety of melodic formulas and motivic configurations. The amalgamation of these elements yields specific melody types that are imbued with ethical, emotional, and cosmological connotations and form the basis of musical creation. Whereas the Western composer strives for originality and individual expression, his Eastern counterpart submits to the limitations of existing melody types, seeking to excel in an exploitation of their potentials.

The *rāga* and the *maqām*

The most elaborate modal concepts are those of the Indian *rāga* and of the Arabian-Persian *maqām*. They correspond to the Javanese *patet*, the Jewish *nigun*, and the aforementioned Greek *nomos*. The Oriental musician first exposes the characteristic features of a particular melody type in a free, improvisatory prelude leading to the more formalized section of the composition. These improvised introductions developed into a specific art form, called in India *ālāpa* ("conversation"), in Java *bebooka* ("guide"), in Iran *mukhtaṣarī* ("summary"), in Egypt and Turkey *taqsīm* ("dissection, analysis"), and in northwestern Africa *istaḥbar* ("information"). The following example (recorded by G. Schünemann, transcribed by R. Lachmann)—the first of four phrases constituting an introduction to a Tunisian art song composed in the *maqām raṣd ad-dīl*—illustrates this aspect of modal exposure.

From Robert Lachmann, *Musik des Orients* (1929); Ferdinand Hirt



Rāgas and *maqāmāt* embrace a wide variety of emotional content. They can be courageous, amorous, melancholy, cheerful, soothing, or ecstatic and are capable of conveying these qualities to the listener. Some melody types are supposed to influence illnesses, calm storms, tame wild animals, and increase the fertility of the soil. Others have pernicious power; for example, a certain *maqām* attracts evil spirits, while a certain *rāga* may cause fire. According to an ancient legend, a singer who performed such a *rāga* under the reign of Emperor Akbar (1556–1605) was reduced to ashes, although as a precaution he had submerged his body in the Ganges River. Cosmological connotations have caused melody types to be assigned to different parts of the day; for example, a mid-morning *rāga* may not be performed during the evening. The Westernized younger generation, however, tends to disregard these traditional restrictions.

The music of many tribal societies shows well-organized scalar and modal patterns, but they have not been explicitly formulated and systematized by the peoples involved. A comparative analysis reveals that, in spite of a great structural diversity, scalar and modal correlations exist not only among culturally unrelated tribal societies but also among tribal, Western folk, and Eastern art music. Modal systems and their unconscious counterparts thus may be said to have contributed substantially to the structure of a vast amount of the world's music.

(M.Ko.)

HARMONY

In music, harmony can be broadly defined as the sound of two or more notes heard simultaneously. In practice, this broad definition can also include some instances of notes sounded one after the other. If the consecutively sounded notes call to mind the notes of a familiar chord (a group of notes sounded together), the ear creates its own simultaneity in the same way that the eye perceives movement in a motion picture. In such cases the ear perceives the harmony that would result if the notes had sounded together. In a narrower sense, harmony refers to the extensively developed system of chords and the rules that allow or forbid relations between chords that characterizes Western music.

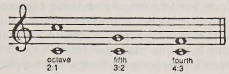
Musical sound may be regarded as having both horizontal and vertical components. The horizontal aspects are those that proceed during time such as melody, counterpoint (or the interweaving of simultaneous melodies), and rhythm. The vertical aspect comprises the sum total of what is happening at any given moment: the result either of notes that sound against each other in counterpoint, or, as in the case of a melody and accompaniment, of the underpinning of chords that the composer gives the principal notes of the melody. In this analogy, harmony is primarily a vertical phenomenon. It also has a horizontal aspect, however, since the composer not only creates a harmonic sound at any given moment but also joins these sounds in a succession of harmonies that gives the music its distinctive personality.

Non-harmonic music

Melody and rhythm can exist without harmony. By far the greatest part of the world's music is nonharmonic. Many highly sophisticated musical styles, such as those of India and China, consist basically of unharmonized melodic lines and their rhythmic organization. In only a few instances of folk and primitive music are simple chords specifically cultivated. Harmony in the Western sense is a comparatively recent invention having a rather limited geographic spread. It arose less than a millennium ago in the music of western Europe and is embraced today only in those musical cultures that trace their origins to that area.

The concept of harmony and harmonic relationships is not an arbitrary creation. It is based on certain relationships among musical tones that the human ear accepts almost reflexively and that are also expressible through elementary scientific investigation. These relationships were first demonstrated by the Greek philosopher Pythagoras in the 6th century BC. In one of his most famous experiments, a stretched string was divided by simple arithmetical ratios (1:2, 2:3, 3:4, . . .) and plucked. By this means he demon-

strated that the intervals, or distances between tones, that the string sounded before and after it was divided are the most fundamental intervals the ear perceives. These intervals, which occur in the music of nearly all cultures, either in melody or in harmony, are the octave, the fifth, and the fourth. (An octave, as from C to the C above it, encompasses eight white notes on a piano keyboard, or a comparable mixture of white and black notes. A fifth, as from C to G, encompasses five white notes; a fourth, as from C to F, four white notes.) In Pythagoras' experiment, for example, a string sounding C when cut in half sounds C, or the note an octave above it. In other words, a string divided in the ratio 1:2 yields the octave (c) of its fundamental note (C). Likewise the ratio 2:3 (or two-thirds of its length) yields the fifth, and the ratio 3:4, the fourth. These notes—the fundamental and the notes a fourth, fifth, and



octave above it—form the primary musical intervals, the cornerstones on which Western harmony is built.

The roots of harmony. The organized system of Western harmony as practiced from *c.* 1650 to *c.* 1900 evolved from earlier musical practices: from the polyphony—music in several voices, or parts—of the late Middle Ages and the Renaissance and, ultimately, from the strictly melodic music of the Middle Ages that gave rise to polyphony. The organization of medieval music, in turn, derives from the medieval theorists' fragmented knowledge of ancient Greek music.

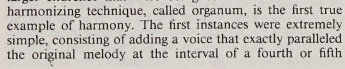
Although the music of ancient Greece consisted entirely of melodies sung in unison or, in the case of voices of unequal range, at the octave, the term harmony occurs frequently in the writings on music at the time. Leading theorists such as Aristoxenus (fl. 4th century BC) provide a clear picture of a musical style consisting of a wide choice of "harmonies," and Plato and Aristotle discuss the ethical and moral value of one "harmony" over another.

Greek scales

In Greek music a "harmony" was the succession of tones within an octave—in modern usage, a scale. The Greek system embraced seven "harmonies," or scale types, distinguished from one another by their particular order of succession of tones and semitones (*i.e.,* whole steps and half steps). These "harmonies" were later erroneously called modes, a broader term involving the characteristic contours of a melody, as well as the scale it used (see above *Mode*).

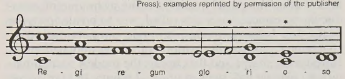
Harmony before the common practice period. By the 9th century the practice arose in many churches of performing portions of plainchant melodies with an added, harmonizing voice—possibly as a means of greater emphasis, or of reinforcing the sound to carry through the larger churches that were being built at the time. This harmonizing technique, called organum, is the first true example of harmony. The first instances were extremely simple, consisting of adding a voice that exactly paralleled the original melody at the interval of a fourth or fifth

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(parallel organum). Within a short time the new technique was explored in far greater diversity. Added harmonic lines took on melodic independence, often moving in opposite, or contrary, motion to the given melody. This style was called free organum. In such cases it was impossible to maintain at all times the accepted harmonies of fourth, fifth, and octave. These intervals were considered consonances—*i.e.,* intervals that because of their clear sonority, implied repose, or resolution of tension. In free organum they were used at the principal points of articulation: the beginnings and ends of phrases and at key words in the text. In between occurred other intervals that were relatively dissonant; *i.e.,* they implied less repose and more tension. In the following example of free organum, dissonances are marked by asterisks. Free organum is an early example of harmonic motion from repose to tension to repose, basic to Western harmony. The emphasis on con-

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sonances at the end of compositions set the final points of arrival in strong relief and reinforced the idea of the cadence, or the finality of the keynote of a mode (on which pieces normally ended).

Until the late 14th century the attitude toward consonance, especially among continental composers, adhered largely to the Pythagorean ideal, which accepted as consonances only intervals expressible in the simplest numerical ratios—fourths, fifths, and octaves. But in England the interval of the third (as from C to E) had been in common use for some time, although it is not expressible as such a simple ratio. A kind of English organum known as gymel, in which the voices move parallel to each other at the interval of a third, existed in the late 12th century; and in the famous *Sumer is icumen in* canon of the 13th century, a remarkably elaborate piece for the time, the harmonic style is almost entirely centred on thirds. The sixth (as from E to C), an interval closely related to the third, was also common in English music. These two intervals sounded much sweeter than did the hollow-sounding fourths, fifths, and octaves.

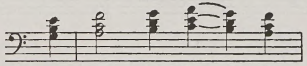
Rise of the intervals of the third and the sixth

By the early 15th century, in part because of the visits of the illustrious English composer John Dunstable to the courts of northern France, the third and sixth became accepted in European music as consonant intervals (prior to this time they were considered mildly dissonant). The result was an enrichment of the harmony in musical compositions.

This was a time, too, of a developing awareness of tonality, the concept of developing a composition with a definite keynote used as a point of departure at the beginning and as a point of arrival at the final cadence.

At this time there also began the tendency by composers to think of harmony as a "vertical" phenomenon, to regard the sound of notes heard simultaneously as a definite entity. Although the basic style of composition was primarily linear—*i.e.,* concerned with counterpoint—the chords that emerged from the coincidences of notes in contrapuntal lines took on a personality of their own. One phenomenon that bears out this development is fauxbourdon (French: "false bass"), or, in England, faburden. The following example illustrates English faburden of about 1300. This was a musical style in which three voices move

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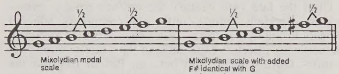


parallel to each other; the middle voice consisted of a succession of notes in parallel organum a fourth below the top voice; the lowest voice paralleled the sequence a third below the middle voice, producing a chord such as G–B–E, known as a $\frac{6}{3}$, or first inversion, chord. This was originally an English development adopted in the 15th century by continental composers seeking to enrich their harmonies. It combined the continental fondness for "pure" intervals such as the fourth (here, B–E) with the English taste for parallel thirds (here, G–B) and sixths (here, G–E).

A final phenomenon in early 15th-century harmonic

The weakening of the modes

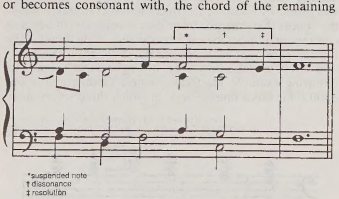
practice clearly foreshadowed the end of the ancient modal system in favour of the major and minor modes of the later common practice period. The old modes were used by composers of the time, and they persisted to some extent until the end of the 16th century. But their purity became undermined by a growing tendency to introduce additional notes outside the mode. This was achieved by writing either a flat or sharp sign into the manuscript, or by leaving the performer to understand that he was expected to improvise accordingly. The effect of this musica ficta (Latin: "invented music"), as the technique of introducing nonmodal notes was called, was to break down the distinction between modes. A mode owes its distinctive character to its specific pattern of whole and half steps. Introducing sharps and flats upsets the mode's normal pattern by placing half steps at unusual points. In many cases the resulting change made one mode resemble another. For example, adding an F♯ to the medieval Mixolydian mode (from G to G on the white keys of the piano) made that mode's intervals identical with those of the Ionian



mode (from C to C on the white keys), which in turn is identical with the modern major scale. Likewise, adding a B♭ to the Dorian mode (from D to D) made its intervals equivalent to those of the Aeolian (A to A) mode, which is identical with one form of the modern minor scale. As this practice became increasingly prevalent, the major and minor modes gradually became predominant over the medieval church modes. The process is especially observable in the music of the late Renaissance.

New uses of dissonance

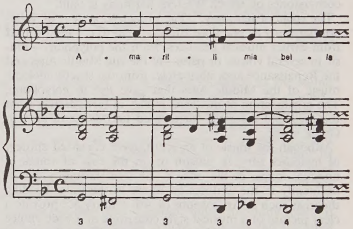
At the same time there emerged a more sophisticated attitude toward dissonance, favouring its use for expressive purposes. By the time of the Flemish Josquin des Prez, the leading composer of the Renaissance, contrapuntal music had assumed a more resonant texture through the use of four-, five-, and six-part writing instead of the older three-part scoring. The increased number of voices led to further enrichment of the harmony. A typical Josquin device using harmony for expressive purposes was the suspension, a type of dissonant harmony that resolved to a consonance. Suspensions arose from the chords occurring in contrapuntal music. In a suspension one note of a chord is sustained while the other voices change to a new chord. In the new chord the sustained, or "suspended," note is dissonant. One or two beats later the suspended voice changes pitch so that it resolves into, or becomes consonant with, the chord of the remaining



voices. The following illustration from Jean d'Okeghem's *Missa prolationum* shows a suspension at the cadence. The suspension, which became a standard musical device, creates tension because the expected harmony is delayed until the suspended voice resolves. Its use as the next to last chord of a cadence, or stopping point, was favoured by composers as a way to enhance, through dissonance resolving to consonance, the sense of completeness of the final chord. The use of suspensions indicates a growing awareness of chords as entities, rather than coincidences, that have expressive potential and of the concept that harmony moves through individual chords toward a goal. This concept was developed in the harmony of the common practice period.

At the end of the 16th century there was an upheaval in musical style. Contrapuntal writing was frequently abandoned, and composers sought out a style that placed greater emphasis on an expressive melodic line accompanied, or supported, by harmonies. This style, called monody, brought about no marked changes in the harmonic language (the particular chords used), although such composers as the Italian Claudio Monteverdi did experiment with a heightened use of dissonance toward expressive ends. The major change at this time was in the conception of harmony. The bass line became the generating force upon which harmonies were built. It was often written out with figures below it to represent the harmonies to be built upon it. From this single line—plus figures, known variously as figured bass, basso continuo, or thorough bass—the accompanying instrumentalists were expected to improvise, or "realize," a full harmonic underpinning for the melody of the topmost voice or voices. In the example below, from the continuo madrigal *Amarilli* by Giulio Caccini, the second line shows the harmonies supplied by the keyboard player. There was, thus, a polarization between

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the melodic and bass lines, with everything in the middle regarded as harmonic filling-in. This contrasts markedly with the older concept, in which all voices were regarded as of equal importance, with the harmony resulting from the interweaving of all parts.

Classical Western harmony. The approach to harmony according to which chords are purposely built up from their bass note marked the beginning of the common practice period of Western harmony. The transition began around 1600 and was nearly complete by 1650. Certain new concepts became important. These had their roots in the harmonic practices of the late Middle Ages and Renaissance and in the medieval modal system. They include the concepts of key, of functional harmony, and of modulation.

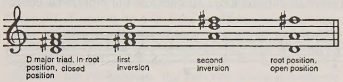
A key is a group of related notes belonging to either a major or minor scale, plus the chords that are formed from those notes, and the hierarchy of relationships among those chords. In a key the tonic, or keynote, such as C in the key of C—and thus the chord built on the keynote—is a focal point toward which all chords and notes in the key gravitate. This is a further development of the idea of a harmonic goal that appeared in the music of the late Renaissance and that ultimately developed from the medieval idea that modes have characteristic final notes.

In the new system keys further assumed relationships to one another. The larger organizational system embracing keys, key relationships, chord relationships, and harmonic goals was called tonality, or the major-minor system of tonality, because the keys were built on major and minor scales. In the tonal system, given chords assumed specific functions in moving toward or away from harmonic goals, and the system assigning goals to all chords was called functional harmony. The main goal was the keynote, or tonic, of the principal, or tonic, key. Modulation, or change of key, became an important factor in composition

because it allowed the composer to exploit the listener's ability to sense the relations between keys.

Rameau's theories of chords

The approach to harmony that emerged about 1650 (the bass-note approach) was soon formalized in one of the most important musical treatises of the common practice period, *Traité de l'harmonie* (1722), by the French composer Jean-Philippe Rameau. The crux of Rameau's theory is the argument that all harmony is based on the "root" or fundamental note of a chord; for example, D. Other notes are placed a third (as D–F or D–F♯) and a fifth (as D–A) above the root. A chord formed in this way is a triad (as D–F–A or D–F♯–A), the basic chord type of the common practice period. The third and fifth above the triad can be placed within the same octave as the root (close position) or can be spread out over several octaves (open position) in compound intervals such as an octave plus a third or two octaves plus a fifth. A triad can exist in its basic, or root position, with the root as the lowest, or bass, note (as D–F♯–A). It can also exist in inversions or rearrangements of its notes placing the third or fifth in the bass, as F♯–A–D (first inversion) and A–D–F♯′ (second inversion). Theorists after Rameau observed that inverted



chords are less stable than chords in root position; at the end of a composition, for example, they do not have sufficient finality. Although Rameau's monumental work contains certain elements that later practices tended to disprove, his writing remains the basis for the study of common-practice harmony.

By Rameau's time no vestige remained of the ancient modal system, which was replaced by 12 major and 12 minor keys beginning on each of the 12 notes of the piano keyboard (C, C♯, D, . . . A♯, B). The invention in the late 17th century of equal temperament (see above *Tuning and temperament*) made it possible to play keyboard and other instrumental music in all 24 keys of the chromatic system, the system embracing all possible notes of the 24 scales. Such a work as J.S. Bach's *Well-Tempered Clavier* was, among many things, a set of exercises to acquaint keyboard players with this newfound freedom. Equal temperament also made it possible for a composer to modulate freely from one key to another to obtain contrast in works of an extended nature. Modulation was no new invention, but it now became of prime importance.

In normal, or functional, harmony, the succession of chords is analyzed by the distance, or interval, between their roots. The most common movement from chord to chord is through "strong" intervals: fourths (as C to F), fifths (as C to G), and seconds (as C to D). A movement from one chord to another having this root relation is strong because the two chords have the fewest notes in common and therefore contrast more with each other. Movement by "weak" intervals—thirds (as C to E) and sixths (as C to the A above it)—is weaker, or less pronounced, because the two chords in this case usually share two out of their three notes; for example, C–E–G and E–G–B, or C–E–G and A–C–E. Similarly, modulation from one key to another in the course of a piece was most characteristically from one key to another whose keynote is a strong interval apart from that of the first key, as from C to G. Usually the modulation was to the key built on the fifth note, or dominant, of the original scale. A work in C major, for example, tended to move toward the area of G. In works in a minor key, the modulation might be to the dominant minor key (A minor to E minor, for example); or it might be to the relative major key (the key that shares the same scale notes as the minor scale but arranging them in major scale order rather than minor scale order [A minor and C major, for example]). In the second case the contrast of major and minor mode appeared to compensate for the weak modulation (A and C are a third apart).

By the early 18th century these modulatory principles were well established and were made use of in musical form. In the keyboard sonatas of Domenico Scarlatti, for example, or the instrumental dance movements in Bach's partitas, the opening key is well established at the beginning of the piece. There then begins a movement to a new key, normally the dominant key. This is characteristically achieved by an emphasis on chords common to both keys (known as "pivots"), plus a strong musical statement in the new key leading to a cadence in that key. After the modulation there is a process of return to the initial key. During this process the harmonic motion tends to be more rapid, passing quickly through many chords and often including momentary diversions into many new keys, thus lending greater impact to the eventual return to the original key. Such a composition is said to be in "binary form." In binary form compositions in a minor key, there occasionally occurred an exception to the rule of return to the home key. The composer could at his option return to the tonic major, the major key built on the same keynote, or tonic, as the original minor key—A major from A minor, for example. But even in this case the harmonic goal toward the tonic note (A in this case) remained the same.

Harmony and modulation in the 18th century

This basic modulatory scheme from tonic key to dominant key back to tonic key formed the basis of the large-scale musical forms that developed during the 18th century and persisted well into the 19th. The sonata forms of Mozart and Haydn, with their exposition, development, and recapitulation, adhere closely to this plan, often greatly expanded. Here the movement from the tonic to the dominant key or to the relative major key made up the exposition; the rapid harmonic movement en route back to the tonic made up the development; and the return to the tonic key—usually reinforced by a return of the initial thematic (melodic) material—signalled the start of the recapitulation. An optional final coda, or concluding section, further strengthened the sense of the tonal journey's having come to an end. In the large, multi-movement works from this period, there was usually a further contrast achieved by having one of the inner movements in another key, but the final movement almost invariably was once again in the same key as the first movement.

Romantic changes in classical harmony

This clear and logical system of organization seemed highly consistent with an age that took its cues from the clarity and balance of ancient classical architecture. It was not so consistent, however, with the ideals of the ensuing era of Romanticism. Already in the mature works of Beethoven, there is the beginnings of a breaking-down of the classic modulatory scheme; the opening movement of the *Waldstein Sonata,* Opus 53 (completed, 1804), for example, is built on a modulation from the tonic, C major, to the sharply contrasting key of E major, instead of the expected key of G. Much of the individual harmonic language of Franz Schubert is based on his purposeful disavowal of modulation via the smooth succession of pivot chords and his fondness, instead, for dropping suddenly into unrelated, and therefore unexpected, keys, as C major to E flat major in the opening movement of the *String Quintet in C Major,* Opus 163 (1828); C major to E minor in the opening movement of the *Symphony No. 9 in C Major* (1828), known as the *Great Symphony.*

Throughout the 19th century there was also a great increase in the use of chromatic tones—tones not belonging to the scale of a given key and that formed "foreign," sometimes dissonant, harmonies with the notes of that key. In addition to the triad, the typical chord of functional harmony, other more complex chords were used, the harmonic functions of which were extremely ambiguous to the listener. As a result the sense of clearly established tonality created by traditional harmonies began to vanish from the musical language—doubtless in line with composers' greater obsession with music and all arts as something mysterious and personalized.

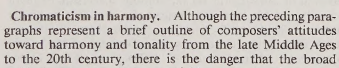
By the time of the German composer Richard Wagner, the sense of tonality as the unifying musical force showed definite signs of disintegration. For one thing, Wagner's idea of the "endless melody" led him in his late works to abjure almost completely, except at the end of acts, the full cadence that establishes tonality. A seeming approach to a cadence in *Tristan und Isolde* or the *Ring des Nibe-*

lungen tetralogy is more often than not thwarted by a quick and unprepared switch to a sharply contrasting key and a continuation of the music in that new area. For another, Wagner's passion for complex chords subject to more than one functional interpretation made the tonality of even short passages difficult to assess.

Although Wagner's specific harmonic concepts were not universally accepted, during his time or afterward, the blurring of the tonal sense by one means or another became prevalent throughout Western music by the last decades of the 19th century. Even in the works of the Italian Giuseppe Verdi, whose music was regarded as the opposite pole from Wagnerian techniques, this abandonment of clear tonal outlines may be noted: the sudden changes to unrelated keys, the piling up of dissonances that leave the sense of key obscured for minutes at a time, the emergence in his late works of a continuous melodic style that avoided regular, key-defining cadences. In France the blurring of clear outlines characteristic of Impressionist painters found its musical counterpart in the music of Claude Debussy, who employed such devices as the scale consisting entirely of whole tones as a means of sidestepping the tonal feeling created by traditional scales. In the music of later French composers, especially the members of the post-World War I group known as "Les Six," a common practice was polytonality, or the sounding of two tonalities simultaneously, each defined with relative clarity but neither dominating the other. Similar polytonal methods also occur in the works of the Hungarian-born Béla Bartók and the Russian émigré Igor Stravinsky.

The Wagnerian influence continued most directly, via the music of Gustav Mahler, into the serial techniques developed in the 1920s by Arnold Schoenberg and his Viennese school. In Schoenberg's serialism the 12 notes of the chromatic scale are arranged into an arbitrary series, or 12-tone row, that becomes the basis for the melodies, counterpoint, and harmonies of the composition. Of these 12 notes no single note is allowed to predominate. This is in complete contrast to the predominance of the tonic, or keynote, in the music of the late Renaissance and the common practice period. Serialism thus completely and systematically obliterated traditional harmonic organization. With no single note serving as a musical goal, tonality—at least as it was known from the 15th century—ceased to be a unifying musical force. Other elements, including serialization of rhythms and tone colours as well as of notes, came to prevail.

Schoenberg's 12-tone row



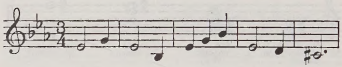
twelve-tone row and chord formed from first four notes of this row

Chromaticism in harmony. Although the preceding paragraphs represent a brief outline of composers' attitudes toward harmony and tonality from the late Middle Ages to the 20th century, there is the danger that the broad outlines may be taken as a rigid statement of standard practices by composers at any period in musical history. Actually, although these outlines remained the general framework in which composers worked, they frequently diverged from it to some extent, particularly in their use of chromatic notes (notes outside the scale of the basic key of the composition) and chromatic chords (chords containing chromatic notes).

The capacity of chromatic tones to add harmonic colour, expressiveness, and interest was apparent to composers from the beginnings of standard harmonic practice. J.S. Bach, for example, in a striking passage at the end of the "Crucifixus" of the *Mass in B Minor,* lent poignance to the verbal description of the burial of Christ by the musical device of a sudden modulation from B minor to a sharply contrasting new key, G major, that contained notes chromatic to the basic key. Mozart, too, derived much of the drive of his harmonic style from a constant use of chromaticism. A characteristic device of Mozart, for example, is his frequent use of secondary dominants to intensify harmonic movement. A secondary dominant is a chord related to the dominant; specifically, it is the dominant of the dominant. If the key is C, the dominant is G and the secondary dominant is D. Secondary dominant chords by their nature contain a note that is chromatic to the basic key. In Mozart's music a harmonic progression from tonic chord (I) to dominant chord (V) will often pass through the dominant of the dominant (V-of-V): from I to V-of-V to V. By using the secondary dominant, he expanded the harmonic range of the composition by introducing chromaticism. In his later works Mozart also came to rely more and more on the dissonant value of suspensions to create harmonic interest. The slow introduction of his *String Quartet in C Major,* K 465 (the *Dissonance Quartet;* 1785), consists of a string of long-delayed suspensions so that the harmonic definition at any given instant is as blurred as anything in Wagner.

Although the harmonic style of the common practice period remained a basic framework, the history of music from Mozart's time to the present shows a constant increase in harmonic density, or the amount of chromaticism and frequent chord changes present. The opening bars of Beethoven's *Eroica Symphony* demonstrate the power of chromaticism to enhance the emotional effect.

Increased use of chromaticism



The first eight notes of the theme are resolutely normal in their outline, the triad of E flat major, the tonic chord of the movement. But the ensuing two notes lead violently away from this harmonic stability, with the 10th note a totally unrelated C sharp. This sudden shift completely upsets the harmonic structure and gives unmistakable notice that a long, complex movement will be necessary to right the imbalance. Not until the coda of the movement is this opening theme allowed to follow the expected harmonic outline dictated by the style of the times.

Throughout the 19th century, composers remained rooted in the basic concept of tonality while at the same time doing everything in their power to complicate or obscure the tonal sense for the listener. Even in the 20th century, the large, varied, and important group of composers who are called conservative—among them, Samuel Barber, Aaron Copland, Sir William Walton, Dmitri Shostakovitch, Gian Carlo Menotti, Benjamin Britten—adhered to the concept of tonality only as a challenge. Tonality in their works exists, in the sense that there are extended stable areas that give the impression of being in some definable key. But the intense chromaticism of 20th-century composition, be it conservative or radical, makes it nearly impossible for the listener to grasp the unity of a work in terms of its adherence to a clear tonal plan. Unity is achieved, rather, by melodic means, the organization of rhythms, or even of tone colour. For all practical purposes, the function of tonality as the prime unifying force in musical structures, known from the 15th through the 19th century, is a thing of the past.

Dissonance in harmony. The very foundation of harmonic music has been the interplay of consonance and dissonance. Consonance can be defined as the normal range of tone combinations accepted by theorists and composers of any given time as implying repose; dissonance, therefore, refers to any sounds outside that range. From the 19th century on, as writers increasingly explored the exact effect of music on the emotions, these two terms took on the aspect of value judgments. There is a tendency to confuse consonance with concord, or sweet sound, dissonance with discord, or clashing sound. This has led to a certain amount of confusion.

Dissonance is in fact the prime element in the harmony that creates movement, and this has been recognized by composers from the dawn of the harmonic millennium. When the human ear recognizes a certain harmony as unstable within the context of a composition, it demands that this instability be rectified by the resolution to a stable harmony. Dissonance, therefore, has never been forbidden in music, for without it music would be hopelessly static.

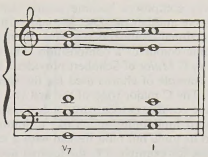
What has been clearly defined in each era has been, rather, the treatment of dissonance, the approach toward it and away from it in a smooth and logical manner so that the musical flow is of a continual tension and relaxation.

The regulation of dissonance. The notion of which specific chords and intervals constitute consonance and dissonance has altered violently from the beginning of harmony. In the earliest harmonic writing, the parallel organum of the 9th century, the accepted intervals were the perfect consonances, or those of the simplest harmonic ratios: the fourth, the fifth, and the octave. As contrapuntal movement among voices became freer, certain other combinations necessarily occurred: thirds and sixths and, in some cases, seconds (as C–D) and sevenths (as C–B). These combinations were regarded as dissonances and were to be confined to weak beats of the musical metre; they were to be resolved, for the most part, by stepwise movement downward to the adjacent consonance. Another interval that the musicians of the modal era took great pains to avoid was the augmented fourth (the tritone, or "devil in music"), an interval containing three whole steps, as between F and B—the whole steps F–G, G–A, and A–B. This interval was considered intolerably dissonant. Primarily to avoid the forbidden, unstable harmonic relationship of the tritone, the use of accidentals (sharps, flats, natural signs) entered music and introduced chromatic tones into a mode.

Chords with a pull to cadence

By the time of Rameau, the concept of the dissonance had altered markedly. The basis of the harmony had changed, as noted above, from the perfect intervals (unison, fourth, fifth, octave) to the triad, or chord such as C–E–G, built of thirds above a root, or bass note. The tonic, or keynote, triad became the point of departure and of arrival for an entire composition and also for melodic phrases and larger sections within that composition. The harmonic movement to the cadence, a prime means of establishing points of articulation, became by the mid-18th century a more or less standard progression of harmonies subject to variation according to the composer's own powers of imagination. Preceding the tonic chord in these cadences, and pushing toward it, was the chord built on the dominant, or fifth note of the scale. This convention developed because of the nature of the dominant chord. In a dominant chord, the note a third above the root (as B in the chord G–B–D—considering the G chord the dominant and the basic key C) is the seventh note of the scale (C, D, E . . . B). This note has a strong leading tendency toward the tonic, or keynote (here, C), because it is only a half step away from the tonic, and is thus called the leading note. Because the leading note is a member of the dominant chord, this chord also has a strong pull toward the tonic chord.

By Rameau's time it was also a common practice to enhance the pull of the dominant chord to the cadence by adding to it the note a seventh above the root of the chord (as F, in the chord G–B–D–F), that note being the fourth note of the scale (C, D, E, F). Such a chord, a dominant seventh chord (V_7) contains two leading notes: the seventh of the scale, here B, with its strong pull toward the tonic, and the fourth of the scale, here F, which has a strong pull toward another of the notes of the tonic chord (in this case toward E in the chord C–E–G), being a half step away from that note. In this way two notes of the dominant seventh chord pulled strongly toward two notes of the tonic chord. Another reason for the strong pull of the seventh chord toward the tonic is that that chord contains a tritone (in this case B–F). Although the tritone was less intolerable by that time than it was to medieval ears, it was still considered a particularly strong dissonance that demanded resolution. This resolution occurred when the dominant seventh chord moved to the tonic chord. In the example below a dominant seventh chord (V_7) moves to a tonic chord (I) in the key of C major. Arrows show the resolution of the tritone dissonance. The dominant seventh chord thus became one of the basic chords in functional harmony. In addition, because it contained two dissonances (a seventh, as G–F in the chord G–B–D–F, and a tritone, as B–F in the same chord), it was the first instance of incorporating dissonance into a



system built on the basically consonant triad. Throughout the common practice period dissonances were continually added to the basic harmonic language, so that the range of harmony and use of dissonance in late 19th-century music had expanded considerably beyond that of the early 17th century.

Music using the system of functional harmony has a flow of harmonic movement through contrasting chords and through passages from consonant to dissonant to consonant chords. If the change of chords is frequent in relation to the musical rhythm, there is said to be a rapid harmonic rhythm. Similarly, a leisurely pace of chord change is a slow harmonic rhythm. The slow or fast harmonic rhythm of a composition helps define its musical character, and by varying the harmonic rhythm within a piece a composer can create contrast, thereby defining sections of musical form.

Modulation and dissonance in the common practice period

Modulation. Modulation, or change of key, was, like dissonance, increasingly explored during the common practice period. In the sonata forms that emerged as the primary musical forms of the mid-18th century, modulation from the tonic to other keys as a means of obtaining contrast became of prime importance. This musical esthetic involved not only the necessity of modulation itself but also drew much of its strength from the varying rate of modulation. Thus, the exposition, or first section, of the "normal" sonata form involves a modulation from the tonic to a nearby related key—usually the dominant, or in works in a minor key, the relative major. The development, or second section, on the other hand, depended on a rapid series of modulations, the purpose being to cast the return to the tonic in as strong a dramatic light as possible by having the stability of the tonic contrast with the instability of rapid modulation that preceded it.

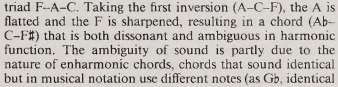
The process of modulation to many keys involved the addition of dissonant, often chromatic, notes to the basic harmonic outline of a composition. A common way of preparing for the appearance of the dominant key area in a sonata exposition was for the composer to overshoot his mark, moving temporarily to the dominant of the dominant, thereby using chromatic chords. Thus, in the transition from tonic key (C major) to dominant key (G major) in the first movement of *Symphony No. 1 in C Major,* Opus 21 (1800), of Beethoven, there is considerable emphasis on the chords of D, both major and minor, establishing D as a dominant leading to a cadence on G, the point of arrival. Much of the dissonance in music of the late classic composers is traceable to this use of secondary dominants. The tendency to move quickly through extended sequences (musical patterns repeated at higher or lower pitch) based on secondary dominant chords became a highly sophisticated technique in the mature works of Haydn and Mozart (as, for example, the extraordinary sequence in the slow movement of Haydn's *Symphony No. 104 in D Major,* the *London Symphony*).

Functional harmony was based on chords built from the diatonic (seven-note) major and minor scales; chromatic notes and chords were integrated into the functional system. Although composers of this period proved remarkably adventurous in straying beyond the limits of purely diatonic harmony, their use of dissonance and chromatism was at all times both rational and functional. Chords, even though complex, normally resolved sooner or later into the chords toward which they tended, even when the composer, as in the Haydn passage cited, added unstable elements to the chord of resolution and therefore occasioned further resolution.

Use of dissonance for harmonic colour. By the early

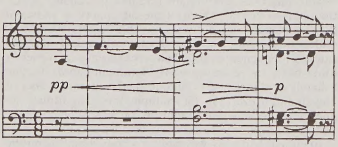
19th century, composers became aware that harmony could also serve another purpose: it could exist outside of a purely functional context as a means of enhancing the pure harmonic colour of a composition. The opening of the *Quintet in C Major* of Schubert provides a simple and quite early example of chords used for the sheer effect of their sound. The C major triad of the first two bars seems to swell in the ensuing two bars into a diminished seventh chord, a chord functioning much like a dominant chord in its pull to its tonic but built instead with a leading note as its root, as, for example, F♯, the leading note of G, on which is built a chord such as F♯–A–C–Eb. (The top and bottom notes of such a chord, here F♯–Eb, encompass the interval of a diminished seventh, giving the chord its name.) In Schubert's quintet the particular diminished seventh chord used would normally resolve to a chord on G. Instead it simply subsides back to the C major triad of the preceding bars, so that there occurs no real harmonic movement in the opening six bars.

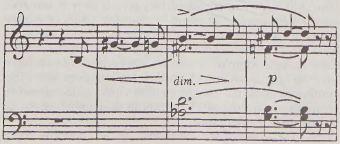
Nineteenth-century harmonic usage, therefore, tended to expand not only the chordal vocabulary itself but also the function of chords. In the former respect there was an increase in the use of chords the particular type of dissonance of which lent them an unstable and a functionally ambiguous quality; for example, a chord that became of prime importance as a means of thickening the harmonic sound and of blurring the exact tonality of a musical passage was the augmented sixth chord. This is an altered chord, or one built by taking a chord normally occurring in its key and chromatically altering it. In this case, two of its notes are changed by a half step. Specifically, an augmented sixth chord is built on the first inversion of a triad, as, for example, A–C–F, the first inversion of the triad F–A–C. Taking the first inversion (A–C–F), the A is flatted and the F is sharpened, resulting in a chord (A♭–C–F♯) that is both dissonant and ambiguous in harmonic function. The ambiguity of sound is partly due to the nature of enharmonic chords, chords that sound identical but in musical notation use different notes (as G♭ identical in sound with F♯). Thus the chord A♭–C–F♯ may move smoothly to a chord built on G, but the identical sounding chord A♭–C–G♭ will progress to a vastly different chord,



on D♭. Composers can thus use such ambiguous chords to achieve unusual or expressive harmonies that blur the listener's expectations and therefore his ability to perceive key and tonality.

The opening of Wagner's music drama *Tristan und Isolde*, famous for its ambiguous sense of tonality, is an augmented sixth chord that resolves by way of a second





dissonance to the dominant seventh chord of the key of A. This sequence is repeated at a higher pitch, here resolving to the dominant seventh chord of the key of C. Although this passage can be explained in terms of normal harmonic analysis, it was in itself strikingly abnormal for its time. The passage occurs at the beginning of the composition, the point where a composer normally would be expected to establish his basic tonality. In addition, there is considerable doubt as to the exact nature of the resolution. The dominant seventh chord (here the chord of resolution) is itself dissonant, although less so than the augmented sixth chord. The tonality of the passage is obscured, for it is impossible to tell whether the passage is in A minor or A major. Since the notes of the scale that would give this information to the listener are missing from the passage, it is clear that Wagner does not want the listener to be sure. He wants the passage, rather, to stand for the substance of the opera itself: unrequited passion is equal to unresolved harmonies.

Dissonance and emotion in Wagner's music

Other composers, too, sought out harmonic as well as melodic and rhythmic means to underscore the content of passion, restlessness, mystery, or tragedy in their scores. The unstable, ambiguous chord of the diminished seventh accompanies the appearances of the evil Samiel and his seven supernatural bullets in the opera *Der Freischütz (The Freeshooter)* by Carl Maria von Weber. Long strings of this chord, moving rapidly up and down the scale for purely colouristic purposes, also appear in climactic passages of the tone poem *Les Préludes*, by Franz Liszt, expressing the struggle of the soul against supernatural forces. The highly embroidered piano style of Frédéric Chopin, touched, in passing, on showers of dissonant, often chromatic tones—again used not for any exploitation of their functional value but as a spray of colour used as an overlay for a basically diatonic (nonchromatic) style, well-hidden underneath and recognizable only at the cadence.

Until the genuinely revolutionary *Tristan und Isolde* of 1865, the increase in the amount of chromaticism in the musical language of the Romantic composers was largely an enhancement of expressive detail. The diatonic (nonchromatic) basis of 18th-century functional harmony was in the main respected, as was the orderly process of modulation as a means for giving structure to large musical forms. With *Tristan*, and even more markedly with Wagner's music drama *Parsifal*, one can discern the beginnings of a gradual but unmistakable dissolution of the diatonic system on which traditional harmony was based. The analysis of *Tristan's* harmony by Rameau's principles, although possible, is simply unimportant. What matters more is the constant flow of chromaticism, of Wagner's wide variety of means—altered chords, chains of secondary dominants, and resolutions to chords that themselves prove unstable—for blurring any sense of functional harmony. Doubtless impelled by the dramatic substance of this music drama, he succeeded in evading the cadence, or coming to rest, that traditionally defined harmonic direction.

The impact of this step became apparent in the directions taken by harmony by the end of the 19th century. After Wagner, dissonance, particularly dissonance caused by chromaticism, largely ceased to function as it had in traditional harmony, and composers created their own individual, often experimental, usage of dissonance. No composer, whether he accepted *Tristan* as a masterpiece or dismissed it as madness, was left untouched by its implications.

Dissonance after Wagner. In France, where musical culture stood in some ways the direct antithesis to Wagnerism, Claude Debussy evolved his own style that succeeded, as Wagner's had, in beclouding the harmonic basis of a work either altogether or for extended periods. Debussy was influenced by a number of sources: the Impressionist painters, who were involved with the renunciation of clear perspectives and outlines in favour of the play of light across surfaces and the effect of images only half seen; exotic music, particularly that of Indonesia; and folk music, especially the modal scales of Russia. All of these led him to a partial abandonment of functional tonality. Among the devices he used toward this end is a scale composed

Debussy's sources

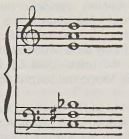
entirely of whole tones (as C–D–E–F♯–G♯–A♯–C). Such a scale lacks the distribution of whole and half steps that define the character of the major and minor scales of the common practice period. Chords built from the whole tone scale are by normal harmonic analysis unstable: all possible triads are augmented (the top note is altered by being sharpened; for example, C–E–G♯ instead of C–E–G) and as a result are dissonant. The perfect fourth and fifth, the ancient cornerstones of harmony, do not exist. Because the chords to which dissonances traditionally resolve are impossible with this scale, a work built upon it—*e.g.,* "Voiles" ("Sails"), from the first book of preludes for piano—can be said to exist without harmonic resolution and, therefore, without traditional tonality. Other Debussian devices include the regarding of the seventh chord (*e.g.,* dominant seventh, diminished seventh) as a self-sufficient harmony instead of as a dissonance that must resolve; sequences of sevenths moving parallel to each other giving the effect, in his music, of lines of harmony plus a dissonant descant (a countermelody in the highest part, or voice) blurring any real sense of traditional harmonic movement. This use of self-sufficient seventh chords was also much exploited by Maurice Ravel and came, through his great appeal, into a great deal of the popular music of western Europe and America from the 1920s onward.

Chord structures of Stravinsky

Again, as with Wagner, Debussy's methods cast their shadow over composers both influenced by and hostile to his musical style. Igor Stravinsky, who was a little of both, first mirrored some of Debussy's harmonic usage in *Le Sacre du printemps* (*The Rite of Spring;* 1913). In *Le Sacre,* chords appear, as they often do in Debussy, purely for their colouristic value, related to each other only by virtue of the rhythmic insistence in the music's patterns. Much of Stravinsky's harmonic style, however, is actually derived from much simpler elements than Debussy's. His complex chord structures often break apart to reveal two unrelated and dissonant diatonic chords sounded simultaneously. In the works of his Neoclassical period, Stravinsky reverts to a clear harmonic language reminiscent, at least as regards individual chords, of the 18th century; but in harmonic movement from chord to chord there is a noticeable difference from earlier styles. Stravinsky, even in this clear compositional style that occupied him in the 1920s and into the 1930s, tends to use these classical harmonies in isolation, for the chords move freely one to the other without their classical function.

Polytonality. Similar in a sense to Stravinsky's pandiatonicism, or use of diatonic chords without the limitations of classical harmonic function, is the tendency toward polytonality in the works of the post-World War I group of French composers known as "Les Six." These composers, notably Darius Milhaud, worked for a time with simple, diatonic chords piled upon each other in a way that suggested a clash between simultaneous tonal areas, almost a kind of counterpoint of tonalities—again leading to the dissolution of any sense of a single, central key area. Some traces of polytonality also occur in the early works of Bartók, who was much taken with French influences early in his career. But Bartók did not pursue this device to any great extent later on. He turned instead to an exploration of the folk styles of eastern Europe—Hungarian and Romanian, predominantly. His music, though harmonically dense and complex, remained rooted in tonality, with an admixture of harmonies gleaned from the modal scales of folk music.

Certain other composers, similarly obsessed with the desire to expand the harmonic vocabulary but loath to abandon the tonal system entirely, experimented with some success with synthetic scales of their own devising and with chords built of intervals other than the third. The Russian mystic Aleksandr Scriabin and the German Paul Hindemith both worked extensively with chords built out of fourths (as C–F–B♭). Scriabin employed these sounds primarily in a quasi-Impressionist way, using their unusual sounds as sonorous self-sufficient units. His "mystic" chord, shown below, formed the entire basis for many of his later works. Hindemith, whose orientation was toward the Neoclassical, dealt with these chords by devising his own system of harmonic function, creating a quite successful reincarnation of the dissonance–consonance tensions of earlier composers.



The direct influence of Wagner's methods, however, was felt within the German–Austrian orbit. The restless, unresolved chromaticism of *Tristan* was directly reflected in the late works of Gustav Mahler. In such a work as the long, slow movement that ends Mahler's *Ninth Symphony,* one feels the *Tristan* influence quite directly: the long, lyric lines move freely through a systematic evasion of cadences and through a widening range of tonalities, often reaching tonal regions far removed from the starting point. Yet Mahler, too, remained a tonal composer, as did Richard Strauss, whose overlays of dissonance in such works as *Elektra* are easily separable from a basically tonal harmonic movement.

Schoenberg's relationship to Wagner

Early scores by the Viennese composer Arnold Schoenberg—such as the string sextet *Verklärte Nacht* (*Transfigured Night;* 1899), the *Chamber Symphony in E Major,* Opus 9 (1906), and the first two string quartets—are direct outgrowths of *Tristan*'s chromaticism, masking but not obliterating the tonal basis. But by 1912 Schoenberg began actively to question tonality as a musical inevitability and to accept the broader implications of Wagner's style. From then on the pileup of dissonance in Schoenberg's music became so pronounced as to make the concept of dissonance itself meaningless. In such a seminal work as the chamber cantata *Pierrot Lunaire* (1912), tonality has been put aside. In this work it is no longer possible to discuss consonance and dissonance, for these concepts relate to the structure of a composition according to the harmonic principles of tonality.

Schoenberg's far-reaching musical philosophies, which were epitomized in his invention of the technique of serialism, have had a potent impact on the music of the decades following his own writing. They have also been resisted by large numbers of composers who are conveniently, if not always accurately, described as conservative. The conflict between tonality and atonality (*i.e.,* nontonality) has provided a dynamic dualism for musical styles ever since.

Harmony and melody. As noted above, melody and harmony were synonymous in classical Greek theory; the term harmony referred not to notes sounded simultaneously, but to the succession of notes, or the scale, out of which melody was formed. During classical antiquity and the European Middle Ages melodies were written that had an inner logic in terms of their scale, or mode, its important notes, and the melodic patterns associated with it. This is also true of many non-Western melodies. After the gradual evolution in Europe, through the polyphony of the late Middle Ages and the Renaissance, of the common practice, or classical, system of Western harmony, the inner logic of melodies was strongly affected by harmony. Because the ear can perceive harmonic patterns in certain groups of notes, even when sounded successively rather than simultaneously, melodies began to carry a strong implication of underlying harmonies. During this period there arose the conception that melody was the surface of harmony. Thus, for example, the partitas for unaccompanied violin by J.S. Bach, despite their melodic basis and lack of outright harmonic underpinning, clearly set forth their basic tonality and harmonic direction. This is achieved by a melodic style that includes frequent scale passages and arpeggiated chords (chord notes played successively, in melodic fashion, rather than simultaneously, as in a chord) that make clear to the listener the scales, harmonies, and keys belonging to the tonality of the composition. Through the 18th century and well into the 19th, melodies tended to be the bearers of their own harmonic implications. The above noted opening of Bee-

Melody as the harmonic surface

thoven's *Eroica Symphony* represents this practice at both its height and at the beginnings of its dissolution. The opening eight notes outline an unmistakable E♭ triad, and would do so even if they were sounded unharmonized; the ensuing plunge to the unexpected C♯ likewise indicates by its mere melodic shape the harmonic unrest arising at this juncture.

Nevertheless, melody in the hands of a composer seeking a genuine expressiveness must function with some degree of independence from its harmonic underpinning. The long, expressive dissonances in the vocal lines of Romantic composers not only heighten the passion sought after in the music but also specifically represent a seeking for a heightened independence of melody from harmony.

The shift of harmonic usage in the 20th century can be viewed partly as a marked change in relationships between melody and harmony. In Schoenberg's techniques, the generating force is the 12-tone row, which is primarily a melodic sequence out of which harmonies, as well as themes, are generated. Thus, it is possible to detect a reversal of the traditional relationship, whereby harmony has become the surface—or at least the final result—of melody.

Harmony in musical form. The chief problem of composition, in any style from ancient times to the present, is the creation of a form, or structure in which the principles of unity and contrast operate in some kind of equilibrium. The listener enters into this process by the use of his powers of recognition and of memory.

In purely melodic, modal music the form often derives from the inner logic of the melody in terms of the important notes and melodic patterns of the mode. In polyphonic music before the common practice period, musical form depended partly on the unity achieved by setting a piece in a given mode, partly on the use of musical themes, and partly on creating harmonic movement and tension toward stopping points, or cadences. During the common practice period—from Bach to Debussy—much of the creation of musical form took place through the organization of harmonies into keys and relationships between keys. Thus, the sonata forms of the 18th and early 19th centuries depended as much on the statement of a key, the movement to other key areas, and the eventual return to the same key as they did on themes and other melodic devices. The composer was likely, of course, to employ the two principles of melody and harmony simultaneously; the return to the tonic key late in the course of a movement was usually reinforced by a restatement of the initial themes. In certain works of Haydn and Mozart, the listener was often thrown off course purposely by the premature return of initial themes in an unexpected key; such devices served further to enhance the drama of the genuine recapitulation, or return to the main key.

By the 19th century, however, the power of harmony to suggest clear formal structures was greatly undermined by freer use of dissonance, which broke down the clarity with which a key was defined. Other customary procedures were also abandoned. Many of Schumann's songs do not return to the tonic, or home key, for the final cadence. The extended length of Wagner's music dramas, and their wide-ranging modulation, make it impossible to regard key as a unifying force. Mahler's *Ninth Symphony*, the first movement of which is in D major, ends with a movement in D flat major, and since the symphony lasts nearly 90 minutes, there seemed to Mahler to be no reason to pay any closer lip service to classical practices of unity of key. Such necessities, by the time of this symphony, had vanished from the musical language.

Avant-garde conceptions of harmony. The course of harmony after Wagner followed three distinct paths. (1) Within the broad outlines of tonality, composers explored the potential of chords of far greater complexity than the traditional triad. In doing so they often allowed unstable chords such as dominant sevenths to stand as self-sufficient entities, and they greatly increased the use of ambiguous chords such as augmented sixths and diminished sevenths to thicken or occasionally to blur the sense of a stable tonality. (2) Composers broke away from the classical system of tonality by using chords that, although clearly recognizable as derived from earlier harmonic practices, resolved in other than the expected direction. Some also went further afield by substituting for the major and minor scales unusual scales such as whole tone and Gypsy folk music scales, by using chords built out of fourths, and by utilizing polytonality. (3) Composers systematically abandoned tonality through Schoenberg's technique of granting equal importance to all 12 chromatic tones, rather than allowing one tone to predominate as tonic. When this was done, the concept of a single, predominant key centre vanished entirely in favour of atonality. In such cases, the traditional duality of consonance and dissonance also disappeared.

New ways of creating harmony

Among most "progressive" composers of the 20th century, atonality has been extensively explored. By far the greatest concern among avant-garde composers has been to revive contrapuntal writing, or composition stressing the combination of independent melodic lines. This was partly a reaction against the lush harmonies and lyricism of the Romantic period. During the common practice period any counterpoint that occurred was subordinated to the principles of traditional harmony. The 20th-century obsession with counterpoint tended to sweep aside concern with harmonic relationships beyond the incidental fact that clusters of notes in counterpoint are indeed heard simultaneously. In the music of the American Charles Ives, for example, many skeins of fully developed atonal, contrapuntal writing pass by simultaneously, producing momentary sonorities. Such sonorities may occasionally, and quite accidentally, be identical with recognizable harmonies; but these accidental sonorities have little to do with traditional harmonic organization. Similarly, the "tone-cluster" writing of another American innovator, Henry Cowell, whereby a pianist's forearm sounds every note it can depress at once, can hardly be analyzed as functional harmony in any sense.

Other developments, too, point to the dissolution of traditional attitudes toward harmony. The aleatory, or indeterminacy, experiments of John Cage, Earle Brown, and others assign part of the composer's melodic, harmonic, and rhythmic events to a specific performer at a specific instance. In such music any discussion of harmonic direction is irrelevant. Most importantly, the rise of electronic music, which breaks away from any traditional scales such as might be produced on "normal" instruments, can only with the greatest stretch of the imagination lend itself to considerations of harmony.

Yet, there is a possible analogy with traditional harmony in electronic music as its musical styles and languages take shape. In the works of Karlheinz Stockhausen, one of the electronic pioneers and a composer of enormous influence among his younger colleagues, there are organizational systems that point to a clear control and regulation of musical elements. The strict control of musical factors such as densities of sonority, rates of rhythmic change and of change in phrase structure, rates of change in the spread of sound in an auditorium through the use of carefully positioned and modulated loudspeakers point toward a new musical system that may possibly be analyzed in terms of a new, fundamentally different harmony.

Search for a new order

The dissolution of harmony in the "progressive" music of the 20th century was not a matter of anarchy replacing order. Actually, the common practice period is of relatively short duration against the entire history of harmony. Before Bach other rules existed. Such rules, in contrast to the later system of traditional harmony, depended not on the contrast of keys but on harmonic unity brought about by the use of a given mode. Since Debussy, similarly, harmonic styles have been dictated by new rules or by the desire of many composers to seek out new rules. And, as both the modal and the common practice systems of harmony evolved only after centuries, so is it also safe to predict that the seeming anarchy of much of 20th-century music represents a state of movement toward new harmonic precepts. The question at hand, moreover, is not one of the dissolution of harmony itself, for any notes sounded simultaneously produce a harmony—whether the notes be from traditional scales or from the infinity of musical pitches produceable through electronic means. The

matter is, rather, the question of the uses to which these harmonies are put and the changing relations of harmony to musical structure.

An awareness of the value of harmony as pure, expressive sound persists among all composers of the present time. Some have pursued the atonal principles toward the point where harmonic sounds are totally dissonant (which is the same as saying that they are all consonant, because the contrast between consonance and dissonance disappears). Others have written works that consist of almost nothing but static, unadorned harmony—not necessarily harmoniousness. Such a work as Terry Riley's *In C*, for example, consists basically of a sustained triad on C (lasting, at the performer's option, anywhere from 30 minutes to several hours), over which fleeting dissonances are occasionally sounded, seldom more revolutionary than an F sharp or B flat. Here again, although one is more conscious of harmony in this work than of any other musical element, the harmony itself does not move or progress in the traditional sense; the sound exists, but not its function. Here one can discuss the work as pure consonance—which is the same, for lack of harmonic contrast, as pure dissonance.

Thus, in the 20th century the concepts basic to traditional harmony began to lose their importance. In counterpoint harmonies became the incidental result of the combination of melodic lines. New experiments with unusual harmonies (such as tone clusters, functionless in the traditional sense), the lessening of the tension between consonance and dissonance, and the creation of unprecedented harmonies by the use of computers have been the result of a search for new methods of musical organization. This in turn was the natural outgrowth of the blurring and final dissolution of the harmonic system that had prevailed for over two centuries in Western music. (A.Ri.)

COUNTERPOINT

A peculiarly Western phenomenon, counterpoint is the art of combining different melodic lines in a musical composition. It is the most characteristic element in Western music and a major distinguishing feature between the music of the West and that of the Orient and of primitive peoples.

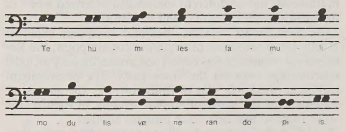
Counterpoint and polyphony distinguished

The word counterpoint is frequently used interchangeably with polyphony. This is not properly correct since polyphony refers generally to music consisting of two or more distinct melodic lines, while counterpoint refers to the compositional technique involved in the handling of these melodic lines. Good counterpoint requires two qualities: (1) a meaningful or harmonious relationship between the lines (a "vertical" consideration—*i.e.*, dealing with harmony), and (2) some degree of independence or individuality within the lines themselves (a "horizontal" consideration, dealing with melody). Musical theorists have tended to emphasize the vertical aspects of counterpoint, defining the combinations of notes that are consonances and dissonances, and prescribing where consonances and dissonances should occur in the strong and weak beats of musical metre. In contrast, composers, especially the great ones, have shown more interest in the horizontal aspects: the movement of the individual melodic lines and long-range relationships of musical design and texture, the balance between vertical and horizontal forces, existing between these lines. The freedoms taken by composers have in turn influenced theorists to revise their laws.

The word counterpoint is occasionally used by ethnomusicologists to describe aspects of heterophony—duplication of a basic melodic line, with certain differences of detail or of decoration, by the various performers. This usage is not entirely appropriate, for such instances as the singing of a single melody at parallel intervals (*e.g.*, one performer beginning on C, the other on G) lack the truly distinct or separate voice parts found in true polyphony and in counterpoint. Finally, contemporary theorists generally use the word counterpoint in a narrow sense for musical styles resembling those of Palestrina or Bach and emphasizing clear melodic relationships (*e.g.*, melodic imitation) between the voice parts.

Counterpoint can be considered more broadly, however, as an essential element in many styles within Western music. Composers in different periods have used counterpoint differently: in the Middle Ages they used it for the superimposing of different rhythmic groupings; in the Renaissance for melodic imitation; in the Baroque for contrasts between groups of instruments or voices; in the Classical period in conjunction with tonality, the organization of music in terms of key; in the Romantic in the combining of leitmotifs, or short melodic fragments; and in 20th-century music in the arrangement of isolated components of sound.

Counterpoint in the Middle Ages. The earliest examples of actual written counterpoint appear in the late 9th-century treatise *Musica enchiriadis*. Here a plainchant



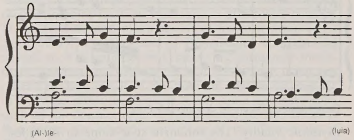
Early organum; from *Musica enchiriadis* (*c.* 859).

Organum: the earliest counterpoint

melody, or "principal voice" (*vox principalis*), is combined with another part, "organal voice" (*vox organalis*), singing the same melody in parallel motion a perfect fourth or fifth below (*e.g.*, G or F below C). Such music was called organum, probably because it resembled the sound of contemporary organs. In the early 11th century the teacher and theorist Guido of Arezzo in his *Micrologus* described a variety of organum in which the accompanying or organal voice had become more individualized. In addition to moving parallel to the main voice, it included oblique (diverging or converging) motion and contrary (opposite) motion. In this era the organal voice remains melodically awkward and subservient to the chant voice, as though it were composed one note at a time simply to colour or ornament each note of the chant. Early organum is thus not far removed from heterophony. Until the end of the 11th century organum was written entirely in note-against-note style, described, in 1336, as *punctus contra punctum* (point against point—*i.e.*, note against note), hence the name counterpoint.

In the 12th century true polyphony comes into being; the melodic lines become individualized mostly by being given different rhythms. There emerges a hierarchy between the voice parts. The emphasis is upon the chant voice, which now becomes the lower part. Its notes are prolonged, or "held," and this part is now called the tenor, from the Latin *tenere*, to hold. The contrapuntal genius of the Middle Ages realizes itself mostly through the use of rhythmic contrasts between the different voice parts, and such contrasts gradually increase in complexity from *c.* 1100 to *c.* 1400. Around 1200 Pérotin, composer at Notre Dame in Paris who wrote some of the earliest music in three and four parts, superimposed different rhythmic modes (short fixed rhythmic patterns) in the voice parts. In his three-part *Alleluia Nativitas*, the voices are in different rhythmic modes, and they are also distinguished

Medieval rhythmic complexity



From *Alleluia Nativitas* by Pérotin.

by different phrase lengths, consisting of more or fewer repetitions of the rhythmic pattern. During the 13th century such contrasts were carried still further in the motet, a musical form usually in three voice parts, each in a different rhythmic mode. The theorist Franco of Cologne advocated the use of consonance at the beginning of each measure; such consonances (usually a chord made up of

the unison, fifth, and octave, such as C–G–C) served as fixed pillars in terms of which the horizontal extensions of different rhythmic lengths were like soaring arches of sound. The tenor voice part in the motets of the 14th and early 15th centuries was organized by huge rhythmic recurrences known as isorhythm (*i.e.*, the return throughout the piece of a complex rhythmic pattern, not necessarily in conjunction with the same pitches of the melody). During the 14th century, particularly in the works of Guillaume de Machaut, the upper voice part was sometimes displaced by a beat or more in respect to the other parts, giving it further rhythmic independence. In the late 14th century complicated syncopations (displaced accents) and the simultaneous use of different metres characterized some of the most complex counterpoint in history.

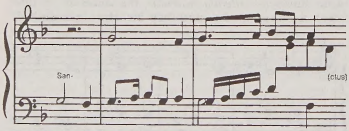
The Renaissance. If the medieval composer explored mostly the possibilities of rhythmic counterpoint, the Renaissance composer was concerned primarily with melodic relationships between the voice parts. The predominant technique used was that of imitation; *i.e.*, the successive statement of the same or similar melody in each of the voice parts so that one voice imitates another.

Imitation had appeared earlier in the Italian caccia and French *chace*, roundlike vocal forms of the 14th century, and in England in the 13th-century round, *Sumer is icumen in*. These compositions anticipate the Renaissance and also emphasize the rhythmic relationships typical of medieval counterpoint.

During the Renaissance the technique of imitation contributed to a new unity between the voices, as opposed to the hierarchy found in medieval counterpoint. Renaissance composers strove also for clear melodic relationships between voices; consequently imitations usually began on the same beat of a measure and were separated in pitch by simple intervals such as the fifth (as, C–G) or octave (as, C–C). The Renaissance theorists, among them Johannes Tinctoris and Gioseffo Zarlino, categorized dissonances according to type and governed each type by definite rhythmic and melodic restrictions.

Golden age of melodic counterpoint

What is often proclaimed as the "golden age" of counterpoint—meaning melodic counterpoint—stretches from the late 15th to the late 16th century, from the Flemish master Jean d'Okeghem to the Spanish Tomás Luis de Victoria and the Elizabethan William Byrd. Its leading masters were Josquin des Prez, Giovanni Pierluigi da Palestrina, and Orlando di Lasso. The northern composers in particular showed a penchant for complex melodic relationships. Okeghem's *Missa prolationum* (*Prolation Mass*), for example, involves simultaneous canons in two pairs of voices. (In a canon, one melody is derived from another. It may be identical, as in a round, or it may be given various alterations, as of speed, or metre or omission of certain notes.) The most versatile craftsman of the Renaissance was Josquin, whose music displays a continual variety of contrapuntal ingenuities, including melodic imitation. His use of successive imitation in several voices, as in his *Missa da pacem* based on the chant melody "Da pacem" ("give peace"), is coupled with melodic smoothness and

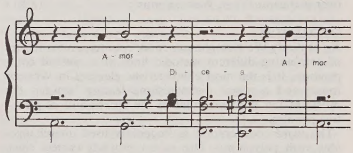


From *Missa da Pacem* by Josquin des Prez.

rhythmic vitality. The imitative style came to its fullest flowering in the late 16th century not only in the masses and motets of di Lasso and Palestrina but also in secular songs such as the French chanson and Italian madrigal. It also flourished in instrumental music in such contrapuntal forms as fantasias, canzonas, and ricercari.

The Baroque period. During the 17th and early 18th centuries the pure linear—*i.e.*, melodic—counterpoint of the Renaissance, now called the first practice, was retained alongside the newer type of counterpoint known as the second practice. This latter type was characterized by a freer treatment of dissonances and a richer employment of tone colour. The new liberties with dissonance disturbed the conservative theorists of the time; but they were justified by their proponents on the ground that they allowed a more expressive treatment of the text. Still more distinct was a new use of tone colour. Although the individual melodic lines often resembled those of the Renaissance, they were intensified and made to stand out through differences of scoring or instrumentation. In figured bass compositions (in which a keyboard instrument improvised the harmonies over a given bass melody) the counterpoint was between the upper melody and the bass line. These stood out clearly from one another because of their differences of instrumental or vocal tone colour. Also significant at this time was the development of concerto-like scoring. In a concerto a soloist or group of instruments is contrasted with the entire orchestra. Hence concerto style emphasized contrasts between the numbers of performers, the high and low registers, and the tone colours of two or more performing groups. This was anticipated in some of the madrigals (Italian part-songs) of the late Renaissance, especially those of Luca Marenzio and Don Carlo Gesualdo, in which two or three voice parts in a high or low register were immediately answered by parts in a contrasting register. Giovanni Gabrieli of Venice expanded this principle in his *Symphoniae Sacrae* (*Sacred Symphonies*) by setting off choirs of voices or instruments, thus achieving a counterpoint of contrasting sonorities. Such concerto-like effects became an essential part of the later madrigals and operas of Claudio Monteverdi. In his madrigal *Lament of the Nymph*, a single soprano voice is pitted against three male voices, and both in turn against

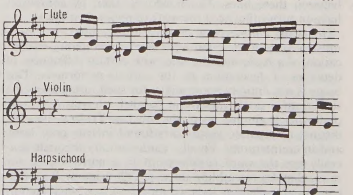
Influence of the concerto



From *Lament of the Nymph* by Claudio Monteverdi.

an instrumental continuo (figured bass played, for example, by cello and harpsichord) in the background. This type of counterpoint was ideal for emphasizing dramatic-contrasts in the new forms of the opera and the oratorio. In these forms soloists, ensembles, and instrumental parts were opposed and combined in a great variety of ways by composers like Heinrich Schütz, Giacomo Carissimi, and Henry Purcell. In the late Baroque Arcangelo Corelli and Antonio Vivaldi added this style of dramatic contrasts to the purely instrumental contrasts of the concerto.The Baroque concerto culminated in the *Brandenburg Concertos* of J.S. Bach, which are characterized by a remarkable fusion of contrapuntal lines and instrumental colours.

Bach's counterpoint has a retrospective side, which uses a mainly melodic approach. The fugue, a composition using the technique of melodic imitation, became highly developed in Bach's hands—*e.g.*, the fugues of the *Well-*



From *Brandenburg Concerto No. 5* by J.S. Bach.

Tempered Clavier and his final compendium of contrapuntal devices, *The Art of the Fugue*. A similar melodic, rather than tone-colour, approach occurs in works such as the *Inventions* and in the canons of the *Musical Offering*. These works are akin to "the first practice," the melodic counterpoint of the Renaissance, although in their use of dissonance and harmony they go considerably beyond Renaissance convention.

The Classical period. The turn from the Baroque to the Classical period in music was marked by the change from a luxuriant polyphonic to a relatively simple homophonic texture—*i.e.*, a texture of a single melodic line plus chordal accompaniment. Composers of the early Classical period (*c.* 1730–70) largely eschewed counterpoint altogether, drawing on it only when preparing church music in the "learned style," as the Renaissance style was then called. Many of the keyboard sonatas of Domenico Scarlatti and Carl Philipp Emanuel Bach, despite a basically homophonic approach, reveal a skillful interplay between the main melody and accompaniment. In the late Classical period (*c.* 1770–1820), especially in the music of the Viennese school of Haydn, Mozart, and Beethoven, there was an ever-increasing penetration of counterpoint into musical forms based on this homophonic style and its contrasts of tonality, or key (see above *Harmony*). This counterpoint in turn was tempered by the Classical style and musical forms. For example, although combined melodic lines are heard as counterpoint, together they can also be heard as a series of harmonies. In this way they form unified phrases in the homophonic style. This satisfied demands for symmetrical phrase lengths and clear-cut cadences, or stopping points, necessary to mark the sections of Classical forms such as the sonata.

Use of counterpoint by Haydn, Mozart, and Beethoven

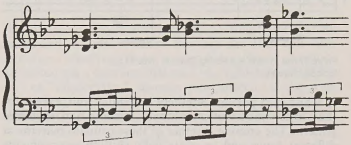
Haydn underwent his contrapuntal "crisis," or movement toward counterpoint, during the 1770s, the period of *Sturm und Drang* ("Storm and Stress") in German literature, which had a deepening effect on other arts as well. Three of his *Sun Quartets* (1772) had fugues as final movements, and in the *Russian Quartets* (1781) Haydn proclaimed "an entirely new manner," in which the thematic material was to be more equally shared by all of the stringed instruments instead of being given to a single principal melody instrument. Haydn heard Handel's oratorios in London, which inspired him to write his own richly contrapuntal late oratorios, *The Creation* and *The Seasons*.

Mozart's discovery of the contrapuntal art of Bach and Handel impressed him so deeply that almost all of his later works were affected. The ensembles of the operas—*e.g.*, *Don Giovanni* and *Così fan tutte*—with their clear delineation of several characters through their vocal lines, only became possible because of his new feeling for counterpoint. And at one point in his *Jupiter Symphony* five different themes are stated simultaneously, singly, or in combination. Nevertheless the counterpoint is kept entirely subservient to the harmonies of the symphony's tonal design, or its use of keys. Each voice is also governed by an underlying phrase structure applied to all of them, so that the combined parts form unified musical phrases.

Beethoven began his career in Vienna under the tutelage of the noted contrapuntal theorist Johann Albrechtsberger, and this, coupled with his admiration for Handel, probably accounts for his lifetime interest in counterpoint. He drew upon counterpoint to create musical intensity, especially in the development section of sonata form (the form prominent in Classical symphonies and chamber music), as in the first movement of the *Razumovsky Quartet*, Opus 59, No. 1, for example. In his late sonatas and quartets, except for obvious fugal works such as the first movement of Opus 131, or the *Great Fugue*, Opus 133, almost every movement shows the interpenetration of the principles of counterpoint, which deals with melodic lines, and tonality, which deals with harmonies.

The Romantic period. Counterpoint in the 19th century had a retrospective side in addition to a characteristically Romantic style. Richard Wagner admired the counterpoint of Palestrina, and Johannes Brahms revered the Baroque masters. Felix Mendelssohn revived Bach's *St. Matthew Passion* in 1829, and this led to numerous Bach-like works, such as the organ sonatas of Mendelssohn and numerous organ works by Max Reger, as well as arrangements of Bach's works by Franz Liszt. Yet the true bent of Romantic composers was toward combinations of motives (small melodic fragments), use of motivic accompaniments against themes, and, later, of the combination of leitmotifs, or motives with significance beyond the music itself. The lieder (songs) of Franz Schubert were highly innovative because of their motivic accompaniments, which balance in interest the vocal part itself and contrapuntally interact with it. This technique is still more pronounced in the songs of Robert Schumann and Hugo Wolf. It is also the tendency in 19th-century opera. In the later operas of Giuseppe Verdi the voices often have a parlante character (imitating speech through music) while the orchestra defines the dramatic substance. This, too, is the principle of the Wagner music dramas, with their "speech-song" (*Sprechgesang*) in the voice balanced contrapuntally by the leitmotifs of the accompaniment. In *Tristan und Isolde* Wagner set the leitmotifs in counterpoint against one another. Similarly, in the Prelude to

Combinations of motives and leitmotifs



From *Siegfried* (Act III) by Richard Wagner.

Act III of *Siegfried*, a motive known as the "Need of the Gods" is cast against one associated with the "Valkyries." This results in a "counterpoint" of connotations and of emotions as well as in a musical counterpoint. In purely instrumental music a similar joining of motives previously heard separately is encountered in the finale of Hector Berlioz's *Symphonie fantastique* when the plainchant melody "Dies Irae" ("Day of Wrath") is heard together with the theme called "Round of Sabbath." Richard Strauss, in his tone poem *Ein Heldenleben (A Hero's Life)*, skillfully combines several themes taken from his earlier tone poems. And in the late symphonies of Gustav Mahler there is sometimes a complex of interwoven motives, each of which stands out contrapuntally through its presentation by a solo instrument.

In the 20th century Arnold Schoenberg carried this technique further, especially in his 12-tone works, which are based on a 12-tone row, or specific ordering of the 12 notes of the chromatic scale, arranged in such a way as to avoid a sense of tonality. In some 12-tone operas—*e.g.*, *Moses und Aron* by Schoenberg and *Lulu* by Alban Berg—there is but one tone row used in the entire work; nonetheless, several hours of music are spun out of it through a continual variety of thematic shapes and contrapuntal combinations.

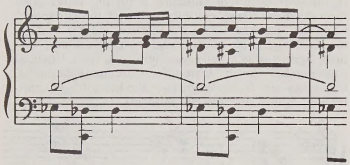
The 20th century. The 20th century, like the 19th, has had its counterpoint inspired by earlier music. Anton Webern, for example, advocated a return to the forms of counterpoint used by Renaissance composers such as Heinrich Isaac, and in numerous of his own works (*e.g.*, *Symphonie*) he makes use of Renaissance contrapuntal devices such as simultaneous canons and retrograde movement between the voice parts—*i.e.*, one voice using the other's melody but with the notes in reverse order. Out of a similar return to Baroque forms came musical works such as the double fugue (a fugue based on two themes) that forms the second movement of the *Symphony of Psalms* by Igor Stravinsky.

But the use of older musical forms is no more of the essence of 20th-century counterpoint than it was of the 19th. A basic characteristic of 20th-century counterpoint is the separation of the voice parts into isolated entities of sound that are of themselves rather static. This may take the form of polytonality (the simultaneous use of two or more keys), using as static entities the notes of each key. It may also take the form of contrast of individual tone

Counterpoint of polytonality and tone colours

colour effects, rather than of melodies, found in much electronic music. (This use extends beyond the original definition of counterpoint simply as the combination of melodies.)

Richard Strauss's *Elektra* (1909) was one of the earliest works to make use of polytonality; in certain passages the instruments and voice parts are grouped into layers, each of which defines a different tonality, or key, although in this case all of the keys can also be interpreted as complicated aspects of the basic key. Stravinsky's *Three Pieces for String Quartet* (No. 1) suggests four keys at the same time: G, B, D, and A♭. In this particular work each instrument is limited throughout the piece to a few notes assigned to



From *Three Pieces for String Quartet* (No. 1) by Igor Stravinsky.

it. Thus each part is absolutely individual and, except for the viola, consists of an ostinato melodic and rhythmic pattern. The coming together of these ostinato patterns at different times and in continually shifting arrangements suggests the effect of a mobile.Béla Bartók carried out a similar procedure in many of the short piano pieces of his *Mikrokosmos,* and in his *Fourth Quartet* (1928) he set apart tone clusters (chords built up in seconds, as C–D–E–F–G) in this way.

Turning now to a counterpoint purely of tone colours, *Intégrales* (1925) by Edgard Varèse presents 11-note "sound-clouds" in the wind instruments in opposition to the sounds of a large battery of percussion instruments. This approach probably grew directly out of earlier experiments with polytonality, but here tone colours, rather than keys or tones, are differentiated. Elliott Carter in his *Double Concerto* (1961) set apart two groups of instruments, one around a piano, another around a harpsichord, each with its distinctive tone colours and its own distinctive harmonic intervals or note combinations. In György Ligeti's *Atmospheres* every instrument in a symphony orchestra, including every string part, plays its own unique, melodic pattern; all of these parts coalesce into gigantic bands, or spectra, of tone colour that contrast with one another. In later experiments, the sound-producing groups are further set off by visual or spatial contrasts in the physical placement of performers; *e.g.,* Ramon Zupko's *Third Planet from the Sun,* 1970.

The literature of counterpoint. Most of the writings on counterpoint have sought to increase the student's skill in musical composition. From the 18th century onward, textbooks of counterpoint have recommended as a model usually Palestrina or Bach, and in some recent cases 20th-century composers. Medieval and Renaissance treatises also were originally intended for student guidance and reflect the taste and attitudes of their own time. Several 20th-century studies deal with the contrapuntal technique of a particular composer or group of composers.

(R.J.J.)

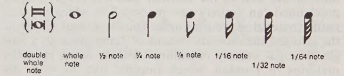
NOTATION

Broadly defined, musical notation is a visual record of heard or imagined musical sound, or a set of visual instructions for performance of music. It usually takes written or printed form and is a conscious, comparatively laborious process. Its use is occasioned by one of two motives: as an aid to memory or as communication. By extension of the former, it helps the shaping of a composition to a level of sophistication that is impossible in a purely oral tradition. By extension of the latter, it serves as a means of preserving music (although incompletely and imperfectly) over long periods of time, facilitates performance by others, and presents music in a form suitable for study and analysis.

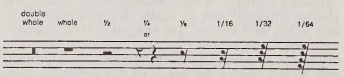
The primary elements of musical sound are pitch, or the location of musical sound on the scale (hence interval, or distance, between notes); duration (hence rhythm, metre, tempo); timbre or tone colour; and volume (hence stress, attack). In practice, no notation can handle all of these elements with precision. Most cope with a selection of them in varying degrees of refinement. Some handle only a single pattern—*e.g.,* a melody, a rhythm; others handle several simultaneous patterns.

General principles of Western staff notation. The position of staff notation as the first notational system to be described in this article acknowledges its international acceptance in the 20th century. As an indirect result of colonization, of missionary activity, and of ethnomusicological research—not because of any innate superiority—it has become a common language among many musical cultures.

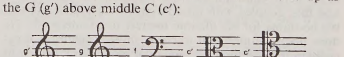
Pitch and duration. Staff notation, as it has developed, is essentially a graph. Its vertical axis is pitch, its horizontal axis, time; and note heads are dots plotting the graph's curve. The five horizontal lines of a musical staff function like horizontal rulings of graph paper, bar lines like vertical rulings. In practice, the system is far more complex and sophisticated than this. The vertical axis of pitch operates to represent melodic contour in music for a single instrument or voice; but when several staves are combined to form a score, the principle breaks down, each staff being a self-contained vertical system. Representation of time (duration) by horizontal spacing is used only in a very limited way. It is in reality made almost redundant because the symbol for a note gives the necessary information itself: not its absolute duration but its duration in relation to the notes around it. These symbols are as follows; each has half the duration of its neighbour to the left:



A system of "rests" measures silence in the same way:



A dot placed to the right of a note head increases by half the duration of that note. Such symbols when placed on a staff may indicate relative pitch and relative duration. In the grid, lines represent alternate notes of the scale and the spaces the intervening notes. Pitch and duration may be fixed by supplying two further indications: a clef and a tempo mark. The clef assigns a definite pitch to a given line of the staff; the first clef fixes the second line up as the G (g′) above middle C (c′):

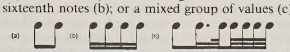


Tempo and duration. The tempo mark is a sign that lies outside the staff. It appears above and may be a precise fixing of one duration ("♩ = 120 MM" means that the quarter note lasts $^1/_{120}$ of a minute, or one-half second), or it may be an approximate verbal indication setting tempo by reference to accepted conventions (allegro, or quickly; moderato, or moderate speed; etc.).

Staff notation is well adapted to two fundamental aspects of Western music: harmony and rhythm. For harmony, note symbols can easily be placed vertically together on a single stem, and these notes need not be all of the same

duration; or more than one stem may be used to indicate multiple melodic lines in the musical texture. For rhythm, the existence of an underlying regular pulse, or stress, must be indicated. This is achieved by two devices: the bar line and the time signature. The bar line primarily indicates a point of main stress. Bar lines are usually equally spaced as to duration, though there are numerous exceptions. A time signature indicates, first, the duration of the space between two bar lines (a measure, or bar); and, second, the subsidiary stress patterns within that space. A supplementary system for indicating stress is the device of linking successive notes together by beaming, or stroking. Two eighth notes may be linked together as shown in (a); four sixteenth notes (b); or a mixed group of values (c):

The function of a time signature



The implication of such grouping is generally that the first note carries a stress. Beaming thus may be used either to reinforce the stress patterns of the time signature (the metre) or to contradict it and set up a cross rhythm.

Accidentals. Staff notation rests firmly on the Western system of scales, within which all notes are assumed to be natural unless accidentals precede them or a key signature is in use. An accidental (♭, or flat; ♯, or sharp) is a temporary lowering or raising of pitch by a semitone; a key signature is the use of the same signs on a more permanent basis, valid to the end of a piece or until countermanded by a new signature. Another accidental, the natural (♮), cancels a previously indicated flat or sharp and may be used to alter one note or in a key signature to emphasize a key change. Any combination of sharps or flats is theoretically possible in a key signature, but the actual combinations are usually governed by the Western system of keys, or groups of interrelated notes and chords.

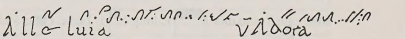
Auxiliary signs. Timbre and volume are specified through a variety of additional signs: symbols such as ≻ (stress) and ——— (increase in volume), and verbal instructions (frequently in Italian) such as forte (loud) and col legno (with the wood of the bow) placed above or below the staff wherever space permits. Additional symbols may also provide information about pitch and duration: the dot for staccato, the fermata, or hold sign (𝄐), the phrase mark, indications of amount of vibrato, and so forth. Other verbal instructions indicate the general manner of performance (pesante, "heavy"; cantabile, "songlike"; etc.) or expression (con dolore, "with suffering"; giocoso, "playfully"; etc.). Further, there are for each type of instrument certain technical signs, as for bowing, breathing, tonguing, or use of mutes.

Types of musical "shorthand"

Other auxiliary signs are a kind of shorthand. Most important are symbols indicating notes not shown on the staff. An ornament sign may call for additional notes to be played within the value of a note. It may even delay the sounding of the main note. The precise meaning of such an ornament varies from one style of music to another and must be interpreted according to the conventions governing a particular style.

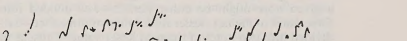
Comparable to the use of "shorthand" signs for ornaments is the system of placing arabic numerals beneath a bass line in keyboard music of the 17th and 18th centuries. A numeral, or "figure," signifies a harmonic (*i.e.*, a vertical) interval; thus a "6" indicates a note six degrees of the scale above a given bass note (A above C, for example). It is in itself an imprecise measurement, specifying neither whether the interval is major or minor nor in which octave register that upper note should be played. But the figures are governed by the same prevailing key signature as notes on the staff and can, like notes, carry their own accidentals. They are thus not an independent type of notation but a hybrid representation of interval/pitch that works in conjunction with staff notation. Its purpose is to indicate the harmonies implied by a bass line (even absence of figuring has a meaning) while at the same time leaving the player free to choose the precise notes to be played. The systems of letters and figures used by jazz musicians have this same imprecision; they are less dependent upon conjunction with staff notation but lack clear rhythmic significance unless allied to staff notation in at least a simplified form. They operate by defining a harmony in relation to the tonic chord (the chord built on the key note, or tonic) rather than by interval or pitch.

Evolution of Western staff notation. *Neumes.* Staff notation has its roots in the neumatic notations of plainchant and secular song of the 9th–12th century. Neumes were graphic signs indicating essentially the rise and fall of the voice. Their origin lies probably 1,000 years earlier in signs devised by Greek and Roman grammarians to guide declamation, such as ∕ *acutus* (high voice), ∖ *gravis* (low), and ∧ *circumflexus* (falling). The musical adaptations of these signs took many different regional forms. Unlike note symbols in staff notation, neumes, with two exceptions, comprised two, three, four, or more notes each and indicated their approximate relative pitches. Each comprised the notes belonging to a single syllable of text, though in florid chant the notes of a single syllable might be split up into several neumes:



Neumes were only a memory aid to singers who knew words and melody by heart. Between the 10th and 12th centuries, however, there occurred significant developments toward a notation that could be sight-read. "Heightened," or "diastematic," neumes were spaced on the page in relation to each other, so that an entire line of them formed a continuous graph of pitch over the words of text:

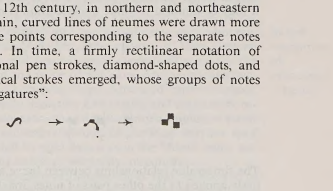
Sight-reading developments



Eventually, precision of pitch was further achieved by using horizontal scratched lines as a grid on which to space the neumes, so that degrees of the scale fell alternately on a line or in a space, and by colouring one line red to signify the pitch F and possibly another yellow to signify C—or by placing a letter F or C at the beginning of the appropriate line. Together, the two devices fixed the relative pitches of all notes by indicating where the semitones of the scale occurred (that is, immediately below the marked lines: E–F or B♮–C). In the 11th century two signs from a quite different system of notation (alphabetical notation; see below) were incorporated as accidentals before the pitch "B": b, the ancestor of ♭; ♮, the ancestor of ♮ and ♯, and also of the German "h," which refers to B♮. These two signs were progressively applied to other pitches in the following centuries. By the 13th century a four-line staff ruled entirely in black or red had become established, using stylized forms of the letters *f*, *c*, and *g* (ancestors of the modern 𝄢, 𝄡, and 𝄞) as clefs. For polyphonic music a five-line staff became standard by the 14th century, but keyboard music in some countries used six- or seven-line staves as late as the mid-17th century.

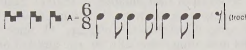
Adoption of the five-line staff

During the 12th century, in northern and northeastern France the thin, curved lines of neumes were drawn more thickly at the points corresponding to the separate notes within them. In time, a firmly rectilinear notation of heavy horizonal pen strokes, diamond-shaped dots, and hairline vertical strokes emerged, whose groups of notes are called "ligatures":



This was the notation of the troubadours' and trouvères' songs; also of plainchant from the 13th century to the present day. It was also used in 12th-century polyphony

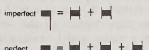
for the upper voices, which were without text. Freed from syllabic considerations, the grouping of notes into ligatures took on rhythmic significance, specific groupings representing short, repeated patterns called rhythmic modes:



A ligature did not yet have a single, unvarying meaning. Its rhythmic pattern depended upon context.

Mensural notation. The freeing of ligatures from considerations of context occurred during the early 13th century. Time values for ligatures, single notes, and rests were codified around 1260 by the influential theorist Franco of Cologne. The notes then in use included the duple long, later called maxima ( ); long ( ); breve ( ); and semibreve ( ). In French music a shorter note value was created: the minim ( ).

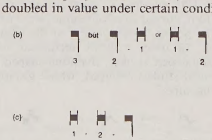
These note symbols provided the basis for notation from the late 13th to the late 15th century. This system, called mensural notation, was based on several fundamental principles that determined the value of a note relative to that of its neighbours. In the terminology of mensural notation a given note might be either perfect—*i.e.*, divided into three notes of the next lesser time value; or imperfect—*i.e.*, divided into two notes of the next lesser value. Thus, as in part (a) of the example below, a long might be perfect, containing three breves; or imperfect, containing two breves.



To determine which note symbols were perfect and imperfect for a given piece, special symbols were devised: , , , , , , , etc.

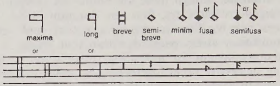
(Of these and survive, together with fractions such as , as modern time signatures.)

Specific rules provided for lengthening or shortening the value of notes in certain instances. To "imperfect" a long meant to shorten it by one-third of its value; this occurred when the long was preceded or followed by a breve or by notes equalling a breve in value, as shown in part (b) of the example below (for purposes of illustration, numbers have been placed under the notes showing their time value relative to the shortest note). Part (c) of the example shows another common alteration of time value: in a composition in which the long is perfect, a breve (brevis) preceding it may be doubled in value under certain conditions.

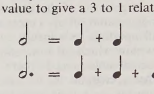


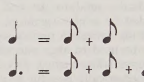
The time-value relationships between breve and long similarly applied to the other pairs of notes: maxima and long (longa); breve and semibreve (semibrevis); and semibreve and minim (minima).

As the system of mensural notation evolved, another device, coloration, came into use. If a composer wished to render a potentially perfect note imperfect, he could write it in red or as a hollow note (as , , or); these two devices had, however, various other, less common meanings. About 1400, hollow note shapes were adopted where full black notes had hitherto been used, and full black served as coloration. The notes then current and their corresponding rests were as follows:



Transition to modern staff notation. In 16th-century manuscripts and, later, in printed music, the diamond-headed notes became rounded. Ligatures were used less often in the later 15th century. The principles of perfection and imperfection gave way to the modern relationship of 2 to 1 between adjacent note values, with the dot adding an extra half value to give a 3 to 1 relationship.





Shorter note values were also introduced, and the old, longer ones became obsolete. Yet, because of a paradoxical survival from 15th-century practice, slow music has tended to be written in short values (*e.g.*, Beethoven's slow movements) and fast music in long values.

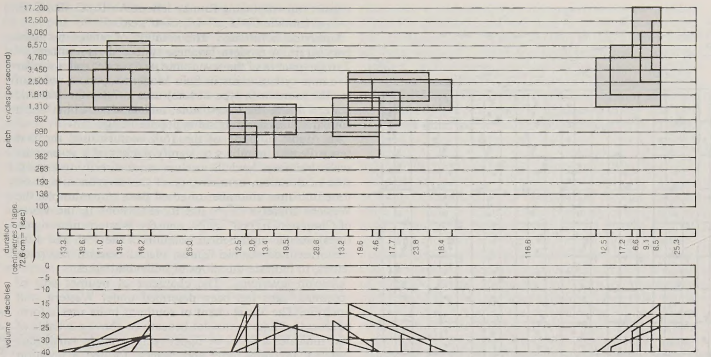
The bar line as a measure of metre arose first in 15th-century tablatures (notation showing playing position rather than pitch, as for lute). Barring entered staff notation in the 17th century, but regularly spaced barring became a practice only in the 18th century. Separate tempo indications, arising first in the 17th century, were verbally expressed; for example, adagio, largo, presto. The range of these terms greatly increased during the 18th and 19th centuries, and the metronome mark, an absolute indication of tempo, has never superseded them since its arrival in Beethoven's day. The bulk of the shorthand devices emerged during the 17th century, figured bass early in the century, the majority of ornamental signs later. Indications for loud and soft arose early in the century, expressed as words (forte, mezzoforte, piano) and later as abbreviations (*f, mf, p*). Graphic signs for dynamic and attack (staccato dot, crescendo mark, for example, and also phrase marking) appeared in the 18th century. A great proliferation of dynamic instructions and signs occurred in the late 19th and early 20th centuries.

Introduction of the bar line

20th-century notation. Two developments in musical style in the 20th century have placed great strain upon staff notation: integral serialism—in which the music is controlled by a mathematical system—and indeterminacy, or chance music. In the former, every note in a texture may have its individual dynamic marking and type of attack (for example, in Olivier Messiaen's *Mode de valeurs et d'intensités* and in parts of *Structures I* and *II* of Pierre Boulez). There may also be extensive use of unconventional playing techniques. Since staff notation indicates volume, attack, and technical effects in a comparatively clumsy manner, the written page becomes cluttered and unclear. In indeterminate and aleatory music (the latter type allowing the performer a limited degree of freedom), the notation must offer choices to the performer or be deliberately imprecise. Staff notation is for these purposes often too specific. In addition, electronic music, composed with such devices as graphs, mathematical symbols, and diagrams, is not easily translated into a readable "score" for publication.

Notation that offers the performer a choice

New systems. Notation, in face of this, has moved in two directions: toward adaptation of staff notation and



Page from the score of Stockhausen's *Electronic Study No. 2.*

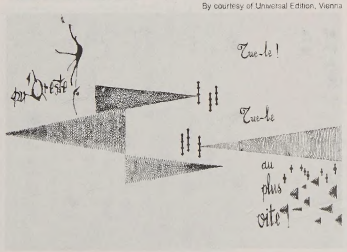
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toward the devising of new notational systems. Music using microtonal intervals (less than a semitone) has tended to adapt by modifying the standard accidental signs—meaning one-third sharp, two-thirds sharp, and so on (*e.g.*, in Krzysztof Penderecki's *Anaklasis*). So-called space time notation is a further adaptation that reasserts the graphic nature of staff notation. It abandons symbolic indication of note values and replaces it by the spacing of note heads horizontally on the staff, accompanied by an instruction such as "1 inch = 1 second." The principle may then be amplified by using different note heads (𝅝, 𝅗𝅥, ♩, etc.) to signify short, medium, and long sustaining of a note, thus obviating the use of rests, and by beaming together notes to be performed in one breath or bow (*e.g.*, Witold Lutosławski's *Trois poèmes d'Henri Michaux* and John Cage's *Music of Changes*).

Indeterminacy. Indeterminate music requires constant experimentation with notation. A composer may offer directions for one element of the music—as rhythm or pitch contour—and leave the performer to improvise the remaining elements. Or he may simply describe the general character of a passage by resorting to a specially designed symbol, a verbal description, or even an impressionistic drawing (as in Earle Brown's *Hodograph*). At the extreme, John Cage supplies "materials" (lines, dots, shapes) and leaves the performer to attach musical significance to them. For electronic music, published scores have so far adopted either strict graph form (Karlheinz Stockhausen, *Electronic Study II*) or pictorial form, using patterned drawings to represent different timbres (as in Henri Pousseur's *Electre* and Stockhausen's *Kontakte*).

Cage's "materials"

By courtesy of Universal Edition, Vienna



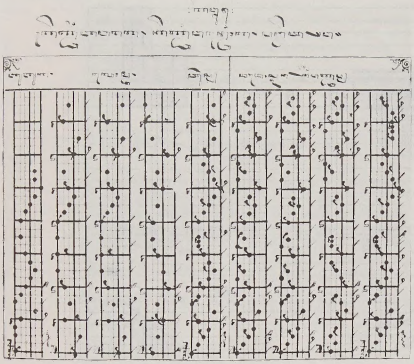
Page from the score of *Electre* by Henri Pousseur.

Adaptation to non-European music. Notations evolve with the musical styles they serve, and they reflect the underlying aesthetics of their own cultures. Thus staff notation is ill-equipped to cope with non-Western scales and tunings, with music to which the idea of the "note" (a stable, sustained pitch) is foreign, or with music whose subtlety lies as much in delicate gradations of volume or timbre as in pitch and rhythm. Ethnomusicologists have developed a range of supplementary symbols—*e.g.*, for notes of uncertain pitch, glissandi (slides), slight lengthening of a value, half-voiced notes, and other sounds. They have also experimented with staves of fewer or more lines. The Western system of proportional note values (for example, quarter note = half of a half note) does not easily cope with fine fluctuations of value; instead, constant changes of metronome tempo mark may be necessary. Among the most complex uses of staff notation in ethnomusicology are the transcriptions of Serbo-Croatian and Romanian folk song by the Hungarian composer Béla Bartók. Other transcribers have used graph paper to draw a curve of pitch against time. Many significant mechanical methods of transcription have been devised. The two most notable are the melograph, invented by the ethnomusicologist Charles Seeger, which traces a pitch/time graph immediately above a volume/time graph, and a device developed by Dahlbeck, which produces two similar graphs by means of a cathode-ray tube. These methods can reveal a level of interpretation by the performer that aural transcription into staff notation fails to bring out.

Other systems of notation. Written notations are to be found in the musical cultures of the Far East, Southeast Asia, South Asia, the Middle East, and the West. Early examples survive from Ancient Egypt and Greece. Notation may be classified into two broad categories: phonetic symbols—words, syllables, abbreviations of these, letters, and numbers; and graphic signs—accentual signs for the rise and fall of the voice (developing into neumelike "ecphonetic" signs), curves, lines, dots, and other symbols, perhaps originally depicting hand signs, and neumes. Symbols in both categories may denote simple sounds or stand for groups of successive sounds. In the West they are read in lines from left to right, whereas in the Orient many are read from right to left or vertically, in columns.

Major categories of notational systems

A second fundamental distinction is that between representational notations, which depict the sound of the music—leaving the player to produce that sound as he wishes—and tablatures, which instruct a player as to the technical means of producing a sound. Phonetic symbols play an important role in both types of notation, while graphic signs contribute mainly to representational nota-



Javanese *kraton* notation.

From Mantle Hood, "Music the Unknown" in Harrison, Hood, and Palisca *Musicology* (1963); reproduced by permission of Prentice-Hall, Inc.

tions. A prime example of non-Western representational notation is the *kraton* notation used in music for the Javanese gamelan orchestra, its grid using the "graph" principle found also in Western staff notation but oriented at a 90° angle relative to the latter.

Verbal and syllabic notations. In oral traditions of music, solmization (the naming of each degree of a basic scale with a word or syllable) is important. The modern European sol-fa method ("do," "re," "mi," etc.) is such a system. The Indian syllables *sa, ṛi, ga, ma, pa, dha, ni* are similar, as are the Balinese *ding, dong, deng, dung, dang;* the ancient five-note Chinese scale *kung, shang, chiao, chih, yü;* and the Korean *tŏng, tung, tang, tong, ting;* and *rŏ, ru, ra, ro, ri* (the two sets being used for different instruments). Slightly different are the 12 chromatic Chinese *lü* syllables: each pitch bears the name of a bell—as *huang chung* ("yellow bell"), *ling chung* ("forest bell")—and its name is reduced to a syllable—*huang, ling, t'ai,* etc. Though primarily for reciting or singing as a melody is being learned, these syllables can be used to write down the notes of a melodic line (each appearing as a single ideogram in the Chinese examples) and thus form a simple syllabic pitch notation. Of the five Balinese syllables, only their vowels are used in written form—*i, o, e, u, a*—so that a letter notation results; this is still an abbreviated syllabic notation, not an alphabetical one.

Notation for duration

In Western plainchant, abbreviated words were used to indicate duration (for example, *c* = *cito* or *celeriter* = "short" value) and direction of melodic movement (*l* = *levare,* and *s* = *sursum* = "upward"). In the notation of early Ethiopian church music a single letter or a pair of letters (short for a passage of text) signified a group of notes, even a complete melodic phrase. The drum syllables of North Indian music are a solmization of timbre (as *na, ta, dhin*) and often also of rhythmic patterns (as *tirikita, dhagina*) and can be written down to make a notation.

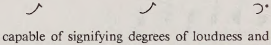
Alphabetical notations. Alphabets are historically a phenomenon of the Middle East, Europe, and the Indian subcontinent. Their ordering of letters provides a convenient reference system for the notes of musical scales in ascending or descending order. Alphabetical notations are among the most ancient musical scripts. Two Greek notations were of this type, the earlier using an archaic alphabet and the latter using the Classical Greek alphabet. Many comparable notations arose in the Middle Ages, and the modern note names, A to G, are an outgrowth of these.

The clefs of staff notations are a formalized survival. The system of pitch notation devised by the 19th-century German philosopher and scientist Hermann Helmholtz was derived from the Greek system, using dashes for octave register but employing Roman letters: A., B., C.–B., C–B, c–b, c′ (middle C)–b′, c″–b″, c‴–b‴, etc.

Numerical notations. The notation of pitches by numbers is rare. A modern Javanese system allots numbers 1–7 to the pitches of the seven-note *pelog* scale, and a similar five-note system exists in Bali. Modern Japanese notation for the samisen (a type of lute) uses 1–7 for the diatonic scale, 7 being the lowest note; and modern China has a similar system for publishing popular songs.

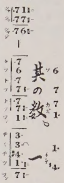
An Arabic notation of the 16th century used the first seven Persian numbers to signify pitches of a seven-note scale. Numbers lend themselves more directly to expression of duration, of metre, or of the division of a basic time unit into a number of equal parts (for example, the Western triplet $\overset{3}{\frown}$ and its extensions in the works of Chopin $\overset{11}{\frown}$ $\overset{21}{\frown}$; and the Western time signatures). Arabic alphabetical notation of the 13th and 14th centuries used Arabic figures, placed beneath the pitch letters, to indicate durations of individual notes.

Graphic notations. The character of neumes and of accentual signs has been described under Western staff notation. The Vedic chant of southern India uses a form of accentual notation: a dot beneath or above a syllable of text indicates a lower or upper reciting pitch. Analogous systems, involving dots and dashes, formed a notation for ancient Jewish cantillation and early Syrian Christian chanting. A more developed form ("ecphonetic" notation) was used for recitation of Byzantine liturgical chants. Besides simple signs for vocal inflection, it also had more elaborate, compound signs, such as



capable of signifying degrees of loudness and changes of voice production. The Western phrase mark and crescendo and decrescendo symbols are graphic signs of this type.

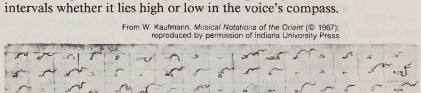
The dividing line between compound ecphonetic signs and neumes is slender. Neumes are concerned not with inflection of the voice between high, medium, and low but with groups of sung pitches rising and falling over a quite narrow range: a neume may represent a given pattern of intervals whether it lies high or low in the voice's compass.



Notation for Japanese samisen from the piece *Tsuru kame.*

From William P. Malm: *Japanese Music;* reproduced by permission of Charles E. Tuttle Co., Inc., Tokyo

From W. Kaufmann, *Musical Notations of the Orient* (© 1967); reproduced by permission of Indiana University Press

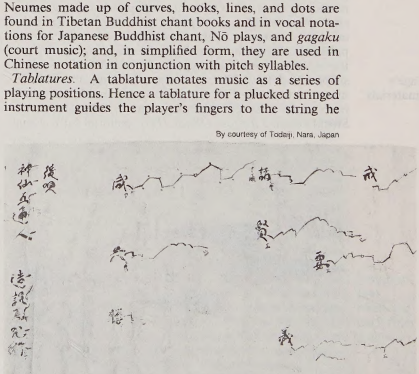


Neumes for a Tibetan Buddhist chant.

Neumes made up of curves, hooks, lines, and dots are found in Tibetan Buddhist chant books and in vocal notations for Japanese Buddhist chant, Nō plays, and *gagaku* (court music); and, in simplified form, they are used in Chinese notation in conjunction with pitch syllables.

Tablatures. A tablature notates music as a series of playing positions. Hence a tablature for a plucked stringed instrument guides the player's fingers to the string he

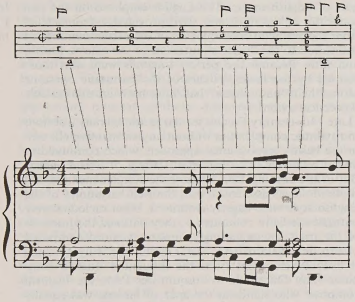
By courtesy of Todaiji, Nara, Japan



Neume notation from the third part of the psalm of Upāli.

must pluck and to the fret at which the string should be stopped. Similarly, a tablature for a wind instrument guides a player's fingers to cover certain holes, and a tablature for percussion directs a player as to which drum to strike, which hand and stick to use, and what type of stroke to execute. Each single instruction in a tablature corresponds to one action by the performer. The order of his actions is automatically prescribed, and more precise rhythmic indication can be given quite easily as the length of time between successive actions—rests are unnecessary. Thus, a tablature for a plucked instrument requires signs for: each string, each fret, and possibly also each right-hand plucking finger, direction of stroke, and ancillary techniques such as harmonics, vibrato, and left-hand plucking. To indicate these, the tablature may use letters, numbers, and graphic signs. Thus 16th-century French lute tablatures indicate the strings (more properly the "courses") graphically as parallel horizontal lines, frets as letters, and right-hand fingering by dots:

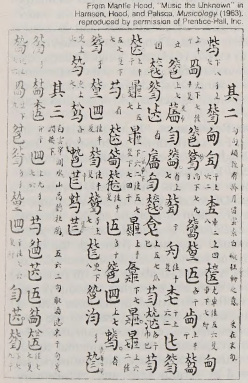
From Francis Pilkington, Brian Jeffrey (ed.), *Complete Works for Solo Lute* (1970), by permission of Oxford University Press, London



Italian lute tablatures use numbers in place of letters.

The tablature for the Japanese koto zither is simpler in that its 13 strings are not stopped. The pitch of each string is indicated at the beginning of a tablature, and thereafter the strings are represented by numbers combined with graphic signs for special technical effects. The tablature for the Chinese *ch'in*, a zither whose strings are stopped, uses a combination of numbers (for strings and for stopping points) and ideograms (for other technical details). These are grouped close together in composite symbols. One composite symbol may contain an ideogram for the left-hand finger; a number for the stopping-point; another number for the string itself; an ideogram for the right-hand finger; and possibly an ideogram indicating loudness, legato, glissando, etc. German 16th-century lute tablature achieved economy of space by indicating string and fret as a single letter (as, *k* = first string stopped at third fret). No grid of lines was necessary. (I.Be.)

From Mantle Hood, "Music the Unknown" in Harrison, Hood, and Palisca, *Musicology* (1963), reproduced by permission of Prentice-Hall, Inc.



Tablature for the Chinese *ch'in*.

HISTORY OF WESTERN COMPOSITIONAL TECHNIQUES

Societal perspectives. Whether referring to the process or to the completed work, composition implies the creation of a unique musical event that may or may not be based on original musical materials. At certain cultural levels and in many non-Western societies, unique performance characteristics tend to assume greater significance than composition itself. In oral traditions, related variants of common origin often take the place of unalterable musical entities, so that tune families rather than single autonomous tunes form the collective repertoire. Where certain patterns of musical structure have gained broad recognition (as the ragas, or melody types, of India), musicians will as a rule rework such patterns extemporaneously though in accordance with prevailing conventions. Oral tradition

European music was communicated orally well into the Middle Ages and received important stimuli from a variety of oral traditions even after musical notation had developed to a high degree of precision. Indeed, the lower population strata, especially in rural areas, never abandoned the relative freedom that comes from reliance on the ear alone, and the sophisticated music of the upper strata, throughout its rapid evolution, rarely severed its connection with folk music altogether. Ultimately, the process of composition, as seen by the American musicologist Alan P. Merriam, does "not seem to differ radically between literate and non-literate peoples save in the question of writing." As a conscious act of social communication it always "involves learning, is subject to public acceptance and rejection, and is therefore a part of the broad learning process which contributes, in turn, to the processes of stability and change." Whether explicitly or not, composition is thus subject to rules that represent the stylistic consensus of a specific segment of society at a given stage of cultural development. During the Middle Ages, when man's natural instincts were held in particularly low esteem, musical compositions were often judged primarily in terms of their adherence to the rules. Hence, the supreme authority in matters musical was the *musicus* as theorist; only he was considered sufficiently conversant with musical science to vouchsafe its continued existence as the sonorous embodiment of universal truths. And it was because the metaphysical properties of numbers were allegedly embedded in the rules of composition that music, on a par with arithmetic, geometry, and astronomy, attained and retained an honorable place as a constituent member of the quadrivium, the more exalted of the two divisions of the seven liberal arts. Characteristically, music was not classified with grammar, rhetoric, and logic, the "rhetorical arts" gathered in the trivium. About 1300, musical composition as a mere craft was ranked by Johannes de Grocheo, a shrewd observer of the Parisian musical scene, with shoemaking and tanning.

Development of composition in the Middle Ages. The European written tradition, largely because it evolved under church auspices, de-emphasized rhythmic distinctiveness long after multipart music had superseded the monophonic plainchant. But multipart music might never have gone beyond the most primitive stages of counterpoint (see above *Counterpoint*) had it not been for the application of organized rhythm to musical structure in the late Middle Ages. This era witnessed the emergence of basic polyphonic concepts identified with European art music ever since. The precise measurement of musical time was simply an indispensable prerequisite for compositions in which separate, yet simultaneously sounded, melodic entities were combined in accordance with the medieval theorists' rules of consonance (specifying the

proper intervals to be used between voice parts, especially at points of musical repose). Toward the end of the 1st millennium of the Christian Era, church singers had grown accustomed to enhancing their chants through organum (see above *Harmony*). "Parallel" organum was followed, in turn, by "free" organum, which allowed the synchronized voice parts to utilize contrary melodic motion.

The decisive relationship between text and melody in early European music led to stylistic distinctions that have survived the ages. Thus, "syllabic" denotes a setting where one syllable corresponds to one note; "melismatic" refers to a phrase or composition employing several distinct pitches for the vocalization of a single syllable. Late medieval composers made clever use of these distinctions, including an intermediate "neumatic" style (Greek *pneuma*, "breath") to create ever more extensive polyphonic pieces. By the 12th century musicians at Notre-Dame in Paris, led by Léonin, the first polyphonic composer known by name, cultivated a type of melismatic organum that featured a highly florid upper part above a slow moving cantus firmus taken from a suitable plainchant melody. The melismatic sections alternated with strictly measured, or "discant," sections. This very effective procedure possibly was inspired by Middle Eastern practices with which the crusaders must have been well acquainted. In Eastern music, the rhythmically measured portions following the virtuoso singer's florid "outpouring of the soul" are nearly always played or at least supported by instruments. In the 13th century the clausula, a short, textless composition in discant style, tended to be dancelike in its systematic sectionalization, strongly suggesting instrumental derivation if not necessarily actual performance. The motet, a major genre of the medieval and Renaissance eras, was in its 13th-century form essentially a texted clausula, frequently employing two or three different texts in as many languages. This fact merely reinforces the suspicion that little distinction was made between vocal and instrumental composition in an era that so blithely based dancelike settings of erotic, in a few instances outright obscene, texts on a chant-derived cantus firmus. The point is not without its broader ramifications. For, brought up largely on 19th-century notions about the "purity" of church music, one easily overlooks the fact that even Bach and Mozart had few compunctions about the use of secular—in their cases mostly operatic—styles and specific tunes in church music. Over the centuries, the church has been the most important employer of composers and has offered far greater outlets for newly created music than any other social institution or category. Thus, composers of sacred music have had to satisfy the aesthetic needs and expectations of its highly differentiated "public." The church in turn repeatedly permitted the adaptation of promising secular types of composition, even though instrumental music, because of its more lascivious associations, remained suspect well into the 17th century.

Rhythmic contrast as a structural device

In accordance with medieval tendencies generally, Gothic polyphonic music was conceived in loosely connected separate layers. Thus, two-part motets could be converted into three-part motets, and Léonin's successor Pérotin expanded the organum to three and four parts. Inevitably, as their compositions gained in length and depth, musicians began to search for new integrative procedures. A system of six rhythmic modes (short, repeated rhythmic patterns) evolved rapidly. Pérotin used a single rhythmic mode for the multiple upper parts of his organums so that, separated from their cantus firmus, they resembled the conductus, a syllabic setting of a sacred text for two or three voices sharing the same basic rhythm. Finally, as organum faded into history, conductus-type motets were composed outright. Most prominent among the devices used to achieve structural integration in the 13th century were *color*, or melodic repetition without regard to rhythmic organization; *talea*, or rhythmic repetition without regard to pitch organization; and ostinato, or repetition of a relatively brief melodic-rhythmic pattern. Exchanges of melodic phrases between two or more parts in turn led to canon, a form in which all voice parts are derived from one tune—either by strict imitation of the basic melody or by manipulations stipulated in often quite sophisticated verbal instructions (canon = law). For instance, the canon *Ma fin est mon commencement (My End Is My Beginning)*, by Guillaume de Machaut, the leading French composer of the 14th century, demands the simultaneous performance of a melody and its retrograde version (the notes are sung in reverse order). French musicians of the 14th century were particularly partial tomisorhythm, which refers to repetition of the rhythmic organization of all the voices in a given compositional segment. It enjoyed considerable popularity for more than 100 years.

Melodic and rhythmic manipulation

Meanwhile, though somewhat eclipsed historically by the increasingly abstract nature of polyphony, the primacy of poetry was safeguarded in 13th-century music by the troubadours of southern France and their northern counterparts, the trouvères, as well as the German Minnesingers. These noble poet-composers created a rich tradition of purely monophonic secular song that furnished convenient points of departure for much of the secular polyphonic music in both 14th-century France and 15th-century Germany. By the beginning of the 15th century, European music had also begun to feel the impact of English music. The English emphasis on the rich sonorities of the third and sixth provided welcome relief from the aesthetic consequences of the earlier continental dedication to the "perfect" intervals of the octave, fourth, and fifth. Because the perfect intervals were also those formed by the lowest pitches of the harmonic overtone series, their "naturalness" had long been an unassailable theoretical axiom.

Impact of English music

Late 14th-century French secular music literally lost itself in rhythmic complexities without any substantive changes in the basic compositional approach, which continued to favour relatively brief three-part settings of lyrical poetry. But in the ensuing 15th century the simpler melodic and rhythmic ideas associated with the rich harmonies of the English style were eagerly embraced: often melodies were outright triadic in contour; *i.e.*, they outlined the intervals of the triad, an increasingly important chord composed of two linked thirds (*e.g.*, C-E-G). But the truly amazing stylistic development from the influential English composer John Dunstable to Josquin des Prez, the Flemish composer who stands at the apex of his era, was equally indebted to the flowing cantilenas, or lyric melodies, that characterized the top parts of Italian trecento music. If the French music of the waning Middle Ages was structured essentially from the bottom up, with relatively angular melodic and rhythmic patterns above the two-dimensional substructure of tenor and countertenor, its Italian counterparts were quite often monodically conceived; *i.e.*, a highly singable tune was sparingly yet effectively supported by a single lower voice. Indeed, the passion for melody, if need be to the detriment of other musical elements, has been a constant of Italian music. It sparked the *nuove musiche*, or "new music," of about 1600 and is exemplified in innumerable works of composers as diverse as Claudio Monteverdi (1567–1643) and Luigi Dallapiccola (1904–75). But it found its first major artistic expression in the city-states of northern Italy during the lifetimes of such 14th-century literary figures as Giovanni Boccaccio and Petrarch.

Composition in the Renaissance. During the latter part of the 15th century, French rhythmic sophistication, Italian cantilena, and English harmony finally found common ground in the style of Renaissance polyphony that, under the aegis of Flemish musicians, dominated Europe for nearly two centuries. Often referred to as modal because it retained the medieval system of melodic modes, Flemish polyphony was characterized by a highly developed sense of structure and textural integration. Although the older cantus firmus technique was never totally abandoned, Renaissance polyphony is identified above all with imitative part writing, inspired no doubt by earlier canonic procedures but devoid of their structural limitations. After a canonic or freely imitational beginning, each of the subunits of such a polyphonic piece proceeds unfettered by canonic restrictions, yet preserves the fundamental equality of the melodic lines in accordance with contrapuntal rules amply discussed by various 15th- and 16th-century theorists and ultimately codified by the Italian theorist

Gioseffo Zarlino. Through the works of Giovanni da Palestrina, the model composer of the Catholic Counter-Reformation, Renaissance modal counterpoint has influenced the teaching of musical composition to the present, suggesting the near perfection with which it conveys some fundamental aspects of the historic European ideal of composition as the art of lasting musical structures.

Changing conceptions of harmony

Whereas imitative polyphony affected virtually all 16th-century music, modal counterpoint was paramount in sacred pieces, specifically the motet and mass, probably because of its close kinship with the traditional modality of liturgical plainchant. In contrast, the beginnings of functional harmony (chordal relationships governed by primary and secondary tonal centres) manifested themselves first in the polyphonic French chanson; its Italian counterpart, the madrigal; and related secular types. Under the influence of less sophisticated music, such as that of the Italian frottola, a popular vocal genre, these secular polyphonic genres favoured rather simple bass lines highlighting a limited number of related harmonies. Thus, undisturbed by the theoretical writings from the pens of church-employed musicians, secular musical practice in the later Renaissance laid the foundations for the harmonic notions that were to dominate three centuries of Western art music. The increasing emotionalism of texts taken from the leading Italian poet of the 16th century, Torquato Tasso, and his immediate successors acted as a further stimulant, as Italian composers, searching for appropriate musical symbols, discovered the expressive possibilities of chordal progressions.

The Baroque period. Inevitably, the strong desire for heightened expression through harmony led at first to new, mostly chromatic, chord progressions. Eventually it precipitated the total abandonment of traditional polyphony about 1600 in the monodic experiments of the Florentine Camerata, a group of aristocratic connoisseurs seeking to emulate the Greek drama of antiquity. The accompaniment for these passionate and heroic solo recitations is based on a simple basso continuo. Only the bass part was written down; it was played by low, sustaining instruments bowed or blown, while plucked or keyboard instruments supplied the chords suggested by the bass and melody lines. The small figures used to indicate the proper harmonies gave the system the alternative name figured bass. Monody had its historical antecedents in mid-16th-century solo lute songs and in the plentiful arrangements of polyphonic vocal compositions for single voices accompanied by plucked instruments and for solo keyboard instruments. But it was the attempt to resurrect the spirit of antique drama in the late Renaissance that created the textural revolution that has been equated with the beginnings of modern music: the monodic style with its polarity of bass and melody lines and emphasis on chords superseded the equal-voiced polyphonic texture of Renaissance music. Monteverdi, the undisputed master of the monodic style, recognized the possibility of two basic approaches to composition: the first, or polyphonic, "practice" and the second, or monodic, "practice." Thus, with penetrating analytical insight he formulated the basic stylistic dialectic that has since governed the course of Western music.

Aesthetic and technical reorientation

The emergence of an essentially nonpolyphonic style went hand-in-hand with the rise of a variety of specifically instrumental idioms. Not only did accompanied vocal music offer instrumentalists various opportunities for improvisation; the basically chordal style also facilitated the emergence of virtuosity in the modern sense of the term, especially among keyboard artists. But as the singer and composer Giulio Caccini demonstrated in the preface to his influential collection *Le nuove musiche* (*The New Music;* 1602), singers, too, put their newly found freedom to good improvisational and ornamentational use. In short, after two centuries dominated by the highly structured, rationalistic polyphony of the Renaissance, the performing musician reiterated his creative rights. Inevitably, under such forceful pressures, the teaching of composition, previously tied to the laws of modal counterpoint, quickly shifted to the harmonic challenges of the figured bass.

Because the bass-oriented music of the 17th century relied primarily on chord progressions as fixed by the bass notes, it was structurally quite open-ended; *i.e.,* the new technique suited any number of formal patterns. Even so, the incipient rationalism that was to reach its peak in the 18th century soon led to the consolidation of broadly accepted structural types. Indeed, the very concept of musical "form," as generally understood from the late 17th century on, was intimately tied to the growing importance of instrumental music, which, in the absence of a text, had nothing to rely upon save its own organically developed laws. At least for a while, vocal music, which had been so largely responsible for the monodic revolution, continued to adhere to the Monteverdian principle that the words must act as "the mistress of harmony." Both melody and harmony, therefore, reflected often minute affective textual differentiations. And as late as the early 18th century similar musico-rhetorical considerations led to *Affektenlehre,* the theory of musical affects (emotions, feelings), developed primarily in Germany. Following this theory, German musicians dealt with composition systematically in terms of a specific but broadly adopted expressive vocabulary of melodic, rhythmic, and harmonic figures. Meanwhile, the Italians laid the foundations for such lasting categories of instrumental music as the symphony, the sonata, and the concerto. In each instance the structural outline was harmonically determined through juxtapositions of principal key areas acting as focal centres of tonality. As for tempo, the earliest 17th-century solo sonatas had relied on drastic short-range changes in accordance with a general predilection for "instant sensations." Subsequently, as musical composition fell in line with the prevailing rationalistic trend, tempo served above all as a means of differentiation between the various movements, or self-contained sections, that constituted the large-scale works of the Italian string school and of French and German instrumental composers as well. Texture, too, was used to provide contrast, particularly within a given movement, as in the concerto grosso with its alternation between small and large groups of players (concertino and tutti).

Emotional expressiveness

Interrelated with the spectacular rise and amazing vitality of instrumental music was its unprecedented variety. By the early 18th century, composers drew freely upon everything from contrapuntal forms like the fugue (an adaptation of the imitative techniques of the Renaissance motet within the context of functional harmony) to stylized popular dances, such as those that make up the suites and partitas of J.S. Bach. The figured bass era took full advantage of the possibilities of variety and contrast through judicious manipulations of all elements of composition. Whereas accompanied solo music pitted bass against treble (the latter often split up into two parts, as in the trio sonata), composers generally liked to juxtapose figured bass and polyphonic textures. Melodically, the far-flung phrases of Italian bel canto, the florid singing style characteristic of opera seria (17th- and 18th-century tragic opera), had little in common with the concise, symmetrically balanced phrases found in music of popular inspiration, whether in opera buffa (Italian comic opera) or the many types of dances. As for the latter, their impact on sophisticated 18th-century music is evident not only in many dance-inspired arias and concerto movements but also in certain polyphonic compositions. Both the chaconne and passacaglia, related polyphonic types, were based on dancelike ostinato patterns, often with specific harmonic implications. Perhaps the most famous example is Bach's "Chaconne" for solo violin, which concludes the *Partita in D Minor.*

Major structural developments of the Baroque

Even though the Baroque preoccupation with style worked somewhat to the detriment of structural definition, certain closed forms did gradually emerge. The da capo aria distinguished clearly between an initial section (A), a contrasting section (B), and the repeat (da capo) of the initial section, as a rule with improvised vocal embellishment. In instrumental music, the French opera overture began with a slow, stately introduction followed by a fast, often fugal movement, whereas its Italian counterpart had a tripartite fast-slow-fast scheme. Dance-based suite movements were binary in outline: the first of the two sections, each separately repeated, moved to the dom-

inant key (a fifth above the tonic or principal key) or to the relative key (*i.e.*, a minor third above the tonic in the case of a minor key); the second section, after some modulatory activity (*i.e.*, passing through several key areas), returned to the central key. Even more decisive in its far-reaching historical consequences was the structural organization of a number of the keyboard "sonatas" of the composer Domenico Scarlatti. These works consisted of single, essentially binary movements, the first section of which differentiated not only between two key areas but two contrasting thematic ideas as well.

The Classical period. The Classical era in music is compositionally defined by the balanced eclecticism of the late 18th- and early 19th-century Viennese "school" of Haydn, Mozart, Beethoven, and Schubert, who completely absorbed and individually fused or transformed the vast array of 18th-century textures and formal types. Expansion of the tripartite Italian overture had produced the basic three-movement scheme of the symphony even before the 18th century reached midpoint. Shortly thereafter, the minuet, borrowed from the dance suite, was inserted with increasing frequency as a fourth movement between the slow movement and the fast finale. The French opera overture in turn lent its slow introduction where needed for structural variety. Texturally, homophony (chordal texture) and polyphony soon assumed rather specific roles, with polyphonic writing usually reserved for the central or development section of the classical first-movement form. The organic fusion of a number of stylistic traits previously associated with strong and immediate contrast is exemplified by the obbligato accompaniment, the texture most typical of Viennese classicism. Here the relative equality of all the melodic parts in a given composition is ensured without denying the melodic supremacy of the treble and the harmonically decisive role of the bass. The evolution of this characteristic texture can be traced in the string quartets of Haydn. At first, following earlier 18th-century custom, Haydn wrote strictly treble-dominated compositions with a simplified bass (as compared with the more varied basso continuo); then, with the six *Sun Quartets*, Opus 20, dating from the early 1770s, he defied precedent and concluded each work with a fugue in the "learned style" of Handel. Finally, in his *Russian Quartets*, Opus 33, written, in his own words, "in a new manner," Haydn achieved the fusion of elements of both the learned and the treble-dominated styles. The result was a harmonically oriented, yet polyphonically animated, texture that was to affect both instrumental and vocal ensemble music for generations. It was also at this point, when compositional procedures reached a degree of stability and universality unmatched since Renaissance polyphony, that composition began to be taken seriously as a separate musicianly discipline. Johann Joseph Fux's famous *Gradus ad Parnassum* (*Steps to Parnassus*), published first in Latin in 1725 and subsequently in every important modern language, was still basically a didactic treatise on counterpoint abstracted from 16th-century practice. As such it served its purpose throughout the 18th century, while harmony continued to be taught as the art of accompaniment—*i.e.*, the improvised realization of a figured bass. But eventually the general fascination with comprehensive knowledge, sparked by the French *Encyclopédie*, inspired at first sporadic, then ever more numerous, volumes dealing progressively with all aspects of composition. During the ensuing 19th century the rapid institutionalization of musical education in the image of the National Conservatory of Music in Paris, created while the French Revolution was still raging, added further to the academic systematization of all musical studies along lines that have essentially remained in force. Thus the teaching of musical composition reflects to this day the biases of the 19th century, specifically its concern with functional harmony as the principal generative force in music—a doctrine first proclaimed in the 1720s in the name of nature (as being consistent with the harmonic overtone series) by the composer and theorist Jean-Philippe Rameau.

Integration of homophony and polyphony

Composition as an academic discipline

The Romantic period. With the onset of the Romantic era in the wake of the French Revolution, composers began to view their own role in society as well as the social function of their work, and hence also its aesthetic prerequisites, in a radically different light. With respect to social function, Beethoven was actually the first musician of stature to achieve emancipation in the sense that his work reflected, with relatively few exceptions, purely personal artistic concerns. He simply took it for granted that patrons would supply funds sufficient for him to pursue his creative career unfettered by financial worries. This attitude represents a total reversal of the basic assumptions of the preceding century, when composers were hired by and large to satisfy the musical needs of specific individuals or institutions.

The view of the composer as artist also changed. If during the Middle Ages the craft of musical composition had been evaluated largely in terms of its strict adherence to established rules, instinctiveness and spontaneity had remained suspect well into the Italian Renaissance. For a 15th-century composer-theorist like Johannes Tinctoris, the value of a musical composition depended on learned judgment as well as spontaneous reaction. Thus his admiration for certain composers of his time stemmed both from the happiness and from the enlightenment that he found in examining their music. But the Swiss theorist Henricus Glareanus, writing 70 years later, explicitly preferred natural talent to the most exquisite craftsmanship. The Renaissance was the first epoch in European intellectual history to recognize that the greatness of a composer rests upon his inherent talent and unique personal style, and that genius supersedes both experience and the observance of theoretical precepts. Likewise, it was the first era in which the process of composition was viewed as linked to powerful internal impulses. The rising tide of academicism notwithstanding, this basic attitude on the whole dominated the European scene more or less consistently from then on. According to E.T.A. Hoffmann, the early 19th-century poet, critic, and composer, "effective composition is nothing but the art of capturing with a higher strength, and fixing in the hieroglyphs of tones, what was received in the mind's unconscious *ecstasis*." And Romantic composers from Schumann and Chopin to Hugo Wolf and Gustav Mahler did in fact produce much of their very best creative work in precisely such a state of exaltation, in a few tragic instances (*e.g.*, Schumann and Wolf) to the ultimate detriment of their sanity.

The composer as genius

The aesthetic effects of this drastic change in conception of the composer's task and potential were immediate and far reaching. For one, every large-scale composition assumed artistic significance of a type previously accorded only a whole series of works, sometimes a composer's entire output. And, concomitantly, many leading composers of the 19th century wrote in considerably smaller quantities than their predecessors. But in exchange they revelled in idiomatic and structural peculiarities even in works that nominally fell into the same formal category. Thus, although "characteristic" symphonies alluding to nonmusical ideas occurred occasionally in the late 18th century, virtually every symphonic composition postdating Beethoven's *Symphony No. 3 in E Flat Major*, Opus 55 (*Eroica;* completed 1804), could be so designated. "Characteristic" works like Beethoven's *Symphony No. 6 in F Major*, Opus 68 (*Pastoral*: 1808), or his overture to Goethe's drama *Egmont* are but one step removed from the kind of characteristic scenes that make up the *Symphonie fantastique* of the French composer Hector Berlioz or, for that matter, Felix Mendelssohn's *Hebrides* (also known as *Fingal's Cave*), an overture unrelated to any particular drama, spoken or sung. Franz Liszt, in the free-wheeling forms of his symphonic poems, simply pursued the individualistic line to its ultimate consequences, severing whatever tenuous ties to traditional structures the works of his immediate predecessors had still maintained. The Romantic composer viewed himself basically as a poet who manipulated musical sounds instead of words. But if the composers catered to poetry, writing Lieder (German songs) and attempting to retell stories in instrumental works, the poets looked with awe and envy upon the composers' use of a language so utterly dissociated from material existence. "All art aspires to the condition of music," said Wordsworth. It is thus hardly surprising

Nonmusical allusions

that opera, whose extramusical connotations had in the past been responsible for some of the most daring stylistic innovations, rapidly incurred the disfavour of progressive composers. Although some, like Berlioz, Mendelssohn, and Schumann, tried their hands at an occasional opera, others, including Chopin, Liszt, and Brahms, felt no inclination whatever to compose for the stage. Instead, each developed personal idioms capable of a depth of expression that words could not match. Mendelssohn spoke indeed for many when he remarked that, as far as he was concerned, music was more precise in meaning than words.

As in the late Renaissance, harmony once again furnished the primary expressive means. In defining musical structure, too, harmonic and modulatory procedures predominated at the expense of the contrapuntal interplay of motives. Numerous Romantic composers excelled in concise forms of strong melodic-harmonic import, variously entitled Impromptu, Nocturne, Song Without Words, Ballade, Capriccio, Prelude, Étude, etc. The form of these works was nearly always tripartite, with a literal or modified repeat of the first part following a melodically and harmonically contrasting middle section. Works of larger scope often consisted of a series of relatively autonomous subunits tied together either by the same tune presented in different guises (as in variation sets) or by fairly literal recurrences of an initial musical idea (the rondo principle). Compositions of the Classical sonata-allegro type, to which motivic-contrapuntal development was essential, inevitably suffered from the Romantic love for pure, harmonically defined melody. Thus Tchaikovsky frankly admitted in 1878 that, although he could not complain of poverty of imagination or lack of inventive power, his lack of structural skill had frequently caused his "seams" to show: "there was no organic union between my individual episodes." Composers such as Tchaikovsky were indeed particularly successful with chainlike formations like the serenade or the ballet suite, which comprised a well-calculated number of carefully wrought smaller entities.

Interrelation of aesthetic, technique, and form

In the context of functional harmony, the Classical motivic-contrapuntal approach had no doubt been exploited in the last sonatas and string quartets of Beethoven to the very limits of its potential to define musical structure. The heroic image of Beethoven as one who had overcome every possible personal and artistic difficulty to achieve the highest aims of the art assumed well-nigh traumatic proportions among 19th-century musicians. Not only did composers ill equipped both by training and artistic temperament try to emulate him, but theorists from Adolf Bernhard Marx to Vincent d'Indy based treatises on his works. Thus, unwittingly the Classical Beethovenian inheritance turned into something of an aesthetic liability for Romantic composers swayed by the image of Beethoven and unable or unwilling to face the fact that their particular talents were totally unsuited for any further capitalization of his basic compositional procedures. Confronted with the task of writing in the Beethovenian manner, a great master like Schumann, who had created the near-perfect, totally Romantic suite *Carnaval,* Opus 9 (1835), was clearly out of his element: the development of his *Symphony No. 1 in B Flat Major,* Opus 38 (*Spring,* 1841), offers a prime example of the "rhythmic paralysis" that affected so many large-scale 19th-century works. That this symphony managed nevertheless to maintain itself in the concert repertoire, on the other hand, demonstrates the extent to which the best among the German composers compensated for obvious weaknesses in handling motivic development by sustaining above all constant harmonic interest. For their part, the French, always coloristically inclined, turned instrumentation into a principal compositional resource, so that in an unadorned piano transcription Berlioz' *Symphonie fantastique* retains little more than its basic contours. That by the end of the century virtuoso instrumentation had become universal practice is attested by any work of Richard Strauss or Gustav Mahler.

Characteristically, the most unique compositional achievement of the 19th century, that of Richard Wagner, was also the most eclectic. Wagner represents the apotheosis of Romanticism in music precisely because he fused into musico-poetic structures of unprecedented proportions virtually every musical resource that went before him. Seen in this light it may be more than mere coincidence that *Tristan und Isolde,* perhaps Wagner's most perfect music drama, begins with the same four notes that make up the motivic substance of four of Beethoven's string quartets (Opuses 130–133). Unlike most instrumental composers after Beethoven, the dramatist Wagner fully assimilated the motivic-contrapuntal process, even though his texture is principally determined by strong harmonic tensions and by a masterful use of instrumental colour in the vein of Berlioz and French grand opera. Just as he integrated diverse compositional techniques, Wagner also achieved a balance of musical and poetic elements so perfect that critics, both favourable and unfavourable, have never ceased to be puzzled by its aesthetic implications. How consciously Wagner proceeded is attested not only by his numerous theoretical writings but also by compositional sketches pointing in some instances to several stages of mutual adjustments involving music and text.

Wagner's fusion of counterpoint with late Romantic harmony

The 20th century. Wagner's highly expressive harmonic bequest could not but drive chromaticism eventually beyond the retaining confines of the idea of a central key, for the extensive use of chromatic chords tends to blur the listener's ability to perceive the basic harmonic relationships that define a key. In their nontonal compositional procedures, Arnold Schoenberg and his 20th-century second Viennese school abandoned the concept of key, using all notes freely without relating them to the system of functional harmony. They thus represent not so much a reaction to as a logical extension of Wagnerian principles. Wagner's compelling artistic personality certainly exercised near-magic powers over many of his younger contemporaries and successors, exceeding even Beethoven's spell. But others, too, contributed to "the music of the future." As Schoenberg was to point out in one of his remarkable essays, even Brahms, who looked upon himself as a conservative in the best sense of the term, was, historically speaking, a true "progressive," especially in his propensity for irregular phrasing and complex motivic manipulations.

The growth of political nationalism in the "peripheral" countries of Europe also had significant repercussions in musical composition. In the last half of the 19th century distinctive folk-music elements, previously totally unheeded by Europe's elitist musical cultures, found enthusiastic response in sophisticated circles, exerting an "exotic" attraction similar to that which had accounted earlier in the century for the Romantic infatuation with Eastern civilizations. Thus at a time when the exhaustion of Europe's "civilized" compositional resources appeared imminent, the "untutored" harmonies of the Russian composer Modest Mussorgsky—steeped in the spirit of Russian folk music and based on chord progressions alien to the standard harmonic usage of his day—helped breathe new life into a harmonic language about to succumb to redundant overdoses of functional chromaticism. Mussorgsky thus paved the way for the later whole-tone and pentatonic (five-note scale) experiments of Claude Debussy and Béla Bartók.

What was being questioned publicly in many quarters at the dawn of the 20th century was the evolutionistic view of Western art music as man's ultimate achievement in the realm of sound and its logical consequent that 19th-century harmony represented in turn music's most advanced stage of development. This increasing skepticism, given by the nature of late 19th-century music itself, was strongly reinforced by the growing awareness of historical compositional techniques that resulted from the mushrooming discoveries of musicological scholarship. Before long, all manner of pre-19th-century textures and structural principles were seized upon to counteract the type of self-defeating post-Wagnerianism—so tragically exemplified in several of the most ambitious works of Max Reger. The 20th-century search for fresh, flexible techniques extended far beyond the nontonal second Viennese school of Schoenberg. In historical perspective, Anton Webern's fascination with 15th-century canonic techniques, Paul Hindemith's predilection for both modal and early-18th-century polyphony, Igor Stravinsky's emulation of

Re-application of older techniques

Domenico Scarlatti, and, for that matter, Kurt Weill's reinterpretation of John Gay's *Beggar's Opera* (1728) represent but various individual and culturally conditioned manifestations of the same determination: to put the burden of history to positive use in a concerted effort to revitalize an art that seemed moribund by the time World War I changed the socio-economic and political physiognomy of Europe.

Historically, Schoenberg's formulation of the laws of composition with 12 tones—involving the consistent melodic and harmonic use of a specifically arranged sequence of the 12 notes of the chromatic scale—sprang in the early 1920s from the same obsession with textural and structural clarity that marked the postwar Neoclassical syndrome as a whole. Schoenberg himself may have considered his most fundamental contribution to musical history to be "the emancipation of dissonance"—a relativistic conception of intervals and chords that disregarded the careful regulation of dissonance characteristic of functional harmony. Actually, the 12-tone procedures he developed so consistently served to restore, to an extent far beyond that which Mahler had been able to achieve within the traditional harmonic framework, the primacy of motivic-contrapuntal development as a musical resource. Thus it was that the profusion of simultaneous melodies that animates Mahler's *Symphony No. 4 in G Major* (completed 1900) found its ultimate potential realized in Schoenberg's most uncompromising polyphonic work, the *Wind Quintet* (1924).

Possibly the most successful attempt to regenerate Beethovenian procedures without the total abandonment of functional tonality is represented by the string quartets and certain other instrumental compositions of Bartók. Drawing upon the rhythmic-melodic properties of Hungarian and Romanian folk music, Bartók produced a unique type of functionally extended harmony determined largely by the contrapuntal interaction of motives. Others, such as Charles Ives in the United States and, under the impact of South American popular music, Darius Milhaud in France, transcended traditional tonality by writing polytonally (in two or three keys simultaneously).

Whatever their specific approach, progressive 20th-century composers everywhere clearly gave precedence to melodic-rhythmic energies. Even instrumental colour was pressed into the service of melodic definition. Years before World War I Schoenberg had advocated in practice (*Five Orchestral Pieces*) and in theory (*Harmonielehre*, 1911; *Theory of Harmony*, 1947 [the English edition omits the pertinent chapter]) the idea of tone-colour melody, or *Klangfarbenmelodie*. But it was his pupil Webern who, in his mature works, divided the individual components of melodic phrases over several instruments as an imaginatively coloristic reinforcement of the complex polyphony that characterized his style. After World War II Webern's procedures were adopted enthusiastically by composers on both sides of the Atlantic. Living in increasingly automated societies, the post-Webern composers soon discovered total serialism, a manner of composition in which all musical parameters follow numerical rules laid down in the course of what has been called the precompositional process. Whereas Schoenberg's row technique merely fixed the sequence of the 12 pitches of the chromatic scale in accordance with the motivic context of a given piece, Webern had indeed begun to serialize rhythm and to some extent instrumentation, possibly under the influence of medieval isorhythmic techniques. But total serialization, as practiced by the post-Webernians, left little, if anything, to spontaneous inspiration, and the 1950s thus witnessed the closing of a creative circle initiated during the early Middle Ages when spontaneous inspiration was manifestly suspect. Perhaps inevitably, such a hermetically closed system of composition provoked reactions that moved the aesthetic pendulum violently to the extreme opposite position. Spur-of-the-moment action became the watchword in music as well as in life generally. Aleatory (chance-music) composition in its more radical manifestations provides only minimal guidelines for performers who are told to improvise freely within certain temporal or spatial limitations, or both.

Serialization of all elements

Thus, with the 20th century in its final quarter, Western man has returned, insofar as is possible, to the pretypographical stage when musical tradition was essentially oral. More than that, the relatively recent replacement of "the public," once essentially the cultural elite, by a whole host of publics to whom mutually exclusive types of composers cater with great solicitude, suggests that the private musical life of Western man in the immediate past is in the process of being transplanted by experiences serving, among other things, the identification of special group interests and needs. At the same time, novelty rather than originality has become the order of the day. Musical compositions, electronically recorded—more recently also electronically produced—and distributed as salable items by mass-oriented corporations, have attained the status of physical objects that are easily discarded and replaced. Still, there are those who try to transform the burdens of history into significant new forms of composition. A new eclecticism is in the making, destined perhaps to preserve a long tradition that has been among Western man's proudest achievements. (A.L.R./Ed.)

INSTRUMENTATION

Most authorities make little distinction between the words instrumentation and orchestration. Both deal with musical instruments and their capabilities of producing various timbres or colours. Orchestration is somewhat the narrower term since it is frequently used to describe the art of instrumentation as related to the symphony orchestra. Instrumentation, therefore, is the art of combining instruments in any sort of musical composition, including such diverse elements as the numerous combinations used in chamber groups, jazz bands, rock ensembles, ensembles employing chorus, symphonic bands, and, of course, the symphony orchestra. Included under this designation are the various instrumental groups that play non-Western music, such as the gamelan orchestras of Bali and Java and the traditional ensembles of India, Africa, the Far East, and the Middle East.

In Western music there are many standard or traditional groups. The modern symphony orchestra usually comprises the following instruments, although they are not necessarily used in every composition:

Constituents of the orchestra

1. Woodwinds: four flutes (one doubling, or duplicating the part of the piccolo), four oboes, English horn (cor anglais), three clarinets, bass clarinet, three bassoons, contrabassoon (double bassoon);

2. Brass: four trumpets, four or five French horns, three trombones, tuba;

3. Strings: two harps, first and second violins, violas, violoncellos, double basses;

4. Percussion; four timpani (played by one player) and at least three general percussion players.

The orchestra has arrived at this complement through centuries of evolution; the present size is needed to perform repertoire from the Baroque, Classical, Romantic, and Impressionistic periods, as well as the repertoire of the 20th century.

The various sections, with the exception of percussion, divide themselves in somewhat the same manner as a choir. The woodwinds, for example, divide into flutes (sopranos), oboes (altos), clarinets (tenors), and bassoons (basses), although this distinction must be greatly qualified. Instrumental range is larger than vocal range, and the clarinets of an orchestra may play higher than the flutes in a woodwind passage.

The standard instrumental groups of Western chamber music include the string quartet (two violins, viola, and violoncello), the woodwind quintet (flute, oboe, clarinet, French horn, and bassoon), the combinations employed in sonatas (one wind or stringed instrument with piano), and the brass quintet (frequently two trumpets, French horn, trombone, and tuba). In addition to these standard groups there are, however, hundreds of other possible combinations.

Other groups that deserve mention are those used in the popular music of the 20th century. The dance band, popular in the 1930s and 1940s, consisted of five saxophones, four trumpets, four trombones, double bass, piano, gui-

tar, and drums. The basic rock ensemble consists of two electric guitars, electric bass, electronic organ (doubling electric piano), drums, and frequently one or more singers. The concert band, which is particularly popular in North America, consists of mixed wind and percussion players totalling from about 40 to well beyond 100 players.

The music of the non-Western world is most frequently performed by groups of chamber music size. In this category would fall the music played by the Javanese gamelan orchestra (consisting mainly of tuned gongs and other metal instruments), Japanese *gagaku* music (performed on flutes, mouth organs, lutes, drums, and gongs), and Chinese music (with a traceable history of about 4,000 years) consisting of sacred, folk, chamber, and operatic music.

Types of instrumentation. The approach to the art of instrumentation is naturally greatly influenced by the type of group for which the composer is writing. He cannot treat a string quartet or a group of brass instruments in the same manner as he would a symphony orchestra. In general, the larger and more diverse the instrumental group, the more coloristic possibilities it presents to the composer. The smaller instrumental groups often have a sound character of their own, and the composer is challenged to find new and interesting ways to deal with this limitation.

The symphony orchestra has had definite traditions in relation to orchestration. The composer of the 18th century was likely to use the orchestral instruments at least part of the time in the following manner: the flutes doubling the same part as the first violins (frequently the melody); the oboes doubling the second violins or the first violins in octaves; the clarinets (by the end of the century) doubling the violas; and the bassoons doubling the violoncellos and double basses. French horns were often used as harmonic "filler" and in conjunction with every section of the orchestra because of their ability to blend easily with both stringed and wind instruments.

Development of wind instruments

These traditional doublings were not so often used in the orchestration of the 19th and 20th centuries because of the great improvement in the making of wind instruments and their consequent ability to function in a solo capacity. Wind instruments became used more and more for colouring; the flutes, for instance, were noted for their bright tone quality and great technical agility, the clarinets for all the aforementioned qualities, and the bassoons for their special tone quality. Brass instruments had to await the development of valves, which increased greatly the musical proficiency of brass players and overcame previous typecasting of these instruments as bugles and hunting horns.

String techniques. The string quartet has long been considered one of the greatest challenges to the composer because the contrast to be achieved by changing from one type of instrument when writing for a full orchestra is simply not available. The composer has had to rely on varying timbres to be arrived at by different playing techniques, such as pizzicato (plucking the strings), tremolo (the quick reiteration of the same tone), sul ponticello (bowing near the bridge of the instrument), sul tasto (bowing on the fingerboard), the use of harmonics (dividing the string in such a way as to produce a high flutelike tone), col legno (striking the strings with the wood of the bow), and many special bowing techniques.

Wind techniques. Special playing techniques also can alter the timbres of wind instruments. For instance, on many, tremolos can be played on two different notes.

Some wind instruments—and the flute is particularly agile in this respect—can produce harmonics. Flutter tonguing (produced by a rapid rolling movement of the tongue) is possible on most wind instruments; so are many other tonguing techniques that affect the quality of sound in orchestration.

Muting. The string mute is a device that softens the tone of the instrument. Muting is also used by brass instruments, particularly the trumpet and trombone, a development that took place in 20th-century popular music and then came into common use in all types of music.

Mutes—of which there are various kinds—provide the trumpet and trombone with a different tone colour. Mutes on woodwind instruments have been experimented with, but the results have not been satisfactory.

Percussion instrumentation. Percussion instruments have become a favourite source of colour for the 20th-century composer, both in the concert and popular fields. Instruments from all over the world are now commonly available and are divided into two categories: of definite and of indefinite pitch. The former include the xylophone, marimba, vibraphone, glockenspiel, timpani, and chimes. Instruments of indefinite pitch exist by the hundreds. Some of the more common ones are the snare drum, tenor drum, tom-tom, bass drum, bongos, Latin American *timbales*, many types of cymbals, maracas, claves, triangles, gongs, and temple blocks.

The availability of these instruments and the great improvement in percussion playing has resulted in an enormous increase in the number of compositions for percussion instruments. The percussion ensemble, a group of from four to eight players, is a chamber group that has existed only in the 20th century, particularly since the late 1940s. One of the interesting features of such an ensemble is that each player in it is capable of playing many instruments. An ensemble of four players, for instance, can easily handle 25 or 30 instruments, once again showing the rich palette available in a single composition.

Keyboard instrumentation. Since the 17th century, keyboard instruments have played an important role in orchestration. Those commonly available today are the harpsichord, celesta, organ (both pipe and electronic), and electric piano, in addition to the instrument for which most of the standard literature has been written—the piano. Keybord instruments vary greatly in the manner in which they produce a sound: the harpsichord has quills that pluck the strings; the piano has hammers that strike the strings; the celesta has hammers that strike a metal bar; the pipe organ sends air through a pipe; the electronic organ employs electronic oscillators to produce its sound. The resulting colours are naturally very different.

The piano, with its wide range (more than seven octaves), has been used in conjunction with virtually every instrument and instrumental combination. In the 18th century it gradually replaced the harpsichord as the common keyboard instrument because of the piano's ability to alter dynamics rapidly and its ability to sustain sounds. There is a vast amount of literature for the piano as the accompanying instrument in sonatas, partly because the piano can function as a "one-man orchestra." Many composers of the 20th century have discovered facets of the piano that had been previously ignored. The inside of the grand piano is a harplike body that has presented many new possibilities to the composer, such as the "prepared" piano. To prepare a piano, objects such as bolts, pennies, and erasers are inserted between the strings, thus producing many different sounds. The piano strings can be plucked or played with percussion mallets and can produce harmonics in the manner of non-keyboard stringed instruments, much to the dismay of piano tuners and traditional pianists.

The "prepared" piano

Electronic instrumentation. The electric piano is one of a number of instruments that have gained in popularity in recent times. These instruments either produce sound by means of electronic oscillators or are amplified acoustic instruments. The sound produced by ensembles playing this type of instrument is distinctive. The rock ensemble is the best known, but rock musicians are by no means the only instrumentalists to employ electric instruments. For the composer, amplified or electric instruments pose certain problems. Balances can be achieved or ruined simply by turning an amplifier up or down. The timbres produced by rock ensembles and other groups employing electronics are unusual for a number of reasons. The electric guitar has such devices as reverberation controls, "wa-wa" pedals, and filters that enable the performer to change timbre radically in the middle of a performance. Composers since the early 1960s, being much concerned with coloristic possibilities of instruments, have found the electronic ones most attractive.

Vocal instrumentation. The largest quantity of literature in Western music has been written for the chorus.

The choir, an instrument capable of great subtleties of colour, has been a favourite of composers for centuries. The range of most individual singing voices is rather limited. Choral singers, who usually have a limited amount of training, are capable of a range of about an octave and a fifth, which is considerably smaller than the range of individual instruments. Singers are usually not capable of singing wide leaps, that is to say, notes that are far apart in range. Great skill is required in the musical setting of the text in a choral work. Attention must be paid to the vocal qualities of vowel sounds as well as to the way in which the consonants are treated.

For centuries composers have been intrigued with the combination of voices and instruments, and many of the most important compositions in Western music have been written for chorus and orchestra. Almost every major composer of the past three centuries has written for choir and large instrumental ensembles.

The development of Western instrumentation. The development of the art of using instruments for their individual properties did not really begin in Western music until about 1600. The known history of musical instruments, however, has been traced back 40,000 years, although nothing is known about the music these early instruments produced. The Greeks left mostly musical theories and only a small amount of extant music. The Romans used instruments particularly in military bands, but, again, little is known of their specific use. The music of the Middle Ages and Renaissance was primarily vocal, although instruments were frequently used in compositions to accompany or reinforce the individual vocal line. Stringed, brass, woodwind, and percussion instruments were added not so much for their coloristic potential but because of their availability. Another practice in the Middle Ages was to make literal instrumental versions of vocal compositions, which, of course, has rather little in common with the modern art of instrumentation.

The Baroque period. Orchestration in a modern sense probably began in the 16th century with Giovanni Gabrieli, organist of St. Mark's in Venice. He was the first composer to sometimes designate specific instruments for each part in a composition, as in his *Sacrae symphoniae* (1597). Claudio Monteverdi made important contributions to the art of orchestration. His opera *Orfeo* was first performed at Mantua (now Mantova, Italy) in 1607 with an orchestra of about 40 instruments, including flutes, cornetts, trumpets, trombones, strings, and keyboard instruments. For the first time, a composer, in order to heighten certain dramatic moments, specified exactly which instruments were to be used.

Monteverdi's orchestra

The century after the first performance of *Orfeo* was characterized by a rise in the use of stringed instruments that were similar to the modern ones. Although that trend helped set the stage for the modern orchestra, it was not a period that made great strides in the art of orchestration: the prevalent practice of writing out only the melody and the bass line of a composition did not lend itself easily to creative scoring. By the end of the 17th century, however, the groundwork had been laid for new developments. Instruments and instrumentalists had improved steadily. Johann Sebastian Bach created works that occasionally exploited the coloristic capabilities of instruments but in a rather limited way. In some of Bach's music the stringed instruments are played pizzicato, although this practice had already been employed by Monteverdi. Bach also wrote for muted strings. Wind instruments were treated occasionally for their special sounds, although more frequently they were simply employed on a musical line that their range happened to fit.

Handel, whose life covered the same period as Bach's, had a keener sense of orchestral effect. He introduced the clarinet into his orchestra, although it was not to become standard until the 19th century, and in his operas Handel often used instrumental colour in a way that did not become common practice until much later. Jean-Philippe Rameau, the leading French composer of the 18th century, also contributed much to the development of orchestration. Rameau, like Handel, was principally famous as an opera composer, and the overtures and dances of his operas represent the most advanced uses of instruments during that period. Rameau was probably the first composer to treat each instrument of the orchestra as a separate entity, and he introduced interesting and unexpected passages for flutes, oboes, and bassoons.

By the middle of the 18th century the symphony orchestra was beginning to resemble the modern instrumental group, yet it was still considerably smaller. The orchestra at the court of Mannheim, Germany, consisted of 20 violins, four violas, four cellos, two double basses, two flutes, two oboes, two bassoons, four French horns, one trumpet, and kettledrums. Baroque composers frequently could not count on a fixed orchestra and therefore had to write the various parts so that they could be played on more than one instrument. The contrapuntal style that prevailed from the time of Monteverdi until the mid-18th century usually meant simply assigning instruments to each line in a composition; the basic consideration was whether that line stayed within the range of the chosen instrument. The fixed personnel of such orchestras as the Mannheim group, therefore, freed the composers to experiment with the capabilities of the instruments within the group. Musical style was also changing, the contrapuntal style of the Baroque giving way to a style that relied more heavily on melodic invention supported by harmony.

The court orchestra in Mannheim

One of the more important composers of the period between the Baroque and Classical eras was Johann Sebastian's son, Carl Philipp Emanuel Bach. In C.P.E. Bach's symphonies the strings become melodic instruments, and the winds—two flutes, two oboes, one or two bassoons, two horns—fill out chords and provide body to the orchestration.

The Classical period. The Classical era, which covers roughly the second half of the 18th century, is one of the most significant periods in the development of orchestration. The most talented composers of this period were Mozart and Haydn. Many important developments took place during this time. The orchestra became standardized. The Classical orchestra came to consist of strings (first and second violins, violas, violoncellos, and double basses), two flutes, two oboes, two clarinets, two bassoons, two or four French horns, two trumpets, and two timpani. Toward the end of his career, in the *London Symphonies*, Haydn introduced clarinets as part of the woodwind section, a change that was to be permanent. Haydn also introduced the following innovations: trumpets were used independently instead of always doubling the horns, cellos became separated from the double basses, and woodwind instruments were often given the main melodic line. In the *Military Symphony (No. 100)* Haydn introduced some percussion instruments not normally used in the orchestras of this time, namely, triangle, hand cymbals, and bass drum; and, what is still more unusual, they are employed in the second movement, which in the Classical tradition is normally the slow movement.

Standardization of the orchestra

In Haydn's music a method of composition appeared that had a bearing on orchestration. This consisted of the conscious use of musical motives; motive is defined in the *Harvard Dictionary of Music* as: "The briefest intelligible and self-contained fragment of a musical theme or subject." Perhaps the best known musical motive in Western music is the four-note group with which Beethoven's *Fifth Symphony* begins. These musical cells became the musical building blocks of the Classical period, particularly in the middle or development section of a movement, with the composer moving the musical motive from instrument to instrument and section to section, giving a new facet to the orchestration. The art of orchestration was thus becoming a major factor in the artistic quality of the music.

Mozart, too, was responsible for great strides in the creative use of instruments. His last two symphonies (*Nos. 40*, K. 550, and *41*, K. 551) are among the most beautifully orchestrated works of this or any period. For his 17 piano concertos, Mozart exhaustively explored the combination of piano and orchestra.

Mozart's special contribution

The Romantic period. Beethoven began his career under the influence of the Classical composers, particularly Haydn, but during his lifetime he transformed this heritage into the foundation of a new musical practice that was to

become known as Romanticism. The Classical composers for the most part attempted to orchestrate with a sense of grace and beauty. Beethoven occasionally made deliberate use of new, intense, often even harsh orchestral sounds. He also, in his later symphonies, augmented the orchestra with a piccolo, contrabassoon, and third and fourth horn. The *Ninth Symphony* has one passage calling for triangle, cymbals, and bass drum, a combination identified with the imitations of Turkish Janissary music in vogue in previous years, and the final movement calls for four vocal soloists and full chorus.

The Romantic era was characterized by great strides in the art of instrumentation, and, in fact, the use of instrumental colour became one of the most salient features of this music. The piano really came into its own as a source of interesting sonorities; the orchestra expanded in size and scope; new instruments were added; and old instruments were improved and made more versatile. The Romantic period saw the appearance of the first textbook on the subject of orchestration. It was the French composer Hector Berlioz' *Traité d'instrumentation et d'orchestration modernes* (1844; *Treatise on Instrumentation and Orchestration*, 1856). Berlioz was one of the most individual orchestrators in the history of music, and his *Symphonie fantastique* (1830) is one of the most remarkable pieces of music to come out of this era. Berlioz made use of colour to depict or suggest events in his music, which was frequently programmatic in character. He called on large forces to express his musical ideas, an idea that persisted throughout the 19th century and into the 20th. Berlioz' *Grande Messe des morts* (*Requiem*, 1837) calls for four flutes, two oboes, two English horns, four clarinets, 12 French horns, eight bassoons, 25 first violins, 25 second violins, 20 violas, 20 violoncellos, 18 double basses, eight pairs of timpani, four tam-tams (a type of gong), bass drum, and 10 pairs of cymbals; four brass choirs placed in various parts of the hall, each consisting of four trumpets, four trombones, two tubas, and four ophicleides (a large, now obsolete brass instrument); and a chorus of 80 sopranos, 80 altos, 60 tenors, and 70 basses. The coloristic ideas in Berlioz' music were carried on in various ways by other important 19th-century composers and reached a culmination in the music of the German composer Richard Strauss and the Austrian Gustav Mahler—both of whom demanded a virtuoso orchestra—and were orchestrated in a complex fashion, although Mahler was capable of very delicate effects.

First treatise on orchestration

Post-Romanticism and the 20th century. Claude Debussy in France was probably the most important composer of the Impressionistic era, which lasted roughly from 1880 until the turn of the century. The Impressionist composers attempted to describe scenes and evoke moods by the use of rich harmonies and a wide palette of timbre. No composer ever handled the colours of the orchestra with greater subtlety. Naturally, this is also dependent on his use of harmony, melody, and rhythm, but the dominant impression of a Debussy work is focussed on his use of orchestral instruments to create light and shadows. Works that exemplify his techniques are *Prélude à l'après-midi d'un faune* (*Prelude to the Afternoon of a Faun*; 1894), *Nocturnes* (1899), and *La Mer* (*The Sea*; 1905). In *Nocturnes*, he uses a wordless women's chorus as a section of the orchestra, functioning as another source of timbre rather than as the transmitter of a text.

The Impressionist school

Many of the composers who followed Debussy and Mahler brought about radical changes in the use of the orchestra. A good example of some of these changes is in *The Rite of Spring* (1913), by the Russian-born composer Igor Stravinsky. The strings frequently do not assume a dominant role but, rather, often play music that is subservient to the brass or woodwinds. Percussion instruments greatly increased in importance and have continued to do so. In 1931, Edgard Varèse composed an important work, *Ionisation*, for 13 percussion players, a landmark in the emergence of percussion instruments as equal partners in music.

The period between World War I and World War II was dominated by two main schools of composers with vastly differing results for orchestration. One was responsible for the Neoclassical style; the other, gathered around the Austrian composer Arnold Schoenberg, drew heavily on the Romantic movement for its direction. The Neoclassical composers sought to free music from the influence of Impressionism. Whereas the Impressionist and Romantic composers had frequently employed the instrumental forces at hand to create a deliberate sense of vagueness, the Neoclassical composers, beginning in about 1917 with a group in France known as Les Six, attempted to recreate the clarity of the Classical period by turning to models found in the popular music of the period, the music of the dance halls and cabarets. The Neoclassical composers also turned away somewhat from the orchestra as a medium, finding the forces of chamber music more suitable for their ideals. Neoclassical music returned to a clearer concept of "sections" in orchestration. The music of a composer such as Paul Hindemith in Germany is closer to the music of Mozart in its sense of instrumentation than it is to Romanticism or Impressionism.

The music of Schoenberg and his fellow Austrian Alban Berg drew heavily on the Romantic movement and eventually became known as Expressionism, which stressed inner experience. Emphasis on the inner man produced a music that was thick, dark, and intense.

In the first half of the 20th century electronic music emerged, although it did not become important until after 1950. The principal reasons for the inclusion here of electronic music are that electronic sounds, either taped or live, frequently are included in a composition combined with traditional instruments, and it has had a decided influence on orchestration. (For a treatment of historical and compositional aspects of electronic music, see MUSICAL FORMS AND GENRES: *Electronic music*.) By the 1960s many composers were writing works for electronic sounds and instruments. The electronic sounds provide a dimension to instrumentation never before possible. A number of things are noteworthy. Electronic sounds are capable of incredibly subtle changes of timbre, pitch, and mode of attack. When combined with traditional instruments they add a rich new spectrum of colour. This in turn has influenced the composer to attempt to produce "electronic" sounds with standard instruments. The result has been a great extension of the sound possibilities of Western instruments.

Importance of electronic music

Another 20th-century trend was away from large orchestras and toward chamber ensembles, often of nontraditional combinations. Compositions for such ensembles may excel in economy of means and explore individual instrumental timbres. To achieve this, unusual playing techniques may be required.

Non-Western instrumentation. Much of music outside the West has entirely different aesthetic aims; the music of the Hindu world, best known to the West through the classical music of India, provides an example. Indian music always has had strong ties with mythology and religion and thus produced an art that is as different from Western music as Hinduism is from Christianity. It achieves unity through similarity rather than through change and is based on a more purely sensual approach. Hindu music is divided, for example, into ragas, or melody types. The word raga means colour or mood. Combined with the ragas are *tālas*, or rhythmic patterns. The possible combinations of *tālas* and ragas are many, producing a music that is wonderfully subtle.

The instruments for this music consist of various drums made of terra-cotta, wood, or metal; cymbals also serve as percussion instruments. Probably the instrument best known to Western audiences is the tabla, a two-drum set capable of very subtle changes in sound. The two best known stringed instruments are the sitar (plucked) and the tamboura, a four-stringed instrument that provides the omnipresent drone accompaniment. In addition, there are various wind instruments, such as the bamboo flute and the *sheh'nai* (oboe).

Instruments of Indian and Balinese music

Balinese and Javanese music is centred on the gamelan orchestra, the instruments of which include the *saron* and *gender* metallophones (like xylophones but with metal, not wooden, keys), the *gambang kayu* xylophone, tuned gongs, flutes, and the *rebab*, a violin-like instrument with

two strings. All the instruments follow the same nuclear melody but elaborate it in different ways. The heavy reliance on tuned percussion instruments has given this music a brilliant quality that Western audiences have found extremely attractive. The gamelan orchestra, for instance, influenced Debussy, who first heard the music at the Paris Exposition in 1889.

The approach to instrumentation in the music of India and Bali is quite different from that of Western music. The concept of contrast created through the various "choirs" of the Western orchestra is not a primary concern. In Indian music a sameness of colour is created through the use of the drone played on the tamboura. This is not to say that this music is uncolourful but that a specific timbre is established for an entire composition. Since the time of Debussy, Western composers have come increasingly into contact with, in particular, the music of India, Bali, and Japan. A comparison of Balinese gamelan music with the *Sonatas and Interludes* for prepared piano by the 20th-century American composer John Cage shows how profound this influence can be.

Arrangement and transcription. A practice that has been much employed in the 20th century, although by no means confined to it, has been the writing of arrangements and transcriptions. Though little distinction is made between the two, there are, at least in current practice, differences. A transcription is essentially the adaptation of a composition for an instrument or instruments other than those for which it was originally written. An arrangement is a similar procedure, although the arranger often feels free to take musical liberties with elements of the original score. This is especially true of arrangements for jazz or rock groups and arrangements of popular compositions or songs from musical comedies.

In the 18th and 19th centuries, chamber and orchestral music was transcribed, or "arranged," for the piano for the purpose of study and, of course, for the pleasure of playing at home the music that had been heard at a concert. This practice has continued. Piano versions of many 18th- and 19th-century orchestral works exist in two- and four-hand arrangements. Another common practice is to reduce the orchestral parts of concertos to a keyboard version to enable students to study and play these works without an orchestra.

Piano versions of orchestral works

The symphonic band, despite its popularity in Great Britain and North America, was faced with a dearth of repertoire written specifically for it. In the past, one answer was to transcribe orchestral works for band, substituting particularly the clarinets, with their wide pitch range, for the strings of the symphony orchestra. The necessity for that substitution is no longer so great because in recent times composers have written much more music specifically for the symphonic band.

The dance band predominant in the 1930s and 1940s is treated roughly in the following way by arrangers: the saxophones carry the melody more frequently than the other sections; the trumpets provide embellishment or figures that work around the melody; the trombones either are combined with the trumpets or serve as a melodic instrument; the piano and guitar provide harmonic filler; and the double bass and drums set the rhythm.

The jazz or rock arranger has done much more than simply transcribe the keyboard version of a song. All forms of popular music in the 20th century have been involved in the art of improvising. Musicians working in this field almost always embellish the music as they perform it. The jazz or rock arranger in a sense improvises on manuscript paper. In making an arrangement for a group of musicians the arranger will embellish both the harmonic structure and the melody of the composition; or the arrangement will be worked out in rehearsal and memorized or written down later. Usually, the arranger keeps enough of the original material to enable the listener to recognize the source. His skill depends on how well he can manipulate the materials of the original and on his originality in scoring the composition for the group at his disposal. The men who work in this field are frequently composers of popular music themselves.

(D.Er.)

The recording of music

TYPES OF REPRODUCTION

The physical reproduction of music has been accomplished in three major ways, which can be designated the mechanical, the acoustical, and the electrical. In the mechanical, an automatic instrument, such as the barrel organ, plays music that has been built, or programmed, into the mechanism by the designer; the resulting sound is that of the apparatus. In the acoustical and electrical methods of reproduction, sonic vibrations themselves are captured in performance and reproduced—by purely mechanical means in the acoustical method and by the use of vacuum tubes, transistors, and other such devices in the electrical. In both cases, the resulting sound is expected to be that of the independent performance.

Mechanical, acoustical, and electrical methods

Until the end of the 19th century, music was reproduced primarily by means of the mechanical method. There are reports of other methods, probably based on the action of wind or forced air, dating as far back as about 1500 BC, in the 18th dynasty of ancient Egypt, when a colossal statue of the god Memnon at Thebes made some sort of sounds to greet his mother, the goddess of the dawn. (Toppled by an earthquake in the year 27, the statue seems to have lost this ability upon reconstruction.) Friar Roger Bacon is reported to have invented some sort of talking head in the Middle Ages, and Josef Faber created in Vienna in 1860 a talking man with ivory reeds for vocal cords, a rubber tongue and lips, and with a keyboard that altered the mouth cavity to control word formation. The most common technique, however, called for a human hand or clockwork to turn a cylinder embedded with pins that would strike or otherwise operate some sound-producing apparatus, such as the metal teeth of a music-box comb; the hammers, quills, or pipes of a keyboard instrument; or the clappers of a set of bells. Automatic carillons are known from the 1300s; automatic harpsichords and organs, from the 1500s. King Henry VIII of England owned an automatic virginal; his daughter Queen Elizabeth I in 1593 sent the sultan of Turkey an elaborate musical clock. Every six hours it played a tune on 16 chimes, followed by a two-trumpet tantara, then by an organ tune and performance by "a holly bushe full of birds and thrushes, which at the end of the musick did singe and shake theire winges." In the 19th century Queen Victoria of Great Britain owned a bustle that would play "God Save the Queen" when she sat down.

Some of the most illustrious composers in the history of music wrote for mechanical devices. Haydn wrote tunes for musical (pipe organ) clocks; Mozart wrote several pieces for mechanical organ; and Beethoven wrote his *Wellington's Victory* (or *Battle Symphony*) for the panharmonicon, a full mechanical orchestra invented by Johann Nepomuk Maelzel (Mälzel), a German musician who perfected the metronome.

At the end of the 19th century two inventions superseded the barrel-and-pin mechanism. One was the player piano, which used a perforated cardboard roll to control a stream of air that activated the piano's hammers. This had the advantage of enabling pianists to record their performances for future playback, and many virtuosos and composers took advantage of this device, among them Ignacy Paderewski, Edvard Grieg, Claude Debussy, and Sergey Rachmaninoff. Some composers, including Igor Stravinsky and Paul Hindemith, wrote music especially for the piano roll, using devices such as combinations of as many as 30 notes played simultaneously; while impossible for two hands, such chords could readily be played by the perforated paper.

The player piano

The second invention, which was to make obsolete all previous music-reproducing apparatuses (except in toys and cuckoo clocks), was the phonograph. (For the technology of musical reproduction, see SOUND: *Sound recording and reproduction.*)

THE INFLUENCE OF RECORDING

Composition. In 1967 a survey of hundreds of American composers indicated that they were almost unanimous in regarding the recordings of their works as being more

important than either printed publication or live performances. Through recordings, composers gained not only an easy familiarity with the music of others but also a new medium for their own works.

The contemporary American composer and teacher Milton Babbitt, in a conversation in 1965 with the Canadian pianist Glenn Gould (who maintained his own reputation largely by means of records and broadcasts, rather than by concert performances), said:

> We have all been affected as composers, as teachers, as musicians by recordings to an extent that cannot possibly be calculated as yet. . . . I don't think one can possibly exaggerate the extent to which the climate of music today is determined by the fact that the total Webern is available on records, that the total Schoenberg is becoming available.

The use of the record as a medium had superficial beginnings as early as 1904 in Ruggero Leoncavallo's song "Mattinata," specifically written for the record according to the label. Later, in 1925, Stravinsky composed a piano piece, *Serenade in A Major,* expressly for the record medium, though it is also perfectly capable of being performed live. Ottorino Respighi's *Pines of Rome* (1924) incorporates a recording of a nightingale's song in its third movement. Much more important use of recording as a medium occurred toward mid-century in works fundamentally relying on recorded tape, such as Edgard Varèse's *Poème électronique,* an 11-channel tape played through 425 speakers at the 1958 Brussels World Fair, and Morton Subotnick's *Silver Apples of the Moon* (1967), an electronic work playable only as a recording.

Teaching. In music education the phonograph was early adopted as a tool in teaching both serious students and laymen. Teachers who could not adequately illustrate musical examples at the piano found in records a means of demonstration. They could also bring entire orchestras into the classroom by means of the phonograph.

Recorded histories of music

In 1930 the *Columbia History of Music by Ear and Eye,* a phonographic survey that became popular in music history classes, enabled many students—as well as many of their teachers—to hear for the first time such instruments as viols, lutes, virginals, clavichords, and harpsichords together with the then little-known music written for them. A half dozen years later another educational recorded project, *L'Anthologie sonore,* added impetus to this specialized field. By the 1960s the Baroque music of the 17th and 18th centuries—as well as the earlier music of the Renaissance and medieval era—increasingly was recorded in performances using the instruments for which it was written. Such music found a wide audience beyond educational institutions; this audience was developed in large part by the phonograph.

By the late 20th century many conservatories, colleges, and universities, and even some secondary schools, had constructed recording studios to enable students to analyze their own performances or to rehear their own compositions.

Criticism. Records also enabled music critics to expand their knowledge and perspective of music and performance practices. Unfortunately, a record collection also allows reviewers to write on superficial differences between performances with very little expenditure of intellectual energy. New music has suffered especially from the resulting loss of the ability of many critics to expostulate on music for their readers.

Concerts. The impact of recordings on the concert hall has also been enormous, both for classical and for popular performances. Performers today can hardly hope to attract a concert audience if they have not produced distinguished recordings; usually, their audiences, both at home and abroad, consist of persons who know the performers' work through recordings. In the popular music field especially, many performers cannot compete in live appearances with recordings in which they depend heavily on technical aid. There are some who feel that the phonograph may cause the demise of live performance in the concert hall, which, if it survives at all, will do so for social rather than musical reasons. A possible indication of this trend is the disappearance of independent, nonacademic, nonprofessional classical music magazines in America; instead, there are record magazines. Their name changes are significant: *The American Record Guide,* established in 1935 as *The American Music Lover; High Fidelity,* established in 1951; and *Stereo Review,* established in 1958 as *Hi Fi/Music Review.* The record magazine is not a peculiarly American phenomenon; England has *The Gramophone* and *Records and Recording;* France, *Diapason* and *Harmonie;* Germany, *HiFi Stereophonie* and *Fono Forum;* Italy, *Discoteca Hi Fi;* Holland, *Luister;* Belgium, *Hi-Fi Musique;* Sweden, *Musikrevy;* and Japan, *Record Art/Record Geijutsu,* among many other periodical publications.

Musicology. The entire field of comparative musicology—*i.e.,* the study of the relationships between Western, non-Western, and primitive music—depends upon disc and tape recordings. Although the discipline may be traced to the 18th century, it did not emerge from a primitive state until it acquired phonographic tools. Primitive music is generally transmitted orally rather than through a written tradition, and as such its performance practices—certainly in rhythm and intonation—cannot be accurately transcribed into Western notation. Since World War II anthropologists and musicologists have visited the most remote parts of the world with tape machines to record aboriginal music before it was either tainted or wiped out by Western civilization. The most recent studies have been conducted as a race against time or more specifically against the transistor radio, a ubiquitous commodity that is homogenizing the world's musics.

THE ROLE OF THE PRODUCER

Although the record producer has at times become an equal partner with the musicians in creating the recorded performance of classical music, in the popular field he is frequently in total command. Here, in fact, the sounds produced by the musicians may simply be the raw material for the producer to work with; artificial sounds, overlays of sound upon sound, electronically introduced reverberation, multichannel effects with directional interplay and moving instruments, all may serve as vital ingredients of the recording. Paradoxically, as technological advancement brought the recording beyond the mere imitation of live performances, popular musicians began to bring complex electronic equipment into the concert halls to imitate the sounds of their recordings.

In productions of classical music, serious thought is given to whether the recording should faithfully capture the performance as heard from the optimum position in the concert hall or studio or whether the recording setup should be used to "enhance" the performance. Few question any longer the common practice of correcting actual mistakes. Ever since magnetic tape made detailed editing possible, extra takes have been made of sections in which musical problems are evident. The best taping of each section is spliced into a master tape. Even in recordings made during an actual concert, performers sometimes return to the hall afterward to emend any blemishes. The improvements in recorded performances made possible by tape splicing, however, often mislead audiences into anticipating the same perfection in live performances. Also, although tape editing facilitates the excision of poor passages that, while acceptable in the heat of a concert, would become irritating upon repeated hearings, it also has been said to hamper the continuity of the performance. It is unlikely, however, that a listener can spot the rare movement that has required no splicing from the majority that have. This alleged lack of continuity, however, was much worse when music had to be recorded in five-minute segments, for recordings at 78 revolutions per minute (rpm).

Microphone placement

Microphone placement has been perhaps the major criterion in separating the "natural" or "re-creative" from the "creative" technique of large-scale classical recordings. In a natural setup microphones are placed in the optimum positions in the hall—often directly over the conductor—in order to re-create the concert-hall or opera-house effect. In the natural arrangement the conductor is responsible for instrumental and vocal balances.

Some record-producing companies prefer to put microphones closer to the performers—this is called close-miking technique. Here the record producer—generally with the

final approval of the conductor or leader—is responsible for balances, for bringing out particular instrumental or vocal lines; in other words, the producer participates in the interpretation. Studio-made popular recordings—other than those of a lush semiclassical nature—have generally used the close-miking technique; in some cases, each performer in a small musical group is assigned his own microphone. In a close-miked symphonic recording session, as many as 18 microphones may be used: three for violins; one for cellos and basses (sometimes one for each); one each for woodwinds, brasses, timpani, snare drum and triangle, bass drum and cymbals, celesta or harp, and soloist; and from three to six for a chorus. Several separate recordings, or "tracks," each comprising the inputs of several microphones, generally are made at the same time, and the producer must balance the strength of these various inputs during the recording session. Until about 1960 two-track machines were ordinarily used; by 1970 eight-track recorders were in use, allowing much more subtle mixing of channels during the editing sessions subsequent to the actual recording. For popular music sessions 16-track recorders are sometimes used. For stereophony all the recording tracks must be edited and mixed to make the final two channels. The record producer also determines the degree of separation between those two channels, and during a dramatic recording—an opera, for example—he may function as stage director in guiding the performers around the aural stage.

In quadraphony (quadriphony), which has four channels and which, in disc format, unsuccessfully tried to find a market in the early 1970s, the controversy between natural and close-miked recordings persisted. In classical music, when the two rear channels were used mainly for hall ambience, the arguments centred on the placement of the two front channels. Some companies, however, began to use the four channels as equal partners even in the classics. Columbia, for example, sometimes placed the conductor in the middle of the orchestra, which was seated for optimum quadraphonic array rather than for optimum concert-hall effect. In the early 1970s several quadraphonic disc systems competed for prominence, most notably Columbia's SQ, Japan Victor Company's CD-4 (RCA's Quadradisc in the United States), and Sansui's RM (also called QS). Since they were incompatible systems, confused consumers, waiting for one to become standard, withheld their votes from all, and by the end of the decade the aural and aesthetic benefits of quadraphony had all but disappeared from the marketplace.

THE DEVELOPMENT OF MUSICAL RECORDING

In 1877 the U.S. inventor Thomas Alva Edison heard "Mary had a little lamb" emanate from a machine into which he had just spoken the ditty. It was the first time a recording of the human voice had been reproduced, and the event signalled the birth of the phonograph. There was, to be sure, a long gestation period.

Edison sent representatives, machines, and cylinders to Europe almost as soon as he had invented the phonograph, and between 1888 and 1894 recordings were made by such notables as Alfred, Lord Tennyson, Robert Browning, and even Johannes Brahms, who played a Hungarian rhapsody. The first "celebrity" recording, however, was made in Edison's West Orange, New Jersey, laboratories when the pianist Josef Hofmann, then a 12-year-old prodigy, paid a visit to Edison's studio in 1888. Hans von Bülow followed shortly after with a recording of a Chopin mazurka on the piano.

The first "celebrity" recordings

In 1894 Charles and Émile Pathé built a small phonograph factory in a suburb of Paris and began to record singers as eminent as Mary Garden. Within a decade their catalog boasted some 12,000 items, and their name became almost synonymous with the cylinder phonograph in Europe. Meanwhile, Emile Berliner, a German immigrant living in Washington, D.C., had filed a patent in 1887 for a "Gramophone," using a disc rather than a cylinder, and he began manufacturing Gramophones and discs in 1894. The disc had the commercial advantage of being more easily manufactured than the cylinders. One of his representatives established a branch in London, the Gramophone Company (in 1898), a branch in Berlin, Deutsche Grammophon AG, and one in France, the Compagnie Français du Gramophone, while Berliner's brother set up a disc-pressing facility in Hamburg. Most of Europe's recording industry thus was started by Berliner's representatives, and in the United States the small Berliner organization was to turn into the giant Victor company.

By the beginning of the 20th century, recording industries had been established in Germany, Austria, Russia, and Spain. Much of the managerial and technical talent, not to mention equipment, had been imported from America. (By 1970, the positions would be reversed, with Europe in command of most of the American market.)

During the 1890s recordings had become popular primarily through coin-in-the-slot phonographs in public places. Talent was incidental to the novelty of the apparatus; most of the recordings were of whistlers, bands, comic numbers, ditties, ethnic routines, and the like. In the first years of the 20th century, Victor and its affiliates raised cultural expectations with its Red Seal series (Red Label in Europe), particularly with discs made, beginning in 1902, by Enrico Caruso. By 1910 the vast majority of record sales—some estimates are as high as 85 percent—were classical.

The Red Label had been initiated in 1901 in Russia with some of the first 10-inch disc recordings made, and the basso Fyodor Chaliapin was among the first artists to record on the new Russian Red Label.

In 1902 Victor and another major label, Columbia, decided to help the development of the new industry by pooling their patents. Victor was thereby legally able to record on wax (which would then be electroplated) for the first time, and the new wax discs were then used in recording Caruso in Milan. Caruso's discs were a major catalyst in transforming the amusing gadget of a phonograph into a respected cultural phenomenon. That same year the new series received London-made recordings by stars of the Covent Garden opera house, primarily through the efforts of the Gramophone Company's music director, Landon Ronald, a bona fide serious musician and conductor who was able to convince his colleagues of the musical worth of the Gramophone. One instrumentalist also appeared in the new Red Label series, the violinist Jan Kubelík.

In the United States, Columbia followed suit in 1903 with its 10-inch Grand Opera Records, recording Metropolitan Opera stars. Shortly after, Victor began its own celebrity recording sessions of opera stars and others on 3½-minute 12-inch discs. Victor also made many of its associated European companies' Red Label recordings—which included Mary Garden singing music by Debussy with the composer at the piano—available in the United States on its Red Seal series. Columbia soon dropped its opera series when the recordings did not sell as well as songs and marches, but Victor saw an institutional value in the celebrity recordings. The prestige of the Red Seal influenced Victor's other products: "Victrola" became, in the popular mind, almost a generic term for the (disc) phonograph, and the company practically monopolized the quality-minded market for many years. Indeed, the total Western Hemisphere record market became virtually monopolized by Victor and Columbia, while their London affiliates controlled the rest of the world. The first major break did not come until World War I, when ties were severed with Deutsche Grammophon, which emerged after the war as the independent Deutsche Grammophon Gesellschaft (DGG).

Between 1907 and 1910 Columbia tried to approach Victor's cultural prominence by releasing records from Europe and later by reinstating its own recording sessions with operatic singers. Columbia also began issuing double-sided discs, as had already been done in Europe. Victor did not do so until 1923.

During the early days of recording, both the cylinder and the disc were produced acoustically rather than electronically. A singer would sing into a horn, and the accompanist behind him played a piano placed on a platform so that the rear of the instrument—with the back removed—would also be level with the horn. With the development of a sound box to be placed on violins and violas, small

orchestras could be used as accompaniment, but bassoons were required to play the cello part and a tuba the double bass part. It was an event worthy of a London newspaper announcement in 1904 when Kubelík made two records with his own Stradivarius, rather than on a violin with the sound box. When symphonic recordings came to be made, the wind and brass instruments still played or doubled the parts written for the lower strings, which could not be reproduced adequately. Although acoustical recordings were improved by the 1920s, the problems were not overcome until the introduction of the microphone and the consequent electrical recording process around 1925.

Birth of a mass medium

In the decade 1910–20, the phonograph became a truly mass medium for popular music, and recordings of large-scale orchestral works and other classical instrumental music proliferated. The rise of the popular record coincided in the United States with the new ragtime, popularized by Scott Joplin's rags at the turn of the century and sensationalized by Irving Berlin's "Alexander's Ragtime Band," written in 1910, which swept the country the following year. It stimulated an unprecedented dance craze at a time when the phonograph was becoming increasingly available. As the fad spread to millions who had never danced before, phonographs were sold to people who had never owned records before. Between 1914 and 1919 phonograph sales increased more than fivefold. In 1917 Victor issued the first jazz recordings, by the Original Dixieland Jass (sic) Band, but few major jazz releases appeared before the 1920s.

The first large-scale symphonic recording, Tchaikovsky's *Nutcracker Suite*, was issued in 1909 in England. The first attempt to record a concerto came the following year, also in London, when Wilhelm Backhaus recorded a cut version of the first movement of Grieg's *Piano Concerto*. In 1913 the first complete symphonies, Beethoven's *Fifth* and *Sixth*, were recorded in Germany under an anonymous conductor; later that year, a celebrity conductor, Arthur Nikisch, led a full-scale symphony for the first time, again the Beethoven *Fifth*. Solo instrumentalists vied with the opera singers for the record-buying public's affection, mainly by recording tidbits. In 1917 Victor began to record with a combination that was to prove its star classical music attraction for decades: Leopold Stokowski and the Philadelphia Orchestra.

The serious recording of serious music became a growing phenomenon as the phonograph matured during the early 1920s. Tidbits and orchestral snatches gave way to a spate of uncut symphonies, sonatas, quartets, and concerti; the music itself came to mean as much as its star performers, and the electrical recording process, from 1925 on, raised the quality of the recordings as well. But in the mid-1920s radio, which provided free music, developed, and this new factor, plus the worldwide economic depression of the 1930s, threw the phonograph industry into serious decline.

The companies realigned themselves. In 1929 the Radio Corporation of America (RCA) bought Victor. Later that year, Edison left the phonograph business he had created. In 1931 the English Columbia Graphophone Company divested itself of its near-defunct American progenitor and joined the Gramophone Company to form Electric and Musical Industries, Ltd. (EMI), bringing into the merger nearly every important European firm except DGG and its export label, Polydor. American Columbia was revived by its purchase, in 1938, by the Columbia Broadcasting System.

During the 1930s, as the American companies relied mainly on dance records in jukeboxes to satisfy a dwindled market, Europe supplied a slow but steady trickle of classical recordings. In 1931 the His Master's Voice (HMV) label in Great Britain began its "Society" issues: a limited public was asked to subscribe in advance to then esoteric releases—the complete Beethoven piano sonatas played by Artur Schnabel or Pablo Casals performing the Bach unaccompanied cello suites. A new British company, Decca, organized in 1929, also began to issue serious recordings. In the United States, Columbia began to record a number of distinguished orchestras, including those of New York City, Chicago, Cleveland, and Minneapolis. RCA retained its leadership, however, with the Philadelphia Orchestra under Eugene Ormandy, the Boston Symphony Orchestra under Serge Koussevitzky, and—perhaps the greatest orchestral combination ever assembled—the NBC Symphony under Arturo Toscanini, as well as with the violinist Jascha Heifetz and the pianist Vladimir Horowitz.

British Decca had a far-reaching role to play after World War II when its ffrr—full frequency range recording—became internationally known. The frequency range of discs had been dramatically extended, and Ernest Ansermet's recording of Stravinsky's *Petrushka* in the new process was to awaken the unsuspecting ears of many record collectors in 1946 to the future high fidelity, or "hi-fi," possibilities of the phonograph.

Two other developments in the late 1940s combined with the extended frequency range to produce a radical change in the development of recordings: magnetic recording and the first commercially successful long-playing (LP) record. In 1948 Columbia Records demonstrated 12-inch unbreakable vinyl discs that could play about 25 minutes of music per side. The standard shellac disc had revolved at 78 rpm, and a 12-inch disc had to be changed, automatically or manually, every five minutes, thus breaking up the continuity of longer works; the 12-inch LP, revolving at $33\frac{1}{3}$ rpm, could hold the average symphony, sonata, or quartet on a single side. And the vinyl discs had quieter surfaces than the shellac. Victor soon countered with its own microgroove records: seven-inch vinyl discs at 45 rpm. Each contained approximately as much music as a 12-inch 78-rpm disc, but the package was smaller. By 1950, a pattern had been set: 12-inch LPs for classical works and popular albums, 45s for individual popular songs. Extended-play 45s also were developed and successfully marketed. The LP opened up an entirely new market—not only newcomers but older record collectors who could see the advantage of the new technology and were willing to repurchase their collections as LPs. The 78-rpm shellac disc followed the cylinder into oblivion.

Tape had a major impact on recording starting in the late 1940s: anyone with a good recorder and microphone could become a record producer. Small companies sprang up in areas of music ignored by the giants: the esoteric and the avant-garde, the music of the periods before and after the highly popular Romantic classics of the 19th century. Chamber music, as well as Baroque works of the 18th century and earlier, which required paying fewer musicians than an entire symphony orchestra, flooded record stores and resulted in an unprecedented Baroque revival among music lovers. All-Vivaldi concerts were sold out, and Bach became a best-seller. Orchestral recordings of less familiar works—produced in a Europe that had been ravaged by World War II, where musicians' fees were minimal—crested the flood. New companies recorded for the first time many symphonies, quartets, masses, little-known operas, and many other once esoteric works, some of which were now available in competing versions. The more popular standard works, the symphonies of Beethoven, Brahms, and Tchaikovsky, became duplicated by the dozens. By the mid-1950s it seemed that most of the worthwhile musical output of Western civilization—and much from Asia and Africa—had been made available to the average home.

The stereo revolution

For a few owners of some deluxe tape recorders, a new listening experience was available by 1956: stereophonic tape recordings. Within two years stereo discs made their commercial appearance; every major U.S. company began issuing stereo discs by the end of 1958.

Now a new flood of records hit the market: notably popular were those that displayed the spectacular effects possible with stereo. It was again Decca/London that convinced the serious music lover of the musical benefits of stereo with the release in 1959 of Wagner's *Das Rheingold*, conducted by Georg (later Sir Georg) Solti, a pioneer work in the "creative" school of classical record production. Within a decade two complete recordings of Wagner's *Ring* cycle, comprising four complete operas on 19 discs, were available. Again, as with the advent of the LP, a technical advance spurred the record industry into recording an even greater repertoire than was available previously. By the late 1960s most American record com-

panies had discontinued their monaural recordings, except for "historical reissues."

The 1950s saw a rearrangement of record company alliances, as Europe began its strong invasion of America. By the 1970s not only did Europe own a sizable chunk of the American record industry, but it had taken over the recording, for the first time, of many of the most prestigious U.S. orchestras.

Another far-reaching phenomenon of the 1950s was Elvis Presley, a popular U.S. singer who inspired a new, militantly youth-oriented style of music: rock and roll. It generated a multitude of solo singers and groups as well as a teenage and subteen culture of rabid record buyers. The success of the British rock group the Beatles helped stimulate record sales in the 1960s to an all-time high. The sales of classical records, however, represented a declining portion of the total. It seemed that most people who wanted the standard classics had already bought them and that few new standard works of any length were being written. Rather than new classical recordings, re-releases were issued in new packages (*e.g.*, "Debussy's Greatest Hits") and in the new medium of tape. During the mid-1960s two small and conveniently packaged tape formats began a steady rise to popularity: the continuous-loop one-reel cartridge and the two-reel cassette. Each obviated the need for threading tape in order to play it. The cartridge first achieved consumer acceptance as an automobile accessory and was designed primarily as a playback-only format; the cassette configuration was first introduced in an inexpensive portable recorder player.

Cartridges, cassettes, and videotape

Cassettes had the advantage over continuous-loop cartridges in being rewindable and thus easier to control for selective "spotting" and for amateur recording. For nonselective music or music in which it is not necessary to start at the beginning—background music, for instance—the continuous-loop cartridge had the advantage of not having to be rewound at all. By the end of 1982 sales of recorded music on cassettes had overtaken those of LP discs in the United States.

Meanwhile, a new recording technique that boasted, among other things, a wider dynamic range had begun to revolutionize the market for quality recordings: the music was taped "digitally," via pulse-code modulation. Pioneered by the Denon label in Japan, it was most enthusiastically adopted by Cleveland-based Telarc Records in the late 1970s. Another small company, Sheffield Lab, had already been producing impressive-sounding results by recording directly onto disc, foregoing the tape stage entirely. These and other "audiophile" companies began to corner the quality market, while charging two to three times the price of standard discs for their products: by 1983 this had led more than 40 companies, including the major labels, to adopt audiophile, primarily digital, techniques for at least their new classical releases. The first true digital discs, called Compact Discs, played back with a laser as the "stylus," became available in Japan in 1982 and in Europe and the United States in 1983.

Video has continued to be used to record musical performances via several incompatible disc and tape formats. The first years of the medium demonstrated that the grafting of images onto music would become viable only with the emergence of genius comparable to that of the great composers themselves. (L.M.M.)

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Western compositional technique: Because most writings on musical composition were conceived as didactic treatises for would-be composers, their content has virtually no bearing on a better understanding of crucial aesthetic attitudes and mental processes. Instead, depending on the era from which they hail as well as the specific outlook of their authors, such treatises deal for the most part with contrapuntal rules, harmonic laws,

and the like. While numerous books of this type appeared through the ages, it was only with the creation of the educational institutions known as conservatories of music, following the lead of the National Conservatory of France established in the last years of the 18th century, that composition became a discipline formally taught and hence requiring comprehensive textbooks, including the theory of form and instrumentation. This profitable need was satisfied by the voluminous activities of 19th-century writers from J.J. Momigny and Anton Reicha to Vincent d'Indy in France and from Heinrich Christoph Koch to Hugo Riemann in Germany. Few of these books were translated into English, and they are of primary interest to the specialist. The following is a selection of easily accessible monographs and documentary collections with emphasis on firsthand testimonies of the creative artists themselves.

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The History of Western Music

All ancient civilizations entered historical times with a flourishing musical culture. That the earliest writers explained it in terms of legend and myth is evidence of the remote beginnings of the art of sound. Among the speculations about its origin, the more plausible are that it began as a primitive form of communication, that it grew out of a device to expedite communal labour, or that it originated as a powerful adjunct to religious ceremonies. While such theories must necessarily remain speculative, it is clear, despite the prehistoric musical artifacts found in central Europe, that the cradle of Western music was the fertile crescent cupping the eastern end of the Mediterranean Sea. There the Mesopotamian, Egyptian, and Hebrew nations, among others, evolved political, social cultures that were absorbed by the conquering Greeks and, in turn, by the Romans, who transported a relatively sophisticated art form back to western Europe.

In all of these early cultures the social functions of music were essentially the same since their climate, geographic location, cultural pace, and mutual influences produced many more social similarities than differences. The primary function of music was apparently religious, ranging from heightening the effect of "magic" to ennobling liturgies. The other musical occasions depicted in both pictures and written accounts were equally functional: stirring incitements to military zeal, soothing accompaniments to communal or solitary labour, heightening aids to dramatic spectacles, and enlivening backgrounds to social gatherings that involved either singing or dancing or both. In every case musical sounds were an adjunct either to bodily movement (dance, march, game, or work) or to song. Many centuries were to pass before pleasure in euphonious sound became an end in itself.

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The establishment of Western musical traditions

ROOTS IN ANTIQUITY

Ancient Middle East and Egypt. The inhabitants of the Mesopotamian region around the Tigris and Euphrates rivers (the Sumerians, the Babylonians, and the Assyrians) flourished from *c.* 3500 to *c.* 500 BC. Their pictures and the few surviving artifacts indicate that they had instruments of every basic type—idiophones, whose sound is made by resonating as a whole; aerophones, which resonate a column of blown air; chordophones, with strings to be plucked or struck; and membranophones, made of stretched skins over a resonating body. An undecipherable hymn engraved in stone, dating from *c.* 800 BC, is evidence of a primitive system of musical notation.

The Egyptians, entering historical times about 500 years later than the Mesopotamians, enjoyed all of the same types of activities and instruments, as may be deduced from numerous written references to music as well as seen on many artifacts, especially the pictures preserved on pottery utensils.

The musical culture of the Hebrew peoples, recorded from about 2000 BC and documented primarily in the Old Testament, was more directly influential in the West because of its adoption and adaptation into the Christian liturgy. Because of the prohibition of Jewish religious law against the making of "graven images," there are very few surviving artifacts or pictures. Among the established practices of the temple service still current in the synagogue are the extensive use of the shofar (a ritualistic ram's-horn trumpet) and the singing of passages from the Pentateuch (the first five books of the Old Testament), prayers, and songs of praise.

Ancient Greece. Of the eastern Mediterranean cultures, it was undoubtedly that of the Greeks that furnished the most direct link with musical development in western Europe, by way of the Romans, who defeated them but adopted much of Greek culture intact. Entering historical times relatively late, *c.* 1000 BC, the Greeks soon dominated their neighbours and absorbed many elements of earlier cultures, which they modified and combined into an enlightened and sophisticated civilization. The two basic Greek religious cults—one devoted to Apollo, the other to Dionysus—became the prototypes for the two aesthetic poles, classical and romantic, that have contended throughout Western cultural history. The Apollonians were characterized by objectivity of expression, simplicity, and clarity, and their favoured instrument was the kithara, a type of lyre. The Dionysians, on the other hand, preferred the reed-blown aulos and were identified by subjectivity, emotional abandon, and sensuality.

Apollonian and Dionysiac expression

The prevailing doctrine of ethos, as explained by ancient Greek philosophers such as Plato and Aristotle, was based on the belief that music has a direct effect upon the soul and actions of mankind. As a result, the Greek political and social systems were intertwined with music, which had a primary role in the dramas of Aeschylus, Sophocles, Euripides, and Aristophanes. And the Grecian educational system was focused upon *musica* and *gymnastica*, the former referring to all cultural and intellectual studies, as distinguished from those related to physical training.

Origin of musical modes

To support its fundamental role in society, an intricate scientific rationale of music evolved, encompassing tuning, instruments, modes (melodic formulas based on certain scales), and rhythms. The 6th-century-BC philosopher and mathematician Pythagoras was the first to record the vibratory ratios that established the series of notes still used in Western music. From the total gamut of notes used were derived the various modes bearing the names of Grecian tribes—Dorian, Phrygian, Lydian, etc. The rhythmic system, deriving from poetry, was based on long–short relationships rather than strong–weak accentual metre. After Pythagoras, Aristoxenus was the major historian and theoretician of Greek music.

Ancient Rome. When the musical culture of the eastern Mediterranean was transplanted into the western Mediterranean by the returning Roman legions, it was inevitably modified by local tastes and traditions. In most cases, the resulting practices were more limited than their models. The diatonic (seven-note) scale, for example, became the standard, displacing the chromatic and enharmonic structures of the Grecian system. Of particular consequence was the new concept of metre as a series of equal durations, with emphasis being determined by accent (stress) rather than by duration.

An inventory of the musical heritage transplanted from the ancient East (particularly Greece) to Rome reveals the rich treasure inherited: an acoustical theory that accounted for the identification and classification of tones; a concept of tonal organization resulting in the system of modes; principles of rhythmic organization; basic principles of instrument construction; a system of notation that conveyed all necessary indications of pitch and duration; and a large repertory of melodies to serve as models for further composition.

THE MIDDLE AGES

Monophonic liturgical chant. With the decline of the Roman Empire, the institution destined to perpetuate and expand the musical heritage of antiquity was the Christian Church, but it was not a unified process. Many of the cultural centres of the Western church developed distinctive characteristics while sharing the common heritage of the Hebrew liturgy and Greek culture. In Milan, for example, metrical hymnody, as distinguished from the earlier practice of unmetred psalmody, was cultivated, particularly under the influence of the 4th-century Bishop Ambrose, who first attempted to codify the growing repertory of chants. This body of Milanese church music, therefore, came to be called Ambrosian chant. Somewhat later a unique style and repertory known as Mozarabic chant evolved in Spain, and in France the Gallican style prevailed.

Gregorian chant

But the mainstream of church music was the type of chant practiced in Rome. Beginning in the late 6th century, according to tradition, with Pope Gregory I, the vast number of traditional melodies that became the foundation for the later development of Western art music were codified and organized. A systematic organization of tonal materials also was gradually accomplished, resulting in the eight church modes. Each melody was assigned a specific function in the services of the liturgical year—some for the mass and some for the divine offices such as Matins, Vespers, and Compline. After a period of assimilation, the Gregorian chant repertory began a process of expansion in the 9th century, when the practice of troping originated. A trope is either a text or a melodic section added to a preexisting melody or a combination of text and music incorporated into existing liturgical music. It is not surprising that church musicians, after years of singing traditional chants, should want to express themselves by adding words to vocalized melodies. Perhaps the motive was more functional: the added syllables would make the long textless passages easier to remember. Tuotilo (died 915), a monk of St. Gall in Switzerland, is credited with the invention of tropes. Notker Balbulus (died 912) is notable for his association with the sequence, a long hymn that originated as a trope added to the final syllable of the Alleluia of the mass.

Development of polyphony. At the same time that the Gregorian repertory was being expanded by the interpolation of tropes and sequences, it was being further enriched by a revolutionary concept destined to give a new direction to the art of sound for hundreds of years. This concept was polyphony, or the simultaneous sounding of two or more melodic lines. The practice emerged gradually during the Dark Ages, and the lack of definite knowledge regarding its origin has brought forward several plausible theories: it resulted from singers with different natural vocal ranges singing at their most comfortable pitch levels; it was a practice of organists adopted by singers; or it came about when the repetition of a melody at a different pitch level was sung simultaneously with the original statement of the melody. Whatever motivated this dramatic departure from traditional monophony (music consisting of a single voice part), it was an established practice when it was described in *Musica enchiriadis* (*c.* 900), a manual for singers and one of the major musical documents of the Middle Ages. To a given plainsong, or *vox principalis,* a second voice (*vox organalis*) could be added at the interval (distance between notes) of a fourth or fifth (four or five steps) below. Music so performed was known as organum. While it may be assumed that the first attempts at polyphony involved only parallel motion at a set interval, the *Musica enchiriadis* describes and gives examples of two-part singing in similar (but not exactly parallel) and contrary movement—evidence that a considerable process of evolution had already taken place.

The beginnings of polyphony

The next major source of information was the *Micrologus,* written in the early 11th century by the Italian monk and musical theorist Guido of Arezzo. This work documented principles that were crucial to the further development of polyphony. Rhythmic independence was added to melodic independence, and the added voice might sing two or more tones to one in the original plainsong. During the half century after Guido's death, developments came more rapidly as the plainsong chant became the lower rather than the upper voice. After the emancipation of the organal part, *vox organalis,* its ultimate freedom was reached in the organums of the monastery of Saint-Martial in Limoges, France, where the plainsong part was reduced to the role of sustaining each tone while the organal part indulged in free melismata (groups of notes sung to a single syllable), either improvised or composed. This new style was called *organum purum.*

The Notre-Dame school. Early in the 12th century the centre of musical activity shifted to the church of Notre-Dame in Paris, where the French composer Léonin recorded in the *Magnus Liber Organi* ("Great Book of Organum") a collection of two-part organums for the entire church year. A generation later his successor, Pérotin, edited and revised the *Magnus Liber,* incorporating the rhythmic patterns already well-known in secular music and adding more than one part to the cantus firmus (the "given" or preexisting plainsong melody). When metre was applied to the original plainsong as well as to the *vox organalis,* the resulting form was called a clausula. Then, when words were provided for the added part or parts, a clausula became a motet. At first the words given to the motet were a commentary in Latin on the text of the original plainsong tenor (the voice part "holding" the cantus firmus; from Latin *tenere,* "to hold"). Later in the 13th century the added words were in French and secular in nature. Finally, each added part was given its own text, resulting in the classic Paris motet: a three-part composition consisting of a portion of plainchant (tenor) overlaid with two faster moving parts, each with its own secular text in French. At the same time another polyphonic form, the conductus, was flourishing. It differed from a motet in that its basic part was not plainsong and that all parts sang the same Latin text in note-against-note style. The conductus gradually disappeared with the rise of the motet, which apparently served both liturgical and secular functions.

The beginnings of the motet

Ars Nova. When the influential treatise *Ars Nova* ("New Art") by the composer Philippe de Vitry appeared early in the 14th century, the preceding epoch acquired its designation of Ars Antiqua (Old Art), for it was only in retrospect that the rapid developments of the century and a half from *c.* 1150 to *c.* 1300 could appear as antiquated. De Vitry recorded the innovations of his day, particularly

in the areas of metre and harmony. While 13th-century music had been organized around the triple "modal" rhythms derived from secular music and a harmonic vocabulary based on "perfect" consonances (unison, fourth, fifth, octave), the New Art of the 14th century used duple as well as triple divisions of the basic pulse and brought about a taste for harmonious intervals of thirds and sixths.

The musical centre of 14th-century Italy was Florence, where a blind organist, Francisco Landini, and his predecessors and contemporaries Giovanni da Cascia, Jacopo da Bologna, and Lorenzo and Ghirardello da Firenze were the leading composers of several new forms: madrigals (contrapuntal compositions for several voices), ballatas (similar to the French virelai), and caccias (three-voice songs using melodic imitation).

Monophonic secular song. Secular music undoubtedly flourished during the early Middle Ages, but, aside from sporadic references, the earliest accounts of such music in the Western world described the music of the goliards; these people were itinerant minor clerics and students who, from the 7th century on, roamed the land singing and playing topical songs dealing with love, war, famine, and other issues of the day. The emergence in France of a fully developed secular-musical tradition about the beginning of the 12th century is evidence that the art had been evolving continuously before that time. Partially motivated by the attitude of chivalry engendered by the Crusades, a new life-style began among the nobility of southern France. Calling themselves troubadours, they circulated among the leading courts of the region, devoting themselves to writing and singing poetry in the vernacular. The troubadour movement flourished in Provence during the 12th and 13th centuries. About the middle of the 12th century, noblemen of northern France, most notably Adam de La Halle, took up the pastime, calling themselves trouvères. In Germany a similar group known as Minnesingers, represented by Walther von der Vogelweide, began their activities about 1150 and continued for almost a century after their French counterparts had ceased composing. Late in the 13th century the burgher class in Germany began imitating the aristocratic Minnesingers. Calling themselves Meistersingers, they flourished for more than 500 years, organizing themselves into fraternities and following strict rules of poetry, music, and performance. The most famous of them, Hans Sachs, was immortalized in the 19th century in Richard Wagner's opera *Die Meistersinger von Nürnberg.* Relatively little is known of similar secular-musical activities in Italy, Spain, and England. Closely associated with the entertainments of the aristocratic dilettantes were the professional musicians of the peasant class called jongleurs and minstrels in France, *Gaukler* in Germany, and scops and gleemen in England.

Troubadours and Meistersingers

The musical style that had been established by the troubadours—which was monophonic, of limited range, and sectional in structure—was adopted by each of the succeeding groups. Of particular significance in view of its influence on polyphonic music was the metric system, which is based on six rhythmic modes. Supposedly derived from Greek poetic metres such as trochaic (long–short) and iambic (short–long), these modes brought about a prevailing triple metre in French music, while German poetry produced duple as well as triple metre. A great variety of formal patterns evolved, in which musical structure and poetic structure were closely related. The most characteristic was the ballade, which was called *Bar* form in Germany, with an AAB structure. This type, along with the rondeau (song for solo voice with choral refrain) and the similar virelai (an analogue of the Italian ballata), was destined to become a favoured form employed by composers of polyphony such as Guillaume de Machaut, the universally acknowledged master of French music of the Ars Nova period. Machaut also continued the composition of motets, organizing them around recurrent rhythmic patterns (isorhythm), a major structural technique of the age. The beginnings of an independent instrumental repertory during the 13th century are represented by the estampie, a monophonic dance form almost identical in style to the vocal secular music.

THE RENAISSANCE PERIOD

The term Renaissance, in spite of its various connotations, is difficult to apply to music. Borrowed from the visual arts and literature, the term is meaningful primarily as a chronological designation. Some historians date the beginning of the musical Renaissance at about 1400, some with the rise of imitative counterpoint, about 1450. Others relate it to the musical association with Humanistic poetry at the beginning of the 16th century, and still others reserve the term for the conscious attempt to recreate and imitate supposedly classical models that took place about 1600.

The court of Burgundy. No one line of demarcation is completely satisfactory, but, adhering to commonly accepted usage, one may conveniently accept as the beginning of the musical Renaissance the flourishing and secularization of music at the beginning of the 15th century, particularly at the court of Burgundy. Certainly many manifestations of a cultural renaissance were evident at the time: interest in preserving artifacts and literature of classical antiquity, the waning authority and influence of the church, the waxing Humanism, the burgeoning of urban centres and universities, and the growing economic affluence of the states of western Europe.

As one manifestation of their cultivation of elegant living, the aristocracy of both church and state vied with one another in maintaining resident musicians who could serve both chapel and banqueting hall. The frequent interchange of these musicians accounts for the rapid dissemination of new musical techniques and tastes. Partly because of economic advantages, Burgundy and its capital, Dijon, became the centre of European activity in music as well as the intellectual and artistic focus of northern Europe during the first half of the 15th century. Comprising most of eastern France and the Low Countries, the courts of Philip the Good and Charles the Bold attracted the leading musicians of western Europe. Prime among them was Guillaume Dufay, who had spent some time in Rome and Florence before settling in Cambrai about 1440. An important contemporary of Dufay was Gilles Binchois, who served at Dijon from about 1430 until 1460. The alliance of Burgundy with England accounted for the presence on the Continent of the English composer John Dunstable, who had a profound influence on Dufay. While the contributions of the English to the mainstream of continental music are sparsely documented, the differences in style between Dufay and his predecessor Machaut are partially accounted for by the new techniques and, especially, the richer harmonies adopted by the Burgundian composers from their English allies.

Rivalry between church and state in musical patronage

New religious musical forms. The social circumstances of the age determined that composers would devote their efforts to the mass, the motet, and the chanson (secular French song). During the first half of the 15th century, the mass became established as a unified polyphonic setting of the five main parts of the Ordinary of the mass (Kyrie, Gloria, Credo, Sanctus, Agnus Dei), with each movement based on either the relevant portion of plainsong or, reflecting the dawning Renaissance, a secular song such as the popular "L'Homme armé" ("The Armed Man") and "Se la face ay pale." Still reflecting medieval practices, the preexisting melody (or cantus firmus) was usually in the tenor (or lowest) part and in long, sustained tones, while the upper parts provided free elaboration. Dufay's nine complete settings of the mass, compared with Machaut's single setting, give a clear indication of the growing importance of the mass as a musical form. The motet became simply a setting of a Latin text from Scriptures or the liturgy in the prevailing polyphonic style of the time. It was no longer necessarily anchored to a plainsong tenor; the composer could give free reign to his invention, although some did, of course, resort to older techniques.

Importance of the mass

Secular music. It was in secular music that giant strides took place. While their chansons continued the tradition of rondeaux, virelais, and ballades, Dufay and his contemporaries added free forms divorced from the ordered patterns of the Ars Antiqua and Ars Nova periods.

Among the distinctive features of Burgundian musical style was the prevailing three-part texture, with melodic

and rhythmic interest centred in the top part. Because it was so typical of secular songs, this texture is commonly referred to as "ballade style" whether it appears in mass, motet, or chanson. Its possible stylistic implication is that a solo voice sang the upper melody, accompanied by instruments playing the lower parts, although no documents remain to establish exactly how the music was performed. There was probably no standard performing medium: all parts may have been sung; some or all may have been doubled by instruments; or there may have been one vocal part supported by instrumental accompaniment.

The Franco-Flemish school. A watershed in the history of music occurred about the middle of the 15th century. The fall of Constantinople in 1453 and the end of the Hundred Years' War at about the same time increased commerce from the East and affluence in the West. Most significant musically was the pervasive influence of musicians from the Low Countries, whose domination of the musical scene during the last half of the 15th century is reflected in the period designations the Netherlands school and the Franco-Flemish school. These musicians travelled and resided throughout Europe in response to their great demand at princely courts, including those of the Medici family in Florence and the Sforzas in Milan. Further dissemination of knowledge resulted from the invention and development of printing.

Travelling musicians at courts

The leading composers, whose patrons were now members of the civil aristocracy as well as princes of the church, were Jean d'Okeghem, Jakob Obrecht, and, especially, Josquin des Prez. D'Okeghem, born and trained in Flanders, spent most of his life in the service of the kings of France and was recognized by his contemporaries as the "Prince of Music." Obrecht remained near his birthplace in the Netherlands, going occasionally to Italy in the retinue of Duca Ercole I (Duke Hercules I) of Ferrara. More typical of the peripatetic Netherlanders was the career of Josquin, the most influential composer of the period. After training at St. Quentin, he served the Sforza family in Milan, the papal choir in Rome, Ercole I, and King Louis XII of France before returning to his native Flanders in 1516. These three composers and several contemporaries hastened the development of the musical techniques that became the basis of 16th-century practice and influenced succeeding developments.

Rather than the three parts typical of most Burgundian music, four parts became standard for vocal polyphony in the late 15th century. The fourth part was added below the tenor, increasing the total range and resulting in greater breadth of sound. The presence of the four parts also allowed for contrasts of texture such as the "duet style" so characteristic of Josquin, when the two upper parts might sing a passage alone and be echoed by the two lower parts alone. The emergence of the technique of imitation (one voice repeating recognizably a figure heard first in another voice) as the chief form-generating principle brought about more equality of parts. At the same time "familiar style," in which all parts move together in chords, provided a means of textural contrast. The great variety of rhythmic techniques that evolved during the 14th and early 15th centuries made possible a wide range of expression—from quiet tranquillity for sacred music to lively and spirited secular music. Knowledge of the musical practices comes not only from the thousands of surviving compositions but from informative treatises such as the 12 by the composer Johannes Tinctoris (1436–1511), one of which, *Terminorum musicae diffinitorium* (*c.* 1475), is the earliest printed dictionary of musical terms.

Wider range of expression through rhythmic developments

The chief forms of vocal music continued to be the mass, the motet, and the chanson, to which must be added other national types that developed during the 15th century—the villancico (secular poetry set for voice and lute or for three or four voices) in Spain and the frottola (a simple, chordal setting in three or four parts of an Italian text) in Italy. The emergence of the frottola in northern Italy led to the development of the Renaissance madrigal, which impelled that country to musical supremacy in Europe.

Instrumental music. At the same time, an independent instrumental idiom was evolving. While instruments had been in common usage throughout the Middle Ages, their function was primarily to double or to substitute for voices in vocal polyphonic music or to provide music for dancing. Techniques unsuitable for voices were doubtless part of an instrumentalist's musical vocabulary, but most such music was improvised rather than being written. Although there are a few sources of instrumental music dating from the 13th and 14th centuries, the earliest relatively extensive documentation comes from the 15th century, particularly from German sources, such as the *Buxheimer Orgelbuch* and Conrad Paumann's *Fundamentum organisandi* (*Fundamentals of Organ Playing*). The compositions in both collections are of two basic types, arrangements of vocal works and keyboard pieces entitled *Praeambulum* (*Prelude*).

During the course of the 16th century, instrumental music burgeoned rapidly, along with the continually developing idiomatically instrumental techniques, such as strongly accented rhythms, rapid repeated tones and figures, angular melodic lines involving wide intervallic skips, wide ranges, long, sustained tones and phrases, and much melodic ornamentation.

Musical forms. Dance forms, a continuation of a tradition unbroken since the beginnings of recorded music history, were most characteristically composed in pairs, although single dances as well as embryonic suites of three or more dances appeared. The pairs usually consisted of pieces in contrasting tempo and metre that often were unified by sharing a common melody. Common dance pairs included the pavane and galliard, the allemande and courante, and the basse danse and tourdion.

Preludes continued as a major form of organ music and were joined by the fantasia, the *intonazione,* and the toccata in a category frequently referred to as "free forms" because of the inconsistency and unpredictability of their structure and musical content—sections in imitative counterpoint, sections of sustained chords, sections in virtuoso figuration. If a distinction must be made, it might be said in very general terms that the fantasia tended to be more contrapuntal while the toccata (or "touch piece") featured passages designed to demonstrate the performer's agility, although the designations were freely interchangeable. To the same category belong the descriptive pieces such as *The King's Hunt,* which featured naive musical representations of natural sounds.

Fantasias and toccatas

The ricercar and the canzona, generally referred to as fugal forms because of their relationship to the principle of the fugue (that of melodic imitation), arose out of the growing understanding of and dependence on imitation as a unifying structural technique. Although these designations were applied to a great variety of pieces—some identical in style to the fantasia or prelude—the classic ricercar of the 16th century was virtually an instrumental motet, slow and churchlike in character and consisting of a number of sections, each utilizing imitation. The canzona followed the same structural principle but was a lively counterpart to the chanson, with the sections sometimes in contrasting tempo and metre. Cantus firmus compositions were based upon preexisting melody. During the 16th century most were designed for liturgical usage but were based upon both secular melodies and plainsong. In most cases the cantus firmus was sounded in long, sustained tones while the other part or parts added decorative contrapuntal lines. The organ mass, in which the choir and the organ alternated lines of the liturgical text, was a popular practice.

Variations also often used a preexisting melody but differed from cantus firmus compositions in that the melody was much shorter and was repeated a number of times, each time with different accompanying parts. The two basic types during the Renaissance were the plain, or melodic, variations and the ground. In the former, the chosen melody usually appeared in the top part and was varied in each repetition with ornamentation and melodic figuration or with changing accompaniments. The ground, or ground bass, was a simple melodic pattern sounded in the lowest part, which served as a foundation for imaginative figuration in the upper parts.

Solo and ensemble instruments. The four major vehicles for instrumental music of the period were the lute, the organ, stringed keyboard instruments, and instrumen-

tal ensembles. Most popular by far was the lute, which could produce the major elements of instrumental style except for long, sustained tones. Noteworthy composers of lute music included Luis Milán in Spain, Arnold Schlick in Germany, and John Dowland in England. The organ, because of its close association with liturgical music, continued to be an important instrument, and its literature includes all of the formal types except dances. Among the leading organ composers were the Germans Paumann, Schlick, and Paul Hofhaimer, the Italians Claudio Merulo and Andrea and Giovanni Gabrieli, the Spaniard Antonio de Cabezón, and the Englishman John Bull.

The two basic classes of stringed keyboard instruments were the harpsichord (virginals, spinet, clavecin, clavicembalo), with quill-plucked strings, and the clavichord, with strings struck by thin metal tongues. Keyboard instruments were highly capable of idiomatically instrumental effects and flourished, particularly in England, from the last half of the 16th century onward, thanks to the composers William Byrd, John Bull, and Orlando Gibbons. A major manuscript source of the keyboard works of these masters is the famous *Fitzwilliam Virginal Book* of the 17th century.

Instrumental ensembles of the Renaissance were not standardized, although consorts (groups) of viols, of woodwind instruments such as recorders and shawms (loud oboes), or of brass-family instruments such as the cornet and sackbut (early trombone) were common. More common, however, were mixed consorts of various types of instruments, depending on the players available. All types of instrumental forms were performed by ensembles except for the prelude and the toccata, which were essentially keyboard works. Representative composers included the Gabrielis and Gibbons.

Vocal music in the 16th century. At the beginning of the 16th century the style of vocal music was generally uniform because of the pervading influence of Netherlanders during the preceding half century. That uniformity persisted well into the late Renaissance but was gradually superseded by emerging national differences, new forms, and the increasing importance of Italy as a musical centre during the last half of the 16th century.

The rapid accumulation of new musical techniques and resources produced a wide vocabulary of artistic expression, and the invention of music printing helped the rapid dispersal of new techniques. In an age in which music was an essential social grace, composers wrote more secular music, in which fewer technical restrictions were in force and experimentation and novelty were applauded. Advances were particularly apparent in venturesome harmonies as chromaticism (the use of notes not belonging to the mode of the composition) sounded the death knell of the modal system.

Harmonic experiment

Liturgical practice dictated that the mass and the motet remain the chief forms of sacred vocal music. Compared with secular music, their style was conservative, but inevitably some of the newer secular techniques crept in and figured effectively in the music of the Counter-Reformation within the Roman Catholic Church.

Four distinct types of mass settings were established during the century. Two types were continuations of earlier practice: the tenor mass, in which the same cantus firmus served for all five portions of the Ordinary of the mass, and the plainsong mass, in which the cantus firmus (usually a corresponding section of plainsong) differed for each portion. Reflecting the more liberal attitudes of the Renaissance were the free mass, with no borrowed materials, and the parody mass, in which the entire polyphonic web was freely adapted from a motet or a secular composition. In all cases when a cantus firmus was used, the preexistent melody might appear in its original form or in paraphrased version, with tones added, omitted, or altered. As a result of the upheaval in the church caused by the Reformation, new forms derived from established models appeared in Protestant worship: the German Lutheran chorale (hymn tune, arranged from plainsong or a secular melody), the chorale motet, English anthems (Anglican form of motet) and services, and the psalm tunes in Calvinist areas.

Italy. While not young in a chronological sense, the musical life of Italy was reborn at the beginning of the 16th century after a century of relative dormancy. The frottola remained the prevailing secular form in northern Italy for the first three decades of the century.

When the humanistic poets, seeking a more refined expression, and the Netherlanders and composers trained by them, applying a more sophisticated musical technique, turned their efforts to the frottola, the result was the madrigal. The name was borrowed from the 14th-century form, but there was no resemblance in poetic or musical structure. Compared to the frottola, the earliest Renaissance madrigals, dating from about 1530, were characterized by quiet and restrained expression. Usually written for three or four voices, they were mostly homophonic (melody supported by chords) with occasional bits of imitation. Among the early madrigal composers were several Flemish composers resident in Italy, among them Adriaan Willaert, Jacques Arcadelt, and Philippe Verdelot. About 1560 the normal number of parts increased to five or six, and the texture became more consistently polyphonic. At the same time, more attention was given to expressive settings of the text, notably in the madrigals of Cipriano de Rore, Philippe de Monte, and the Gabrielis. During the last two decades of the century and continuing until the middle of the 17th century, the musical style of the madrigal changed appreciably. The late madrigals were of a very dramatic nature, featuring colouristic effects, vivid word-painting, and extensive chromaticism. Their declamatory character dictated a return to a more homophonic style. Noteworthy among the many composers of the late madrigal were Luca Marenzio, Don Carlo Gesualdo, and Claudio Monteverdi.

Birth of the madrigal

During the course of the century simpler secular forms, such as the villanella, the canzonetta, and the balletto, appeared in Italy, largely as a reaction against the refinement, complication, and sophistication of the madrigal. They reverted to the chordal style of the frottola, often with intentionally parodistic lyrics. The balletto was particularly distinguished by a refrain of nonsense syllables such as "fa la la."

England. Most of the Italian forms, along with their designations, were adopted by Elizabethan England during the last half of the 16th century. Most leading English composers, from William Byrd and Thomas Morley to John Wilbye, Thomas Weelkes, and Orlando Gibbons, contributed to the vast treasury of English secular music. Morley is particularly important as the editor of the most significant collection of English madrigals, the *Triumphes of Oriana,* published in 1603 and dedicated to Queen Elizabeth I (Oriana). These pieces correspond in style roughly to the middle-period Italian madrigal. English counterparts of the canzonetta and balletto were the canzonet and ballett. A late 16th-century innovation in both Italy and England was the ayre (air), a simple, chordal setting especially suitable for a solo voice with a lute or a consort of instruments playing the other parts. John Dowland and Thomas Campion were notable composers of ayres.

France. The French counterpart of Italian and English madrigals was the polyphonic chanson, a continuation of the chief medieval and early Renaissance form of secular music. Revitalized by composers such as Josquin, Clément Janequin, and Claudin de Sermisy, the chanson developed several distinctive features: a clearly delineated sectional structure with some repetition of sections, much vivid programmatic writing, and occasional use of irregular metric organization. The irregular metric structure, called *musique mesurée,* was used for maintaining faithfully the accentuation of the poetry and reflects the traditional primacy of textual over musical considerations in French music.

The chanson

Germany. The lied, or song, continued its 15th-century role as the chief secular form in Germanic areas, but it did not develop to the same extent as the madrigal and the chanson. Throughout the Renaissance it was relatively conservative in its adherence to the cantus firmus principle and its tendency toward chordal over contrapuntal texture. Following Heinrich Isaac in the 15th century, the major 16th-century lieder composers were Ludwig Senfl, Hans Leo Hassler, and Johann Hermann Schein. To all

national schools of the 16th century must be added the name of the Flemish composer Orlando di Lasso, who wrote in French, Italian, or German, depending on his current employment. The Spanish villancico was a flourishing popular form, but there was no Iberian equivalent to the madrigal, the chanson, or the lied.

The tonal era and after: 1600 to the present

The beginning of the 17th century was one of the most dramatic turning points in the history of music, even more so than the beginning of the Ars Nova and almost as revolutionary as the beginning of the 20th century. The winds of change had been felt several decades earlier, and the establishment of the new style required several decades after the turn of the century, but the year 1600 saw the performance of several works destined to change the course of music.

THE BAROQUE ERA

The spirit of the Baroque

Originally used in a derogatory sense of referring to something bizarre, degenerate, and abnormal, the term Baroque gradually acquired a positive connotation for the grandiose, dramatic, energetic spirit in art that prevailed during the period from about 1600 to about 1750. The new spirit required a vastly expanded musical vocabulary, and a rapid evolution of new techniques occurred, particularly in vocal music. Two distinct musical styles were recognized. One, the *prima prattica* (or *stile antico*), was the universal style of the 16th century, the culmination of two centuries of adherence to Flemish models. The other, called *seconda prattica*, or *stile moderno*, referred to the new theatrical style emanating from Italy.

The expanded vocabulary allowed for a clearer distinction between sacred and secular music as well as between vocal and instrumental idioms, and national differences became more pronounced. The tonal organization of music evolved also, as the medieval modes that had previously served as the basis of melody and harmony were gradually replaced, during the 17th century, by the system of tonality dominating Western music until about 1900: a system based on contrasting keys, or sets of interrelated notes and chords deriving from a major or minor scale. Viewing the period as a whole, two additional innovations most clearly distinguish it from the preceding Renaissance: concertato, or the contrast, combination, and alternation of voices and instruments, and basso continuo (thorough bass, figured bass), an accompaniment consisting of a low-pitched instrument, such as a violoncello or a bassoon, combined with a keyboard instrument or lute capable of harmonic elaboration.

Opera. Most typical of the emerging style were the dramatic productions of the Camerata, a group in Florence who were dedicated to recreating and imitating the musical ideals and practices of classical antiquity—in a sense, the musical manifestation of the Renaissance. Their guiding philosophy was the preeminence of textual over musical considerations; their belief was that the function of music was to heighten the dramatic impact of words. The musical result was monody: originally recitative (solo singing reflecting speech rhythms), later also arioso (more lyric than recitative) and aria (more elaborate song), accompanied by a basso continuo that could provide an innocuous background to a solo voice. Among the major figures in this revolutionary movement were Giulio Caccini and Jacopo Peri, both of whom composed operas based on the legend of Orpheus and Eurydice. Caccini also provided the name for the new movement with his publication of *Le nuove musiche*, a collection of solo songs with continuo accompaniment. The ideas and techniques conceived by the Camerata spread rapidly over Italy and, subsequently, all over Europe.

17th-century developments in Rome

Early Italian operatic schools. During the 1620s and 1630s the centre of operatic activity shifted from Florence to Rome, where several distinctive features developed: a chorus was used extensively, dancing was incorporated into the dramatic spectacle, and an overture in the style of a canzona became the accepted norm. A flourishing operatic activity developed a decade later in Venice, where the first public opera house was opened in 1637. Public taste began to influence operatic composition, and, as a result, several innovations, such as the extensive use of popular tunes, spectacular staging, and short, fanfare-like overtures, were introduced. The audience's desire for tuneful songs also contributed to the clear distinction between recitative and aria, which began with the Venetian school. Foremost among contemporary composers was Monteverdi, who had known of the activities of the Florentine Camerata while serving as musical director to the Gonzaga family in nearby Mantua. He adopted the new style for his later madrigals and wrote two operas, *Orfeo* (1607) and *L'Arianna* (1608), before moving to Venice in 1613. Francesco Cavalli and Antonio Cesti became the leading Venetian operatic composers after Monteverdi's death in 1643.

Neapolitan opera. The last major operatic centre to develop in Italy began its activities in the 1670s in Naples. Neapolitan opera seria, or serious opera, with characters from classical history or mythology, dominated Europe for a century. It was essentially a series of recitatives and arias, the latter mostly of the da capo type (ABA, the A section given improvised embellishment on its repetition) characterized by florid virtuosic singing. Other features were, first, the distinction between recitativo secco (dry recitative), accompanied by the continuo, and recitativo accompagnato, or stromentato, accompanied by the orchestra, and, second, the establishment of the Italian overture. Called a sinfonia, the overture in three parts (fast–slow–fast) evolved into the symphony during the 18th century. Alessandro Scarlatti was the most influential of the early Neapolitan operatic composers.

The joining of the French and Italian forms

France. During the same period, opera was introduced at courtly functions outside Italy. After Luigi Rossi's *Orfeo* was performed in Paris in 1647, the Italian form was gradually merged with the major French dramatic form, the ballet; the importance of dancing in French operas thereafter is not surprising. Another distinguishing feature was the French overture (a slow movement, a fast movement, and, occasionally, a return to the opening slow section), which, like the Italian overture, later had an independent life. The masters of French opera during the Baroque period were Jean-Baptiste Lully and his successor Jean-Philippe Rameau. Because of the social and political upheaval of the Thirty Years' War, there was less operatic activity in Germany than in France, and the activity that did occur was more completely dominated by the Italian style. Hamburg, Munich, Dresden, and Vienna were the major centres, with Reinhard Keiser and Georg Philipp Telemann as the most prolific composers.

England. The situation in England resembled that in France, since the English also had a flourishing musico-dramatic form, the masque, which gradually merged with Italian opera. Henry Purcell and John Blow were the chief composers of opera in English before Italian domination of serious opera became almost complete during the 18th century.

Cantata and oratorio. The leading Neapolitan opera composers also helped to establish the Baroque successor to the madrigal—the cantata—which originated as a secular form for solo voice with instrumental accompaniment. Giacomo Carissimi standardized the form as a short drama in verse consisting of two or more arias with their preceding recitatives. The cantata was introduced into France by one of Carissimi's students, Marc-Antoine Charpentier; Louis Nicolas Clérambault continued the tradition in the late Baroque period. With the fading stylistic distinction between sacred and secular music, the cantata was quickly converted to church purposes, particularly in Germany, where it became the chief decorative service music for the Lutheran Church. Dietrich Buxtehude and Johann Kuhnau were two of the leading composers of such church cantatas.

While the new concertato techniques were being applied to established forms of church music, such as the mass, service, motet, anthem, and chorale, new forms emerged that were clear departures from Renaissance styles and types. The oratorio and settings of the Passion story developed simultaneously with opera and on almost identical

lines, consisting of recitatives, arias, vocal ensembles, instrumental interludes, and choruses. Emilio del Cavaliere was the "founder" of the oratorio with his *La rappresentazione di anima e di corpo* (*The Representation of the Soul and the Body*). Produced in Rome in 1600, this work, unlike true oratorio, used actors and costumes. Carissimi and Alessandro Scarlatti were the chief Italian Baroque composers of oratorio, and Heinrich Schütz, a pupil of both Giovanni Gabrieli and Monteverdi in Venice, was the leading 17th-century German composer in this field.

Instrumental music. The new techniques of *Le nuove musiche* were to be heard in music for instruments, especially now that they participated in genres formerly written for unaccompanied voices (*e.g.,* the motet). The forms and mediums of instrumental music remained essentially the same but with considerably different emphasis. The lute, for example, lost status quickly with the rise of the harpsichord as the most common instrument for continuo accompaniment of dramatic productions. The organ, as the traditional church instrument, retained its position and assimilated the evolving forms.

Continuo instruments

Modification and expansion of older forms. Dance pairs of the Renaissance grew, about the middle of the 17th century, into dance suites consisting basically of four dances: allemande, courante, saraband, and gigue, with optional dances such as the gavotte, the bourrée, and the minuet sometimes inserted before the final movement. Variation forms—the chaconne (in which a set of harmonies or a bass theme is continuously repeated), the passacaglia (in which the theme is repeated but not necessarily in the bass), along with the ground bass and variations on well-known melodies—continued to be popular. Free forms also continued in the patterns of their Renaissance antecedents, while growing in dimension and inventiveness. The toccata, prelude, and fantasia were expanded into multisectional forms using the three basic instrumental textures—imitative counterpoint, chordal homophony, and virtuosic passage work—in combination, alternation, and contrast. The Renaissance fugal forms, chiefly the canzona and the ricercar, gradually evolved into the late Baroque fugue, and cantus firmus compositions continued to flourish as a result of their liturgical function.

The sonata and concerto. The major new categories of instrumental music during the Baroque period were the sonata and the concerto. Originally applied to instrumental ensemble pieces derived from the canzona, the term sonata became the designation for a form that was to dominate instrumental music from the mid-18th until the 20th century. In its keyboard manifestation, it was a binary (two-part) structure similar to a dance-suite movement. For small ensemble, it evolved into a series of independent movements (usually in a slow–fast–slow–fast arrangement) called a *sonata da chiesa* ("church sonata") or a dance suite called a *sonata da camera* ("chamber sonata"). Especially prominent was the trio sonata, for two violins (or flutes or oboes) and cello with continuo. Eventually, similar forms were adopted for orchestra (sinfonia or concerto), for orchestra with a small group of featured instruments (concerto grosso), or for a solo instrument with orchestra (solo concerto). The fundamental principle of the concerto was that of contrast of instrumental groups and musical textures.

Throughout the period, keyboard music flourished, notably in the hands of Jan Pieterszoon Sweelinck in the Netherlands, Johann Pachelbel and Johann Froberger in Germany, Girolamo Frescobaldi in Italy, and Domenico Scarlatti in Spain; in France the chief exponents included Rameau and François Couperin.

Instrumental ensemble music, both chamber and orchestral, was dominated by Italians, chiefly from Bologna, the Bolognese school producing such composers as Arcangelo Corelli, Antonio Vivaldi, and Giuseppe Tartini. Purcell in England and Couperin and Jean-Marie Leclair in France are representative of the many composers in other nations who were influenced by Italian models of instrumental ensemble music.

The late Baroque. The Baroque era reached its zenith in the work of Johann Sebastian Bach (1685–1750) and George Frideric Handel (1685–1759). Both were born in the same part of Germany; both were reared in the Lutheran Church; and both were primarily organists; but because of different environmental circumstances each became a master of different musical forms. Handel, because of his conditioning in Italy, was primarily a dramatic composer, writing opera, oratorio, and secular cantatas, mostly after he reached England. He also wrote quite extensively for orchestra and instrumental ensemble. Bach, by contrast, was influenced by his lifelong employment in the church and by his dedication as a teacher; his works thus include Passions, cantatas for church services, liturgical organ pieces, and harpsichord compositions, many instructional in purpose.

The primacy of Bach and Handel

In the works of both Handel and Bach changes in technique reached a culmination with the clear establishment of the tonal system, allowing for modulation from one key centre to another, primarily as a device for formal organization. Rich, chromatic harmonic language was both reason and result of such a change. The fusion of contrapuntal technique with homophonic style resulted in a distinctive hybrid texture that employed figured bass (homophony) as a foundation for two or more independent melodic lines (polyphony).

THE CLASSICAL PERIOD

The term classical

As in the case of the Renaissance, difficulties with terminology again arise with the label classical. Does it refer to a period of time, a distinctive musical style, an aesthetic attitude, an ideal standard, or an established norm? Again, the term was borrowed from the visual arts of the same epoch and is awkward when applied to music in that there were no known models from classical antiquity for composers to imitate. A full understanding of the term depends on a clear conception of the term romantic, for the two stand at opposite poles. Each represents a set of artistic ideals that has been in opposition to the other since both were recognized by early Grecian writers. As has been noted, the ancient Greek followers of Apollo established the ideal of classicism, whereas the cult of Dionysus produced the prototype of romanticism. A mixture of the two qualities has prevailed throughout recorded history, with first one and then the other in the ascendancy. Thus, there have been many "classic" and many "romantic" eras, but the labels have come to refer most specifically to the last half of the 18th century and the 19th century, respectively, because those periods represent most vividly the two tempers.

The social and political scene during the late 18th century was hardly a setting for a quiet, composed "classical" age in view of the prevailing revolutionary spirit and colonial rivalry. The revolutionary movement did have a direct effect on music in that "music for the masses" became a new ideal—music directly appealing to a large number of unsophisticated people who had previously been excluded from courtly entertainments.

Precursors of the Classical style. *The Rococo style galant.* As the pendulum swung from the predominantly romantic Baroque period toward the Classical period, there was an inevitable overlapping of the old and the new. While Bach was composing his intricate and erudite polyphony, his sons were reflecting a new ideal, the Rococo. Fostered by the court of the French king Louis XV, whose life-style was far less formal than that of his illustrious great grandfather, the Rococo ideal was artistic expression dedicated to elegance, frivolity, and gracefulness; a work of art must be delicate, playful, entertaining, and immediately appealing. The result was often artificial and unrealistic, but it succeeded in capturing the discreetly sentimental and hedonistic attitudes of the times. Powdered wigs, lace cuffs, and perfumed handkerchiefs for both sexes were other manifestations of the same playful spirit that produced music in the *style galant.*

The empfindsamer Stil. The German counterpart of the essentially French Rococo was the *empfindsamer Stil,* or "sentimental style," which flourished in the 1750s and 1760s. Its leading exponent was one of J.S. Bach's sons, Carl Philip Emanuel Bach, who served for a time at the court of Frederick the Great in Berlin. The distinguishing feature of this German reaction against Baroque profun-

dity was its concern with emotional feeling in the music itself, on the part of the performers and, hopefully, in the reaction of the audience. The French obsession with lightness, gracefulness, and decoration was countered by the German determination to affect sensibilities that were often more attuned to tears than to laughter. A late and less reserved manifestation of *Empfindsamkeit* was the *Sturm und Drang* ("storm and stress") movement in the arts during the 1770s and 1780s. The inclination toward the more intense personal expression of that movement was a harbinger of the coming Romantic period.

Consolidation of the Classical style. The fundamental changes in musical style that distinguished Classical from Baroque were inspired by Rococo ideals and refined and stabilized by the Classicists, particularly Joseph Haydn, Wolfgang Amadeus Mozart, Christoph Willibald Gluck, and the young Ludwig van Beethoven.

Central role of instrumental music

Stylistic elements. For the first time in the history of music, instrumental music became more important than vocal music. The orchestra and chamber groups, such as the string quartet, trio, and quintet, and the piano trio became standardized and replaced the heterogeneous trio sonata and other ensembles of the Baroque period. The basic duple and triple organization of metre remained unchanged, but rhythmic patterns tending toward more regularity and simplicity became the rule, producing the "tyranny of the bar line" that was to prevail for more than a century.

Melody was inclined to be more motivistic, tuneful, and epigrammatic, in contrast to the extended, figurative style of many Baroque melodies. Harmony was second only to melody as a focal element. Harmonic patterns that clearly established the tonal centre were the rule of the day.

As a reaction against the intricate polyphony of the later Baroque period, homophonic texture dominated by melody became the norm, but the accompanying patterns were different from those of the early Baroque, when monody supported by sustained chords was the prevailing style. In the late 18th century, figurations such as the Alberti bass (form of accompanying figure consisting of broken chords) and rhythmically enlivened repeated chords formed the typical textural patterns. Counterpoint was retained in some forms, however, and regained status particularly in development sections of works in sonata form.

Formal structure, a definitive aspect of classical style, was characterized by simplicity and clarity. Sectional forms (created by contrast and repetition of thematic materials, tonalities, and textures), variations, and the new principle of development (fragmentation, expansion, and modification of themes) were the established norms. Phrases of musical material became shorter and more clearly demarcated as well as more balanced and regular. A new concept of dynamic contrast also contributed to formal clarity. Shading from loud to soft or vice versa provided a dramatic means of building toward an expressive climax. Orchestration and instrumentation were closely allied to dynamic variation, and much more colour contrast and variety appeared in orchestral music, even though the ensemble was more standardized than formerly.

Sonata form. The pattern that served as the structural basis for most instrumental music of the classical period was the sonata. A large-scale work in several movements, it evolved from several Baroque predecessors, chiefly the Italian overture, the *sonata da chiesa*, and the concerto grosso. Depending on the medium of performance for which it was intended, it would be called, for example, a symphony, a concerto, a string quartet, a sextet, a trio. The designation sonata was reserved for a solo instrument or for an instrument accompanied by harpsichord or piano. Originally in three movements, the sonata became standardized as a four-movement form when a minuet was incorporated in the following sequence: (1) a serious allegro, (2) a slow, lyrical movement (andante or adagio), (3) a minuet and trio, and (4) a brilliant, vivacious finale. The internal structure of the first movement was so uniform that it acquired the designation sonata-allegro form; that is, the form employed in the allegro movement of a sonata, consisting basically of exposition, development, and recapitulation. The slower second movement is less structurally predictable. It is frequently a sectional form (for example, ABA, AABA, ABCA) or a set of variations. It may, even though in a slow tempo, be a sonata-allegro form, illustrating again the inconsistency of musical terminology. The third movement, usually omitted in the concerto and sometimes in other forms, is either a graceful minuet or a scherzo, a lively rhythmic form derived from the minuet. The structural pattern of the minuet had been fixed when it was established as the official court dance by Louis XIV in the mid-17th century. The last movement is frequently a rondo form, in which the principal theme recurs regularly between subordinate themes.

Instrumental music. *The symphony.* The most important and influential manifestation of the sonata form was that played by an orchestra—the symphony. During the 17th century the term sinfonia had been used for various kinds of instrumental music. "Sonata" was equally ambiguous. Late in the century, the designation sinfonia began to be confined to the Italian opera overture—a three-movement arrangement, fast–slow–fast. By the mid-18th century, opera overtures were being played independently in concerts. The insertion of the minuet between the last two movements resulted in the prototype of the Classical symphony.

During the waning Baroque period, vigorous advocates of the burgeoning Rococo and *Empfindsamkeit* ideals were active in Milan, Vienna, and Mannheim. In Milan, Giovanni Battista Sammartini began writing his symphonies, some 25 of them, in the 1730s. While employing the continuo of his models, Corelli and Giuseppe Torelli, the bithematic plan for his opening movements foreshadowed the exposition of the Classical symphonies. At about the same time, young composers in Vienna were experimenting with the new genre, thus laying the foundation for the later Viennese masters. The most famous and probably the most influential group was active in Mannheim in the court orchestra of Karl Theodor, the elector of the Palatinate. Their activity began in the 1740s, when Johann Stamitz became leader of the orchestra. His experiments with dynamic techniques—crescendo (increasing in loudness), diminuendo (decreasing in loudness), sforzando (special emphasis)—with homophonic textures featuring the first violins in virtuoso passages and with tremolo and other dramatic effects, became the hallmarks of the Mannheim style and served as models for his son Karl Stamitz and for composers in Vienna. Thanks to the fortuitous presence of certain instrumentalists as well as to benevolent patronage, the basic ensemble of the modern symphony orchestra was gradually established: violins, violas, violoncellos, and double basses; two flutes, two oboes, and two bassoons; two French horns and two tympani. Trumpets were added for festive occasions.

The Mannheim school

The concerto. Unlike the symphony, which had its origins in other forms, the Classical concerto grew directly out of the Baroque solo concerto and resembles it in that it is based on exchange of musical material between solo instrument or instruments and orchestra. While directly derived from the ritornello principle of the Baroque concerto (that of a recurrent musical passage when the soloists are silent), the internal structure of the first movement assimilated the developmental principle of sonata-allegro form. Pietro Locatelli and Giuseppe Tartini are especially notable for their numerous late-Baroque violin concerti.

Chamber music. While music for small instrumental ensembles had flourished for over 200 years previously, the late 18th century witnessed the establishment of chamber music in the modern sense of the term: music in sonata form for a small group of instruments with one player for each part. Replacing the trio sonata of the Baroque period, the most popular classical ensemble was a group of four stringed instruments—two violins, a viola, and a violoncello. Both the group itself and a sonata written for the group were called a string quartet. Among other popular ensembles were the string trio (violin, viola, and violoncello; or two violins and a violoncello) and the piano trio (violin, violoncello, and piano).

The keyboard sonata. The solo keyboard sonata was one of the most vital forms of the period, partly because

of the great increase in amateur performers resulting from the newly affluent middle class. The sonatas of Domenico Paradisi, of J.S. Bach's sons, and of Haydn and Mozart reflect the evolution from the one-movement, binary form of the Baroque period to the standard classical three-movement form. A four-movement form did not become popular until the time of Beethoven. A celebrated contemporary of Mozart, Muzio Clementi, composed more than 60 sonatas for the piano alone and half again as many for piano and violin or flute and strongly influenced the style of piano writing.

Clementi's 60 sonatas

Other instrumental forms. While the sonata was unquestionably the most important form of instrumental music during the period, several other types were cultivated. For orchestra and chamber ensemble, a suitelike work called variously divertimento, serenade, cassation, or notturno was popular for light entertainment, differing from the more serious symphonies, concerti, and sonatas (which were intended for attentive listening) in that the ensemble of instruments was inconsistent, unpredictable, and often unspecified. The number, types, and arrangements of movements were equally flexible, ranging from three to 10 or more, some in dance forms and others in forms suitable for a sonata. While nonsonata forms for solo instruments (particularly keyboard) occasionally bear these designations, the most popular smaller solo forms were sets of variations, individual dances or marches, fantasies, and small pieces that would have been appropriate as movements of sonatas. For some reason, composition for the organ dwindled drastically after the death of J.S. Bach, in 1750.

Vocal music. *Opera.* There was less distinction between Baroque and Classical opera than between instrumental styles of the two periods because opera, with musical interest centred on a solo voice, had been largely melodic-homophonic since its inception. Another reason for the continuity of operatic style throughout the 18th century was the universal domination by the Neapolitan opera seria. Even in Paris, where the Lully-Rameau tradition maintained its vitality, there was an Italian opera theatre. While there was some effective reform of certain aspects of Neapolitan style that had become decadent and some nationalistic reaction in the field of comic opera, nothing in the nature of serious opera challenged Neapolitan supremacy. As a result, the late 18th century was a period of great vitality in operatic composition.

Domination of opera seria

The distinguishing characteristics of Neapolitan opera seria reveal why it is little known and rarely heard today. It was a very conventionalized form, with artificial and overcomplex plots. There were usually six main characters representing three of each sex, with some of the male and female parts sung by castrati (emasculated male sopranos and contraltos). Each character was allotted a standardized number of arias in fairly standardized succession. Obviously, with such constant interruption of the action, dramatic truth received little if any consideration. The singers and the arias were the focus of the entire production, with little of musical interest in the parlando recitatives (*i.e.*, using speech rhythms), little use of chorus, and little function for the orchestra aside from providing a subordinate accompaniment.

Objections to the decadence and artificiality of the Neapolitan style, which had begun to appear as early as the 1720s, would have been fruitless had not a champion appeared to put suggestions and theories for reform into actual practice. Culminating the movement for reform was Christoph Willibald Gluck, who began his career in the 1740s by writing about 20 operas in the prevailing style. Then, beginning with *Orfeo ed Euridice* in 1762, he attempted to enhance both the dramatic and musical components of opera. Superfluous virtuosity and vocal display were drastically curtailed if not eliminated by providing music that reflected the emotional or dramatic situation. As a result of Gluck's reforms, opera moved toward a classical simplicity of style of which his and Mozart's works were the culmination.

A second challenge to established Neapolitan opera was emerging through comic opera in which the subject matter was light, sentimental, often topical, and satirical, reflecting both the social changes of the period and ridicule of serious opera. The music was engagingly tuneful, easy to perform and to comprehend. Comic opera had appeared during the 17th century but began its independent existence during the first half of the 18th century in Italy, where it was called the opera buffa. The French opéra comique evolved during the same period and was given new impetus by the *guerre des bouffons* ("war of the buffoons") of the early 1750s, when support of the Italian opera buffa company then performing in Paris exceeded that of the French heroic opera of Rameau. In England, ballad opera, beginning with *The Beggar's Opera* in 1728, followed a course of development similar in both period and style to that of the opéra comique. German singspiel grew out of translations and imitations of English ballad opera. Models that centred on Vienna adhered to the Italian style and culminated in Mozart's *The Abduction from the Seraglio* and *The Magic Flute*. Yet Mozart also brought the old Italian style to its zenith in *Le Nozze di Figaro* (*The Marriage of Figaro*), *Così fan tutte* (*Thus Do They All*), and *Don Giovanni*.

Comic opera

Other vocal music. Aside from opera, secular vocal music was composed for solo voice and chorus. But the production of solo songs and cantatas in other countries could not compare with the growing interest in the German lied, which flourished under C.P.E. Bach and later composers. The most extensive development of secular part-songs took place in England, where numerous catches and glees were written.

Large-scale sacred choral music of the period was strongly influenced by the prevailing operatic style. Except for the text, some passages from oratorios and passions are indistinguishable from an operatic excerpt. But the Handelian tradition combined with the Neapolitan style and culminated in Haydn's two noble oratorios, *The Creation* and *The Seasons*. Liturgical music, such as masses, motets, litanies, psalms, and canticles, also demonstrated that the same composers were writing for both church and theatre. In many instances the style was uniform for the two types, although the chorus naturally played a much greater role in church music.

THE ROMANTIC PERIOD

The beginning of the 19th century witnessed a change of both musical style and aesthetic attitude that has become identified as Romantic. The term romantic originated in German literature of the late 18th century, illustrating once again the overlapping of classical and romantic attitudes and ideals. The Franco-Swiss writer Mme de Staël articulated the new ideals of the movement in 1813 as original, modern, national, popular, derived from the soil, religion, and prevailing social institutions. Obviously, some of these proclaimed romantic ideals and purposes were the same as those of the 18th-century Classicists.

Establishment of the Romantic idiom. In defining classicism, it was suggested that the distinctive elements of musical romanticism embrace emotionalism, subjectivity, individualism, nationalism, and a preference for a certain type of subject matter. Emotionalism is reflected in the revelation of intensely personal feelings, indeed, the sentimentality that pervades 19th-century music. Subjectivity replaces the formalism of the Classical period, in that impulse and inspiration play a major role in the motivation of both composer and performer, and the listener's response is expected to be more sensory than intellectual. Closely related to subjectivity is the individualism reflected in the highly self-centred expression of composers of the period, as well as by the conviction that a composer's most personal thoughts and feelings are the ultimate artistic message. In contrast to the universality of musical style that prevailed during the 18th century, much 19th-century music is identifiable in terms of national origin. Nationalism—the consciousness of the distinctive features of a nation and the intent to reveal, emphasize, and glorify those features—played a prominent part in Romantic music, partly as a result of social and political developments. The subject matter favoured by Romantic composers is most apparent in vocal music, where words can convey the explicit theme, but instrumental music was also affected

Personal aspect of romanticism

by the Romantic attraction to national identification and to remoteness, strangeness, and fantasy, particularly to the fantastic aspects of medieval tales and legends.

Stylistic traits. During the 19th century, musical techniques and materials were rapidly enriched by new resources, all devoted to the ideal of emotional or dramatic expressiveness. The orchestra, the piano, the solo voice with piano accompaniment, and the opera were the four predominating mediums; chamber and choral music occupied a less central position. Duple and triple divisions of the measure remained the basis of metre, but there were occasional experiments with metric irregularity, and rhythm was recognized as one of the most effective agents of expressiveness in music. Strong rhythmic energy, frequently produced by dotted patterns, provided a vigorous force that could be enhanced by faster and faster tempi. Flaccid patterns in slower tempi provided for the requisite pensive or sorrowful moods.

Melodic style was determined on one hand by the vocal ideal of song, with long, lyric lines. On the other hand, the new idiomatic possibilities of instruments were being exploited. In either case, expressiveness was the governing ideal. Harmonic and tonal elements were gradually expanded during the century, with more chromaticism, enriched sonorities (seventh and ninth chords), and more nonharmonic tones resulting in a more flexible tonal scheme. Tonic and dominant chords (those based on the first and fifth notes of the key), were no longer the secure poles of tonal movement; frequent and remote modulations (changes from one key to another) contributed to the restlessness of key centres. Because musical interest was centred in melody and harmony, texture remained prevailingly homophonic, though counterpoint played a prominent role in developmental sections. Fugues and other imitative forms occurred as a result of studied archaism or for special effect, but the composers' preoccupation with direct and immediate expression led them to neglect the traditional polyphonic forms, with their inherent traditions and restraints.

Increasing importance of modulation

The Romantic abhorrence of formalism has frequently been exaggerated for the purposes of distinguishing between Classical and Romantic attitudes. Established patterns such as the sonata-allegro and rondo forms were subjected to many modifications and extensions, but musical coherence demands a judicious balance of unity and variety, so most compositions of the 19th century are still fairly clear-cut sectional, variational, or developmental forms. The distinctive new features are largely in the area of emphasis and dimension—symphonies lasting over an hour in contrast to the 20- to 30-minute standard of the Classical period. Instrumental colour and variety, as another aspect of expressiveness, was made possible by a greatly enlarged orchestra and figured prominently in the new sound ideal.

Beethoven as a transitional figure. The Janus-like figure who marked the transition from the Classical to the Romantic style was Beethoven, the first composer whose personality and character made a purposeful impact on the types and style of music he composed. Inspired by the revolutionary forces prevailing at the time, he declared himself a free artistic agent, with neither allegiance nor responsibility to any patron. His early works reflected the 18th-century acceptance of providing music on demand, and he applied his craftsmanship to supplying compositions in hope of financial reward. But in his later works, from about 1820 on, he declared his personal independence and wrote only what his imagination and inspiration dictated, thus establishing individuality, subjectivity, and emotional expression as the standard for Romantic composers. Yet the body of music he produced reflects the tastes of the 18th rather than the 19th century, in that he was attracted more by the absolute forms of instrumental music than by the dramatic and lyrical forms cultivated by the Romanticists. Symphonies, chamber music (particularly string quartets), and piano pieces (including 32 sonatas) far outweigh his one opera, one oratorio, one major mass, and assorted songs and part-songs. His lack of interest in dramatic vocal music reflects the classical side of his nature, though the expressive changes apparent in his instrumental works are evidence of his being the springboard to the Romantic epoch.

Opera. The opera remained a flourishing medium throughout the 19th century, and Italian opera continued as the dominant type during the first half of the century in the hands of Gioacchino Rossini, Vincenzo Bellini, and Gaetano Donizetti. The reforms instigated by Gluck were discernible, but enough of the genre's indigenous Italianate character remained to distinguish it from other national types. The man who, more than any other, personifies Italian opera of the period is Giuseppe Verdi (1813–1901), whose works are still among the most performed. Late in the century, the tendency toward even more realistic and topical subject matter produced the *verismo* ("realism") school of Ruggiero Leoncavallo, Pietro Mascagni, and Giacomo Puccini.

Meanwhile, German opera developed into the epitome of romantic subject matter and expressiveness, beginning in 1821 with the performance of *Der Freischütz* (*The Freeshooter*), by Carl Maria von Weber. Plots based on tales from Teutonic mythology and medieval legend that emphasized the mystical aspects of nature were a distinctive feature of Germanic operas and distinguished them from the more mundane Italianate plots. Richard Wagner (1813–83) crystallized the German Romantic ideal into the music drama, in which all aspects of the production—drama, music, design, performance—were intended to fuse into a manifestation of pure artistic expression in which no one element predominated over the others, as singing still tended to do in Italian opera. There was no development in Germany after Wagner comparable with the post-Verdi *verismo* group in Italy. Wagner's innovations—once again a readjustment of dramatic versus musical forces in musical theatre—were the point of departure for most German opera since his time, from Richard Strauss to the present.

Wagner's music drama

In Paris, the operatic centre of the world from late in the 18th century until well into the 19th, native composers were quick to sense the Gluckian changes in Italian opera as well as the new directions in Germany. Beginning with Rossini's *Guillaume Tell* in 1829 and crystallizing in the operas of Giacomo Meyerbeer in the 1830s and 1840s, French grand opera emerged as the most opulent and grandiose musico-dramatic spectacle of the first half of the century. During the later 19th century, opéra comique and grand opera merged to produce the prevailing French lyric opera. At the same time, opéra comique branched off in another direction to produce operettas, which developed into the musical comedies of the 20th century. Indigenous opera appeared in other regions, especially in Russia, Bohemia, and Scandinavia, as a result of nationalistic fervour.

Orchestral music. Reaching both a culmination and a turning point in the nine symphonies of Beethoven, orchestral music developed in two directions during the 19th century. On the one hand were composers who, because of their training and temperament, adhered primarily to Classical forms and ideals of absolute music. On the other hand were the composers seeking new realms of dramatic content, colour, and expressiveness. Even for the more conservative group, both the forms and the orchestra itself were greatly expanded during the century, but the total output of works was much smaller than in the Classical period. Romantic musical vocabulary replaced the Classical language in symphonies, of course, and programmatic content (*i.e.*, an extramusical image or story) was a frequent element.

New orchestral forms. The more progressive composers cultivated new musical types that represented the tastes and ideals of the Romantic period—the concert overture, the symphonic poem (later called tone poem), the symphonic suite, and symphonic variations. The concert overture, a direct development of overtures to dramatic works, was an attempt to reconcile the old classical demands for form with Romantic desire for programmatic content. It was usually a sonata-allegro form with picturesque themes designed to suggest (with the help of the title) characters, locations, or dramatic situations. Felix Mendelssohn's *Hebrides* overture and Brahms's *Tragic Overture* (completed 1880) are representatives of the genre. The symphonic

Programmatic and picturesque works

poem, foreshadowed in Hector Berlioz' *Symphonie fantastique* (completed 1830), was originated by Franz Liszt at midcentury as an orchestral work, usually in one movement, based on an extramusical idea such as a poem or a narrative. The futility of attempting to depict explicit events and attitudes in purely musical terms resulted in the demise of the form early in the 20th century after the many tone poems of Richard Strauss. The symphonic suite was one of three distinct types: (1) an outgrowth of 18th-century dance suites, divertimentos, or serenades, (2) the extension of the symphonic poem into a composite work of several movements of related programmatic nature, or (3) a group of selections from a dramatic work such as a ballet. Rimsky-Korsakov's *Scheherazade* represents the second type, and Tchaikovsky's *Nutcracker Suite* is typical of the third. While variations had appeared as movements of symphonies and concerti since the mid-18th century, they became an independent orchestral form during the last quarter of the 19th century. César Franck's *Variations symphoniques* (1885) is a good example of the type. Popular orchestral pieces, such as the waltzes of Johann Strauss, also flourished.

The mainstream of composers whose orchestral music reflected most clearly their allegiance to Classical forms and models—though conditioned by Romanticism, of course—is represented by Beethoven, Franz Schubert, Robert Schumann, Johannes Brahms, and Anton Bruckner. The more overtly Romantic contingent was centred around Berlioz, Liszt, Gustav Mahler, and Richard Strauss.

The movement toward national expression. A third group, chiefly nationalists who were reacting against Germanic domination of instrumental music as well as reflecting the sociopolitical developments of the era, combined features of both conservative and progressive camps, to which they added national characteristics. While there were manifestations of the movement in countries such as Hungary, Poland, Spain, and England, the most productive and outstanding of those who sought to reflect national distinctiveness were the Russian "Five"—César Cui, Mily Balakirev, Aleksandr Borodin, Modest Mussorgsky, and Nikolay Rimsky-Korsakov—the Bohemians Bedřich Smetana and Antonín Dvořák, and the Scandinavians Edvard Grieg, Carl Nielsen, and Jean Sibelius. French composers such as Camille Saint-Saëns, César Franck, and Vincent d'Indy were motivated by the same impulse of independence, but they could hardly be categorized as nationalists in the same sense as their eastern European colleagues, since there was less distinctive folk material from which to draw colourful materials and since they had been in the mainstream of musical development all along.

Piano music. One of the most popular media of the Romantic era, thanks to the rapid technical development of the instrument, was piano music. Another reason for the popularity of the piano was the growing demand for recreation and entertainment on the part of the newly affluent middle class. In tune with the taste of the times, small pieces of distinctive expressive character (hence, "character pieces") were the most popular type, either as single pieces or as parts of composite works. Stylized dances continued to be popular, but nationalistic types such as the polonaise and mazurka and the novel waltz replaced the staid minuets of the previous era. Sonatas continued to occupy serious composers, and sets of variations continued to flourish. The virtuosity of the violinist Niccolò Paganini and his contemporaries led to many studies, or études, designed to exhibit the performer's dexterity as well as the invention of the composer. Chopin, Schumann, Liszt, and Brahms were the major composers of piano music after Beethoven, but practically all composers of the time contributed to the literature.

Songs. The vocal counterpart of the keyboard character piece was the solo song with piano accompaniment. With the rise of the German romantic poetry of Goethe, Schiller, Heine, and others, about the beginning of the 19th century, the German lied ("song") flourished. After 1850, composers of other nations, especially France and Russia, also produced a song literature of universal appeal. A pioneer and certainly the most prolific composer of lieder was Schubert, who in his short life wrote more than 600 songs. His chief successors, in chronological order, were Karl Loewe, Mendelssohn, Schumann, Brahms, Hugo Wolf, and Richard Strauss.

Schubert's 600 lieder

Chamber and choral music. The great Viennese tradition of chamber music reached its zenith in the works of Beethoven and with the death of Schubert came temporarily to a close. The conciseness, unity, and balance that were basic to the Classical ideal were incompatible with the essence of musical Romanticism. When writing for instruments, the typical Romantic composer was inclined toward the colouristic effects and expressive possibilities of the orchestra. Chamber music continued to be written and performed, of course, but nowhere was it one of the primary interests of composers as it had been during the 18th century. Predictably, the more conservative composers, such as Mendelssohn, Schumann, and Brahms, were the chief composers of chamber music.

While the same musical vocabulary and style had served both church and opera house since the rise of dramatic music, the 19th century witnessed a separation of musical idioms according to function—sacred or secular. Music for use in church was generally conservative, especially after the "rediscovery" of Palestrina and systematic research into the reform of Gregorian chant. On the other hand, cantatas and popular part-songs produced for the many amateur choral societies incorporated as many of the new techniques as could be managed by the singers. There was some fusion of the two idioms in oratorios and in settings of liturgical texts for the concert hall or for special occasions. The requiem mass, with its vividly dramatic content, was attractive to Romantic composers, and Berlioz's and Verdi's settings remain as emotionally telling today as most operas of the period.

MODERN PERIOD

Diversity of styles. The striking changes in musical style that occurred about 1900 were a turning point in the history of Western music comparable to the dramatic transformation of the early 14th and early 17th centuries. But never before had the change been so rapid, and never before had there been such a diversity of resulting styles. The last decades of the 19th century witnessed what might be termed the diffusion of Romanticism, when significant departures from the current musical vocabulary appeared in the works of some nationalist composers and especially in the Impressionistic style represented in France by Claude Debussy and Maurice Ravel. The amorphous rhythmic patterns, the whole-tone scale, the concept of free relationship of adjacent harmonies, and the kaleidoscopic textures of musical Impressionism were musical manifestations of the aesthetic movements current in painting and literature.

The experimental works of Arnold Schoenberg and Igor Stravinsky about 1910 heralded a new epoch in music. Schoenberg was the pioneer when his adoption of the ideals of the Expressionist movement—like Impressionism an aesthetic development shared by other art forms—resulted in his discarding traditional harmonic concepts of consonance and dissonance and led to the development of atonality and 12-tone technique (in which all 12 tones of the octave are serialized, or given an ordered relationship). Stravinsky's revolutionary style, variously labelled "dynamism," "barbarism," or "primitivism," concentrated on metric imbalance and percussive dissonance and introduced a decade of extreme experimentation that coincided with World War I, a period of major social and political upheaval.

Stravinsky's innovations and experiments in Neoclassicism

In contrast with Schoenberg's and Stravinsky's experiments during the second decade of the century, another line of demarcation appeared about 1920 with a general return to the aesthetic ideals of the late 18th century. Following the leadership of Stravinsky, Paul Hindemith, Béla Bartók, and Sergey Prokofiev, among others, most prominent composers entered a Neoclassical period characterized by restraint of emotional content; simplification of materials, structures, and textures; a greater attention to craftsmanship; and a revival of concern for linear counterpoint rather than instrumental or harmonic colour. Baroque emphasis on counterpoint and Classical formal-

ism were now clothed in 20th-century melodic, harmonic, rhythmic, tonal, and orchestral idioms. The Expressionist followers of Schoenberg, most notably Alban Berg, continued in their preoccupation with serial techniques.

Neoclassicism continued as the dominant trend throughout the period from about 1920 until World War II, while many of the experimental techniques introduced during the revolutionary second decade of the century were gradually refined, modified, and assimilated into the accepted musical vocabulary. At the same time, experimentation continued alongside a tenacious conservatism that echoed Romantic ideals and styles. Nationalism also continued to flourish, reaching a level in some countries never achieved during the 19th century.

After World War II the two leading artistic attitudes tended to merge when the followers of Anton von Webern carried serial composition to such a rigorous extreme that its craftsmanship and intellectual orientation suggested Classicism rather than Expressionism. Shortly afterward, Stravinsky, the doyen of the Neoclassical group, began experimenting with serialism. Avant-garde music since that time has begun to employ the techniques made possible by technological developments in electronics.

Advent of electronic composition. Beginning about 1950, two leading groups began experimenting with electronic music, one in Cologne and the other in Paris. The product of the latter group was referred to as *musique concrète* in acknowledgement of the principle that preexisting, or "concrete," recorded sounds serve as the basis of all sonorities in the finished work. The basic sounds, which may be derived from any source—musical, natural, or mechanical—are modified electronically and arranged in any combination and succession suitable to the composer's purpose. The German group, led by Karlheinz Stockhausen, was concerned with a purer form of the medium in that its basic sounds are electrically generated instead of being recorded from sources external to the electronic apparatus. The two approaches share one connecting link with music of the past: all sounds have pitch, intensity, duration, and quality. All other concepts of musical organization have been discarded, including the necessity of a performer. Electronic compositions exist on a tape (or disc), and can be made audible by a speaker system. The dehumanizing of music has been carried several steps further by the use of mathematics and even of computers to determine the nature of sound materials—either electronic or that produced by more conventional means—and their organization. At the other extreme is aleatoric music, in which the performer is allowed to choose the manner and order of presentation of materials specified or simply suggested by the composer.

Computer music

Popular music. Another result of advances in electronics has been the tremendous growth of popular music during the 20th century. New techniques have made possible high-fidelity reproduction of sound and its widespread and rapid dissemination through radio, phonograph, tape recorder, and television. In addition, some of the instruments used in popular music have incorporated electronic amplification as well as sound production. While there has been a popular music as long as mankind has turned to singing and dancing for diversion and recreation, much of it was folk music and existed only as an oral tradition. But popular music in the modern sense originated in the late 18th century, when ballads made popular in ballad opera and dance music received wide circulation. The same types flourished throughout the 19th century and into the 20th, when a new direction was prompted by the emergence of jazz among blacks in the southern United States. After the original ragtime came jazz proper, swing, bebop, and rock in its numerous manifestations—punk, new wave, etc. Early in the century, the novelty of jazz rhythms and dominance of brass, woodwind, and percussion instruments over strings attracted some serious composers who occasionally incorporated suitable jazz idioms into their works. Since about 1930, the influence has worked in both directions, and popular music has gradually adopted techniques that originated in serious music. Regardless of the interaction of popular and serious music, the popularity of the former is one of the most significant musical developments of the 20th century, especially in view of the widening gulf between the serious composer and the potential audience.

Interaction of serious and popular idioms

It is impossible to arrive at a complete and objective description of a revolutionary movement while it is in progress; only a period of time can provide the necessary perspective. It can be acknowledged, however, that music has never before passed through a more anarchic phase than in the 20th century. The tremendous number and diversity of stylistic distinctions has precluded a characteristic designation for the first half of the century, but one must be forthcoming, for musicians of the future will need the terms modern and contemporary for their own times.

Despite the disproportionate publicity given to the most radical experiments, the majority of leading composers working today continue along the moderate path established in the late 1920s and 1930s. And, if one can rely on the lessons of history, the mainstream of music will continue to absorb those new techniques that contribute to expressiveness and communication while discarding that which is merely novel and sensational, so that music history will remain an evolutionary rather than a revolutionary process. (R.T.D.)

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Musical Forms and Genres

The term used for the structure of a musical composition is musical form; this term is regularly used in two senses: to denote a standard type, or genre, and to denote the procedures in a specific work. The nomenclature for the various musical formal types may be determined by the medium of performance, by the technique of composition, or by function.

Music rooted in the European tradition, its major forms and genres, and its outgrowths are the chief subject of this discussion. This type of music, it will be clear, is but one segment of the musical picture. Most other regions of the world also have highly developed musical forms and genres. Based on dissimilar cultures, aesthetics, and traditions, few of these bear much resemblance to Western music, and for most English-language readers they warrant a contextual treatment that will examine a number of aspects of their respective cultures. For a discussion of these, see the music sections of AFRICAN ARTS; AMERICAN PEOPLES, ARTS OF NATIVE; CENTRAL ASIAN ARTS; EAST ASIAN ARTS; ISLĀMIC ARTS; OCEANIC ARTS; SOUTH ASIAN ARTS; and SOUTHEAST ASIAN ARTS. The subject of rock music, a genre that sprang up in the United States during the mid-20th century, is treated separately. For a discussion of rock and its offshoots, see ROCK.

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Development of musical form

PRINCIPLES OF MUSICAL FORM

Music exists in time; as an aesthetician, Susanne K. Langer, put it in *Feeling and Form*, "music is time made audible." The proper perception of a musical work depends in the main on the ability to associate what is happening in the present with what has happened in the past and with what one expects will happen in the future. The frustration or fulfillment of such expectations and the resulting tensions and releases are basic to most musical works.

Musical form depends, therefore, on the disposition of certain structural units successively in time. The basic principles can be discerned from a brief consideration of melody, which may be defined as an organized succession of musical tones. This succession of tones consists of component parts, structural units, the principal of which is the phrase—a complete musical utterance, roughly corresponding to what can be sung or played in one breath or played with a single stroke of the bow. A melody, then, ordinarily consists of a succession of phrases, in which there may occur repetition (the same phrase repeated), contrast (a completely different phrase), or variation (the phrase altered, but in such a way that its identity remains perceptible). The relation between these component phrases is important for form. There may, for instance, be a complementary grouping of phrases as antecedent and consequent or "question and answer." The phrases may or may not be equal in length. Some writers, pressing the analogy between music and language, also distinguish larger groupings of phrases: into periods, sentences, paragraphs, and the like. Most musical forms are thus not only additive but also hierarchical: phrases are conjoined to produce a melody, which in turn may be a constituent part of a larger work. A melodic entity that functions as an element in a larger whole is called a theme.

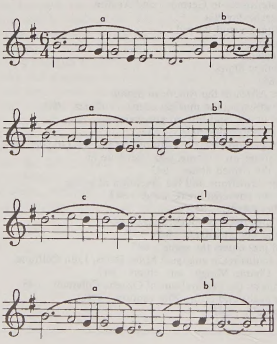
Melody

Coherence may be produced by the use of a motive or figure, *i.e.*, short elements consisting ordinarily of two to four notes. But whereas the motive is usually characterized by a striking interval or rhythmic arrangement, the figure consists of entirely conventional elements (a scale segment, notes of a chord, etc.). Finally, coherence may also be achieved by the consistent use of a rhythmic pattern.

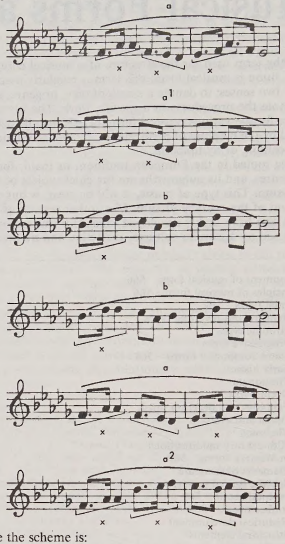
A few examples will serve to illustrate these points. The various phrases have been identified by slurs (phrase marks) and by lowercase letters (the exponential numbers designate variations), whereas larger groupings are designated by capital letters. In the hymn tune "Bethany," by Lowell Mason, shown below, the eight phrases may be grouped in pairs to produce the scheme:

a b a b¹ c c¹ a b¹
A A¹ B A¹ .

This four-phase arrangement with statement, repetition (here with variation at the cadence), contrast, and restatement is extremely common in the traditional and art music of the West.



Other schemes based on repetition and contrast abound. The famous "Largo" from Antonín Dvořák's *New World Symphony*, Opus 95, goes like this:



Here the scheme is:

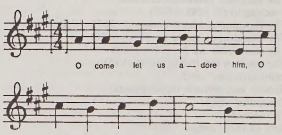
a a¹ b b a a²
A B A¹

This common arrangement is known as three-part form. Coherence is provided by the use of a rhythmic motive,



(marked "x" in the second example).

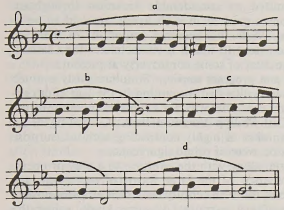
A common device is melodic sequence, in which the phrase is repeated but in transposition, as in the refrain of the Christmas carol "O Come All Ye Faithful."



Different from the above procedures is an English traditional song, "How Should I Your True Love Know" (example follows). The phrase structure here is a b c d, so that there is no repetitive plan. Such a melody is said to be through-composed. In some through-composed melodies a rhythmic pattern may appear throughout to promote coherence.

Other elements contribute to formal organization in music. Among those having solely to do with pitch are range or register—whether most of the activity is high, low, or in the middle, or combinations of these, and whether the range of pitches used is large or small; types of melodic motion, whether conjunct (*i.e.*, by step along the scale) or

Function of pitch



disjunct (by leaps); and the use of different types of scales or modes. Factors included in music's temporal aspect include tempo, whether fast or slow, as well as duration; *i.e.,* whether individual notes are long or short (the gradually increasing use of constantly shorter note values, for instance, is associated with acceleration and accumulation, thus with increasing intensity). Among the harmonic aspects, there is key, or tonality (set of interrelated notes and chords, based on a major or minor scale), whereby the reassertion of a key following the intervention of other keys may produce an effect akin to the restatement of a phrase after a contrasting one has been heard; in this respect, cadences (sections giving the impression of conclusion) are of crucial importance in defining key. Still other factors include the use of dynamics (loud and soft); timbre, or tone colour, especially in the employment of unusual instruments or combinations of instruments; texture, whether monophonic (consisting of a single melodic line) or polyphonic (many-voiced), be it contrapuntal (having simultaneous independent melodic lines) or homophonic (one voice leading melodically, supported by chordal procedures); and, in vocal music, whether the text is set syllabically (one note to a syllable) or melismatically (many notes to a syllable).

FORMAL TYPES

Four basic types of musical forms are distinguished in ethnomusicology: iterative, the same phrase repeated over and over; reverting, with the restatement of a phrase after a contrasting one; strophic, a larger melodic entity repeated over and over to different strophes (stanzas) of a poetic text; and progressive, in which new melodic material is continuously presented (thus synonymous with through-composed). The following discussion deals first with Western and then with non-Western music.

Iterative and reverting types. Iterative types, not common in Western music, may be found in the recitation tones of Gregorian chant, in which, for example, each line of a psalm is sung to the same melodic formula. Far more common, however, are reverting types. In the Middle Ages there existed the fixed forms used in songs, such as the French ballade (a a b), virelai (A b b a A), and rondeau (A B a A a b A B), the Italian ballata (A b b a A) and the German bar form (a a b), where the patterns of repetition and contrast correspond to poetic forms. (In the representations of the reverting types in songs, lowercase letters refer to the same music set to different words, while capital letters indicate that both text and music are the same.) Since the Baroque period (*c.* 1600–*c.* 1750) there has been binary, or two-part form, such as a b. A variety of binary form particularly prominent in the dances of the 18th century is the rounded binary form, the two sections of which are a and b a (*i.e.,* with a final return to original material in the second section), each of which is repeated, part one being heard twice before part two begins: ‖ : a : ‖ ‖ : b a : ‖ (‖ : and : ‖ indicate the enclosed material is to be repeated).

Sonata form

Binary. The rounded binary form took on great importance in the late 18th century, when it was expanded and elaborated into what is known as sonata form (also called sonata-allegro or first movement form), which may be represented thus: ‖ : exposition : ‖ ‖ : development recapitulation : ‖ , whereby the kinship to the ‖ : a : ‖ ‖ : b a: ‖ structure of rounded binary form is clear. Ordinarily, in the exposition the principal musical themes are stated; in the development they are subjected to a process of working out and variation; and, finally, in the recapitulation they are restated. Sometimes the scheme is enlarged by adding a slow introduction before the exposition or a coda (concluding passage) at the end, or both. This formal principle, usually treated with a certain freedom, has been of basic importance in Western instrumental music since the mid-18th century.

Ternary. Another basic reverting type is ternary (three-part) form, a b a, also known as "song form" because of its frequent use in that genre, as well as in character pieces for piano. The form dominates the aria in late Baroque opera (the da capo aria, in which the final statement of a is not written out, but the performers simply follow the written instruction da capo, meaning "from the beginning," and repeat the first part). The da capo principle also appears in the instrumental minuet and scherzo with trio.

Rondo. On a larger scale are refrain schemes, in which contrasting episodes appear between statements of the refrain. In instrumental music this is found most often in a five-part arrangement, the rondo, frequently a b a c a b a; but many departures from the form occur, most common being the replacement of c by a development passage, usually based on the rondo theme. This important variant, known as the sonata-rondo, is particularly associated with Joseph Haydn. The refrain principle also appears in the rondeau of 18th-century French harpsichord music, in which there is no set limit to the number of episodes. The third movements of concertos, with the reversions of the tutti or ritornello (passage for full orchestra) and the intervening episodes for the solo instrument or instruments, are also of this type, as occasionally are large operatic arias.

Strophic types. The strophic type is seen in hymns and traditional ballads, in which different poetic strophes are set to the same melody. Thus, while the melody of a single stanza may accord with one of the reverting types, the hymn or ballad as a whole is strophic; this also applies to the fixed forms of medieval music and to many other types of song, simple and complex.

Theme and variation

The instrumental equivalent of the strophic type is variation (or theme and variation) form, in which a musical theme, often a complete melody with a harmonic accompaniment, is stated and then repeated a number of times, but with variations. A clear example of the relation between variation and strophic form is the chorale-partita of the Baroque era, a keyboard piece based on a hymn, with each varied statement of the hymn tune corresponding to a strophe of the hymn text. But the structure is more common in independent instrumental compositions, often of considerable dimensions (*e.g.,* Beethoven's *Diabelli Variations* for piano). In the Baroque a common type was the ostinato, or variations on a ground, in which the composition was built on a recurring melodic or harmonic pattern, generally in the bass, the accompanying parts being varied with each statement of the pattern, as in Bach's *Passacaglia and Fugue in C Minor* for organ or his "Chaconne" from the *Partita in D Minor* for unaccompanied violin. This procedure is also found in early operatic arias in the strophic variation form, in which each statement of the ostinato corresponds to a strophe of the aria's text. In the 19th century Brahms made impressive use of the ostinato (finales of the *Variations on a Theme by Haydn* and the *Symphony No. 4 in E Minor*).

Progressive types. The progressive type is common in songs and instrumental pieces of the 19th and 20th centuries but is also found in earlier music (*e.g.,* in the melodies used for the Gloria and Credo of the mass in plainchant) and in the prose, or sequence (*c.* 9th–*c.* 12th centuries), the phrases of which are arranged in pairs (a a b b c c d d, etc.), and its instrumental equivalent, the estampie. Polyphonic forms using a cantus firmus or basic melody (often a plainchant excerpt) also belong to the progressive type and include the liturgical organum, the early motet, and the conductus from the medieval era, as well as many chorale-preludes for organ of the Baroque. If, however, the cantus firmus itself is in one of the reverting forms, then the polyphonic setting will frequently follow suit.

The most important forms of Renaissance polyphony also belong to the progressive type, since the characteristic procedure was to give each line of the text its own musical phrase, as in the Renaissance motet and other types of secular polyphonic music. The same applies to the instrumental contrapuntal forms of the late Renaissance and Baroque: the ricercare, canzona, invention, and fugue. Other progressive types include intonations, preludes, toccatas, and fantasias for lute and keyboard of the 16th, 17th, and early 18th centuries, in which the thematic material consists primarily of figurative elements (scale passages, arpeggiated chords, trills, turns, and the like); in larger works of this kind—by Bach for instance—passages in fugal style are often also present. Finally, there is simple binary form (a b), often found in early dances and in large operatic arias of the Classical period (Mozart and Beethoven).

WESTERN COMPOUND FORMS

Early history. With the larger forms of instrumental music there are extended musical pieces, usually called movements, which in their succession and toiality make up a larger whole. An important unifying factor is key: a single key often dominates the work, others being used for contrast. This idea goes back at least to the Baroque, when two formal types were established: the first is the *sonata da camera,* or chamber sonata, consisting of a series of dances in the same key (also known as partita and, later, suite). By J.S. Bach's time (1685–1750) a set arrangement of dances was common: allemande (moderate duple time), courante or corrente (fast triple time), saraband (slow triple time), and gigue (fast duple or quadruple time), usually with some other dance inserted between the saraband and the gigue. The other type is the *sonata da chiesa,* or church sonata, which consists of four movements, again all in the same key, in a slow–fast–slow–fast succession. The distinction between the two types is explicit in Bach's sonatas and partitas for unaccompanied violin: the sonatas are in the "church" form, whereas the partitas are suites. Other large forms of Baroque music are the two types of overture: the French, in two parts, the first slow and stately, the second fast and fugal; and the Italian, in three movements in the succession fast–slow–fast, the middle movement usually in a different key. The instrumental concerto after 1700 usually employed the same scheme as the Italian overture.

The sonata. Around 1750 a combination of these types produced the forms most common in the standard repertory of concert music. The sonata became a piece for either a keyboard instrument or a solo instrument accompanied by keyboard. It ordinarily consisted either of three movements in the arrangement fast–slow–fast or of four, with a minuet inserted between the slow movement and the finale; but there are examples of two-movement sonatas, notably by Beethoven, and even of one-movement sonatas (*e.g.,* by Domenico Scarlatti, the Italian-born composer to the Spanish court). Usually all movements except the slow one (and sometimes the trio, as well) are in the same key. The first movement typically is cast in the sonata form, the slow movement in one of the reverting schemes (often ternary), and the finale either in sonata or rondo form; but variation form may appear in any of these movements.

This large form is also used in chamber music, particularly the string quartet, and in the large form of orchestral music, the symphony, both of which ordinarily have four movements. Notable exceptions to this are the late quartets of Beethoven as well as those of the 20th-century composer Béla Bartók, the latter in two instances using what is called the "arch form," a large reverting arrangement, A B C B A, each element being a separate movement; there are innumerable other exceptions. The concerto, on the other hand, adheres more to the older three-movement form. The various kinds of late 18th-century entertainment music (cassation, divertimento, nocturne, serenade, and the like) may employ any of a number of arrangements, ranging from three movements all the way to six or more.

Exceptions to sonata form

Cyclic form. Some authorities believe that since the 18th century such sonata-form compositions have been organized by the use of a few musical thematic motives, often submitted to considerable variation throughout. Compositions organized in such a way are said to be in cyclic form. While this becomes important in the 19th century, the extent to which it characterizes the Classical period is a matter of some controversy at present.

Fantasias and program music. Simultaneously a much freer form was cultivated, beginning in the late 18th century, the fantasia, primarily for keyboard, notably in the hands of Carl Philipp Emanuel Bach. Consisting of an indefinite number of highly contrasting sections, surprise and expression were of prime significance.

The fantasia, along with the overture to a play or opera, was the precursor of the large forms of orchestral program music of the 19th century, in which an extramusical content (usually a narrative of some kind), called the program, is expressed in the composition. There are two main types: the program symphony, associated with Hector Berlioz, in which the norms of symphonic form are for the most part preserved, and the symphonic poem, associated with Franz Liszt and Richard Strauss, in which the composer allows the extramusical subject matter to determine the structure of the composition. Some 19th-century concert overtures by German composers such as Felix Mendelssohn and Robert Schumann belong to this type of composition. Important here is the association of musical themes with aspects of the program, the themes being used throughout the work, often in varied forms.

The symphonic poem

Another arrangement is called the suite, which no longer consists exclusively of dances but also of instrumental pieces of all kinds. Usually some common element runs throughout: a cyclic theme may be used, as in Schumann's *Carnaval* or the Russian composer Modest Mussorgsky's *Pictures from an Exhibition,* or the music may originally have been intended for use with a play (Mendelssohn's music to *A Midsummer Night's Dream* or the Norwegian Edvard Grieg's for Henrik Ibsen's *Peer Gynt*).

Opera and oratorio. Among the large forms of vocal music, opera and oratorio are the most significant. Both are extended works in which a narrative is set to music. While an opera is performed in a theatre, an oratorio is a concert piece. Both may be either sacred or secular. A special type of oratorio is the Passion, the setting of New Testament accounts of Christ's crucifixion. The cantata may be regarded as a smaller form of oratorio.

Operas and oratorios ordinarily consist of several musical genres: recitative (imitating the manner of speech), aria, ensemble and choral pieces, often with instrumental interludes and an overture (most overtures of the late 18th and 19th centuries being cast in sonata form). Opera often includes ballets and large sectional finales at the ends of acts. With respect to the oratorio, Handel greatly increased the role of the chorus in his work with this genre (especially *Israel in Egypt*), an example seized upon by his successors. Oratorios also differ from operas in that they frequently make use of a *testo* (narrator), who relates the events of the action, usually set in recitative style. Stravinsky's *Oedipus Rex* (1927) combines the two traditions.

Whereas operas are usually composed as a series of enclosed musical forms, the German composer Richard Wagner devised a special kind, known as music drama, in which the music is continuous and in which the distinction between recitative, aria, and ensemble is largely eliminated. Instead, Wagner used a flexible melodic line which he referred to as "tone speech." Wagner also greatly increased the role of the orchestra, stressing the technique of thematic development and transformation borrowed from instrumental music and further associating each theme with an aspect of the operatic plot, such themes being known as leitmotivs ("leading motifs").

Wagner's new operatic form

The mass. Another large vocal form is the mass, the earliest polyphonic settings of which date from the 14th century. At first the mass was set in cantus firmus style, each movement built on the appropriate Gregorian chant melody, as in the mass of the French composer Guillaume de Machaut. In the 15th century a Burgundian composer, Guillaume Dufay, and his contemporaries developed the cyclic mass, in which a single cantus firmus was employed throughout. This idea was extended in the parody mass, built by elaborating thematic material taken from an ex-

isting polyphonic work, usually a motet or chanson; most 16th-century masses are of this kind. In the Baroque mass, each segment of the text is treated as an independent composition (aria, duet, chorus), similar to the procedure in a cantata or oratorio, except that no recitatives are used. J.S. Bach's *Mass in B Minor* is of this type.

In the 16th and 17th centuries, Monteverdi and others grouped madrigals into a kind of cycle around a particular subject; should a dramatic text be involved, the form is known as a madrigal comedy. In the 19th century and after, similarly grouped songs with piano accompaniment are known as a song cycle (*e.g.*, those by Beethoven, Schubert, and Schumann).

20th-century modifications. In the 20th century many composers have continued to use the traditional forms, although in other respects their work makes significant departures from what had been established. Others have virtually discarded them. Radically new elements have been introduced to serve as structural units: instead of the traditional phrases and motives, composers have come to employ what they call "sound events," combinations of textures, types of timbre, aggregates of different simultaneously sounding pitches, and the like. An early example is afforded by the notion of the melody of timbres—the *Klangfarbenmelodie* of Arnold Schoenberg and Anton von Webern. The broadest possible range is included in the conception of a sound event: not merely tones but also noises; in fact, sounds of all kinds. These sound events have been arranged in a complex manner. An important principle of organization has been serialism, originally applied only to pitch, so that the pitch content of the work is decided by reiterations of a series (set or row) of pitches that has been determined in advance (*e.g.*, in the 12-tone compositions of Schoenberg and Webern). Since 1945 the serial principle has been extended to other aspects of music as well: durations, dynamics, and types of attack and tempi, as in the music of the French composer Olivier Messiaen and the German Karlheinz Stockhausen. Other composers, including Stockhausen and the Greek Yannis Xenakis, have used numerical relationships to determine the structure of compositions mathematically. Still others have conceived of form as a dynamic interaction between contrasting and continually evolving sound events—the French composer Edgard Varèse and the American Elliott Carter. Simultaneously, there are works, such as those of the American John Cage, in which the form is not predetermined by the composer but left to chance, such pieces being called indeterminate or aleatoric. These statements apply particularly to electronic music.

"Sound events"

NON-WESTERN FORMS

Elements of structure. In many non-Western civilized cultures, such as those of India and Middle Eastern Islāmic countries, music for the most part is not written down in advance of the performance but improvised upon framework-like patterns. In effect a composition exists only in its performance. Problems are presented by the different scales and intervals, rhythmic patterns, timbres, inflections, and the like. Or, again, a type of polyphony known as heterophony may result from the discrepancies that occur when several different singers or players simultaneously vary the same melodic line. In Japanese *gagaku* music, in which improvisation is not a factor, the beats often vary in duration, producing what is known as "elastic rhythms," akin to the Western tempo rubato. Much non-Western music is functional: each piece has a specific purpose and is associated with certain events, actions, or situations, which often determine the musical structure.

Important elements of form in non-Western music are melody types and rhythmic patterns. By melody type is meant a melodic formula using a recognized scale, stressing particular tones and using specific configurations of intervals, which can provide the basis for a larger piece. In a given society or culture there ordinarily exists a large repertory of these melody types from which the musician, following convention, selects those for use in his rendition. The use of rhythmic patterns for form is seen, for instance, in colotomic structure, in which the composition is marked off in temporal entities by the differing but regularly recurring entrances of particular musical instruments in a set order.

Rhythmic patterns used for form

In the music of nonliterate cultures, simple iterative and strophic structures predominate. These are characterized by short phrases and the frequent use of alternation between a soloist and the group (the "call-and-response" pattern). Such pieces, often associated with dancing, usually belong to specific rituals of one kind or another.

In literate cultures comprehensive theoretical music systems often exist, with elaborate musical forms. Nonetheless, the conception of propriety, that each musical piece has a certain function, is dominant. While strophic forms continue to be important, as in the Indian *gat*, the *umui* religious chants of the Ryukyu Islands (both of which also use variation), and in the popular music of most cultures, there are also such large musical forms as those related to the Indian *rāgas*, the Arabic *maqāmāt* (melody types), and the music of the *gamelan* (gong and percussion ensembles) of Java and Bali.

Specific formal patterns. The term *rāga*, meaning colour or passion, refers not only to a scale but also to the melody type. It has given rise to several musical forms, among them the ancient northern *dhurpad* and the shorter type known as *khyāl* in the North and *kirtana* in the South. These may be vocal, instrumental, or both, the main performer or performers being accompanied by a drone played by a bass lute and by the reiteration of an extended rhythmic pattern (the *tāla*) by a drum. While much variety is possible, a typical formal arrangement includes a prelude which states the *rāga* (scale and melody type) in its simplest form and continues with a number of contrasting sections that differ in the degree of elaboration of the *rāga*, the register exploited, and the rapidity of the notes and figuration, usually reaching a climax near the end, in which daring variations on the *rāga* in the uppermost register are played or sung in very rapid tempo; the performance may conclude with a return to the character of the prelude. Interludes or linking passages, related to the prelude, are often present, so that an irregular reverting scheme results.

The Arabic *maqām*, roughly equivalent to the *rāga*, provides the basis, among others, for the *bashraf*, a reverting type not unlike the Western rondo, and the *nawba*, an extended multisectional performance with some resemblance to the suite. In Java and Bali particularly noteworthy is the *gending* (musical composition) for the *gamelan*, which may take one of several progressive sectional forms in which the colotomic principle is important: the large *gending agen*, usually bipartite, a slow movement followed by a fast one, and the shorter *gending gangsaran*, used as preludes and interludes. (F.E.Ki.)

Instrumental music

CHAMBER MUSIC

In its original sense chamber music refers to music composed for the home, as opposed to that written for the theatre or church; since the "home"—whether it be drawing room, reception hall, or palace chamber—may be assumed to be of limited size, the music is most often composed for a small ensemble, traditionally dispenses with a conductor, and permits no more than one player to a part. Music written for combinations of stringed or wind instruments, often with a keyboard (piano or harpsichord) as well, and music for voices with or without accompaniment have historically been included in the term.

An essential characteristic of chamber music results from the limited size of the performing group employed: it is intimate music, suited to the expression of subtle and refined musical ideas. Rich displays of varied instrumental colour, and striking effects produced by sheer sonority, play little part in chamber music. In place of those effects are refinement, economy of resources, and flawless acoustical balance.

This section discusses instrumental ensemble music written for groups of two to eight players with one player to a part, and in which stringed instruments and piano (or harpsichord) supply the principal interest.

Historical development. Instrumental music designed

for home use has existed since about the middle of the 15th century. It became customary in Germany to supply folk-song melodies with two or three countermelodies, to expand and elaborate the whole, and to arrange the result for groups of instruments; original melodies were given similar treatment. The instruments were not often specified, but on the basis of many paintings of the time one may assume that groups of viols of various sizes predominated.

A more important source of later chamber music is to be found in the arrangements of 16th-century chansons (songs of French origin composed usually for four voices on a variety of secular texts), some for voices and lute, others for lute alone. The typical chanson was characterized by contrasts in musical texture and often in metre; the effect of the whole was that of a short composition in several even shorter sections. That sectional form retained in the arrangements later became a striking feature.

The chanson travelled to Italy about 1525, became known as canzona, and was transcribed for organ. The earliest transcriptions differed from the French arrangements in treating the original chanson with greater freedom, adding ornaments and flourishes, and sometimes inserting new material. Soon original canzonas for organ, modelled on the transcriptions, and for small instrumental ensembles, were composed. One such type, characterized by elaborate figurations and ornamented melodies, became influential in England late in the 17th century and played a role in the works of Henry Purcell.

Development from dance suites

Parallel to the developments that led from the vocal chanson, in France, to the instrumental canzona, primarily in Italy, was the development of the dance suite. Early 16th-century dance tunes in all countries of western Europe usually had appeared in pairs: one was slow, stately in mood, and in duple metre (*i.e.,* with two beats to the measure); the other fast, lively in mood, usually in triple metre, and often melodically similar to the first. Through much of the 16th century, composers in the several countries sought to expand the dance pair into a unified dance suite. Suites based on variations of one movement appeared in England; suites in which each of four dances had its own rhythmic character, melodically based on the first dance, were written in Germany; sets of dances with no internal relationships to each other were common in Italy. The most influential steps were taken in France by composers for the lute or the clavecin (harpsichord). Consisting essentially of four dance forms that were then popular—the allemande, courante, sarabande, and gigue—the suites they composed were based on contrasting tempos, metres, and rhythmic patterns. The French version of the dance suite became the prototype for later chamber-music forms.

Toward the middle of the 17th century the two types of composition—one derived from the canzona and composed in sectional form, the other derived from the dance suite and consisting of several movements—appeared as works for small instrumental ensembles. In Italy small groups of stringed instruments were often employed in Roman Catholic churches to perform appropriate music; thus canzonas came to be widely used for church purposes. For church use the dance movements were omitted, and what came to be called a church sonata (*sonata da chiesa*) resulted. And a set of *sonate da chiesa* composed in 1667 by Giovanni Battista Vitali marked the beginning of the form as a separate entity.

Rosenmüller's chamber sonatas

In the same year Johann Rosenmüller, a German composer working in Venice, published a set of *Sonate da camera cioè Sinfonie . . .* (*Chamber Sonatas, that is, Symphonies . . .*), each consisting of four to six dance movements with an introductory movement (sinfonia) not in dance style. The development of chamber music for the remainder of the century centred upon these two types, *sonata da chiesa* and *sonata da camera.*

The first half of the 17th century was marked by considerable variety in the constitution of chamber-music groups. Compositions were commonly for one to four viols, or for combinations of viols and woodwind instruments, most often with a figured-bass accompaniment, a kind of musical shorthand, employed in virtually all music of the period about 1600 to 1750, in which the composer wrote a bass line and inserted figures and other symbols under certain notes. The figures indicated the nature of the desired chord to be improvised over the note—whether major or minor, whether in normal or in inverted position, and so on—and the figured-bass line was designed to be "realized" or played by a harmony instrument (such as a lute, organ, or harpsichord), often with a melody instrument (bass, cello, or bassoon) to reinforce the bass line. The bass line with its figures and the two instruments performing it were called basso continuo or simply continuo.

As early as 1622, the Italian composer Salomone Rossi had begun to specify two violins and *chittarone* (a large lute) in his dance sets; and soon similar combinations were adopted generally. A work written for two violins and bass (continuo) became known as a *sonata a tre* or "trio sonata"—even though four instruments (the three strings and the lute or harpsichord) were usually involved in the performance. Later in the 17th century works for one instrument and continuo appeared also and were called variously solo sonatas, duos, or *sonate a due.* The combinations of violin and continuo or cello and continuo were favoured, and sonatas for those combinations took regular places in the chamber-music field.

Works for two violins and continuo (with harpsichord and bass understood) virtually dominated the field until the middle of the 18th century. About that time the custom of serenading became popular; small groups of instrumentalists strolled the streets of Austrian and Italian cities, performing serenades and divertimenti. The keyboard instrument realizing the continuo proved unwieldy and was soon abandoned. To the three remaining strings a viola was added to fill out the harmonies, the bass was replaced by a cello, and the string quartet emerged. This new combination of two violins, viola, and cello was then adopted by composers of serious music, and from about 1750 the string quartet took its place as the principal medium for chamber music. Owing its development largely to the Austrian composer Joseph Haydn, it has reigned supreme to the present day. About 1760, other combinations for strings alone began to play important but relatively smaller roles in the field: the string trio (violin, viola, cello), string quintet (quartet plus a second viola), and string sextet (quintet plus a second cello) are chief among them.

Function of the harpsichord

Meanwhile, as the continuo principle gradually approached obsolescence, the harpsichord (which was superseded by the piano about 1770) took on a new function in chamber music. In works with continuo it had been an accompanying instrument, improvising its part according to the directions indicated in the figured bass; now the keyboard instrument became dominant in new combinations that included one to four strings. The most important of these is the piano trio (piano, violin, cello), the repertory of which includes works from Haydn to the present. Various combinations of piano and one instrument loom almost as large. Toward the end of the 18th century and extending through the 19th, the combinations of piano quartet (piano trio plus viola) and piano quintet (piano and string quartet) give rise to a small but significant repertory ornamented by composers such as Mozart, Beethoven, Brahms, and many others.

Finally, works for individual combinations exist in considerable number after about the 1780s. Representative compositions of that nonstandard group include the clarinet quintets (string quartet and clarinet) by Mozart (K. 581) and Brahms (Opus 115); the *Septet,* Opus 20 (violin, viola, cello, bass, clarinet, bassoon, and horn), by Beethoven; the *Octet,* Opus 166 (as in the septet plus a second violin), the *Trout Quintet,* Opus 114 (violin, viola, cello, bass, and piano), and the *String Quintet in C Major,* Opus 163 (two violins, viola, and two cellos), all by Schubert; and the *Horn Trio,* Opus 40 (violin, horn, and piano), by Brahms. Composers of the 20th century have written works for instrumental groups to which a voice is added.

Late Baroque period, c. 1675–1750. The work of Arcangelo Corelli (1653–1713) in standardizing the two major sonata types of his time had tremendous impact on chamber music. Corelli was of considerable influence on Henry

Purcell (*c.* 1659–95), the most important English composer of his time. Purcell's works include 22 trio sonatas closely allied to the *chiesa* type, and over a dozen "fancies" (that is, fantasies), works of a single movement largely in contrapuntal style for groups of three to seven viols. Another Italian Baroque composer of widespread influence, Antonio Vivaldi (1678–1741), in addition to several hundred concertos for various instruments and orchestra, composed some 75 chamber-music works. Of these, 12 trio sonatas, 16 sonatas for violin and continuo, and about 16 for various other instruments have entered the repertory.

Bach's contributions

The contributions of Johann Sebastian Bach (1685–1750) to development of chamber music were noteworthy. In all, Bach's chamber works include 18 sonatas for one instrument (nine for violin, three for viola da gamba, six for flute) and harpsichord, two separate trio sonatas, and two late works of an unusual nature; *Das musikalisches Opfer* (*The Musical Offering*) and *Die Kunst der Fuge* (*The Art of the Fugue*). Half of the sonatas require figured bass; the other half, with written-out keyboard parts, are essentially in three-voice counterpoint: one voice in the solo instrument and two in the keyboard part. *The Musical Offering* consists of 12 canons and fugues for various combinations of two to six instruments and a four-movement trio sonata; the whole is based on a theme given to Bach by Frederick the Great in 1747, upon which Bach improvised in the presence of the King, and which he later elaborated to constitute this "offering." The work reveals Bach's enormous technical skill and is filled with emotional intensity. *The Art of the Fugue,* Bach's last work, is a set of 19 fugues (the last unfinished) for two to four unspecified instruments. The work is based on one theme that is transformed in systematic fashion in successive movements, and employs two additional themes on occasion. The whole summarizes the contrapuntal practices of the past, contains profound spiritual symbolism, and is unique in music.

The 40-odd chamber works of George Frideric Handel (1685–1759), representing both *chiesa* and *camera* types, contain a wealth of melody and carefully worked-out fugal movements and are filled with the rhythmic drive that represents Handel at his best. Of these about 18 are solo sonatas (with continuo) for various instruments, and some 22 are trio sonatas.

Classical period, c. 1750–1825. The 83 string quartets (of which seven are single-movement arrangements of orchestral pieces titled *The Seven Words of Our Saviour on the Cross* and known as *The Seven Last Words*) by Joseph Haydn (1732–1809) constitute a series in which virtually the entire history of the string quartet is represented. Most of them appeared in sets of six, each under a separate opus number. The earliest sets, Opus 1 and 2, express merely the superficial and diverting elements of Rococo style—the fanciful, ornamental style that was prevalent in the 18th century. From Opus 3 onward the four-movement form is regularized, and in Opus 9 thematic materials begin to reveal details that point to the future. Opus 17 discloses a virtuosic element in its first-violin parts, and lower voices are given only a small share in the thematic work. The latter process comes to full expression in Opus 20, for now cello and viola are entrusted with thematic statements and the quartet style is close at hand.

Haydn's 83 quartets

After a nine-year interval (1772–81) Haydn introduced a "new manner" (his phrase) in the quartets of Opus 33; this resulted in the establishment of the principle of thematic development. Motive manipulation is basic to the texture, and the fully developed sonata form appears. Also in Opus 33 Haydn introduced the scherzo in place of the minuet, but did not continue that practice in later quartets.

The 33 quartets from Opus 50 onward (excepting Opus 51, *The Seven Last Words*) include the masterworks on which Haydn's reputation is so firmly founded. Of them 18 (Opus 50, 54, 55, 64) were composed during the time (*c.* 1786–90) Haydn was in close contact with Mozart and are characterized by an increasing use of chromaticism to produce poignant effects. The 15 quartets written after Mozart's death (Opus 71, 74, 76, 77, 103) return to the optimistic style that was innate, and they reveal an ever-increasing expressiveness and mastery of detail.

Haydn also composed more than 30 piano trios, eight violin sonatas, and over 60 string trios. While those works contain attractive melodies, they represent a minor aspect of the composer's activity.

Of the 26 string quartets written by Wolfgang Amadeus Mozart (1756–91) the qualities of the last 10 are such that they have virtually overshadowed the 16 earlier works. Six of the 10 reflect Mozart's first attempts to work in Haydn's "new manner" and reveal how successfully he adopted the principle. The last three, dedicated to King Frederick William II of Prussia, a competent cellist, show Mozart's ability to adapt to the interests of his potential patrons. Here the cello parts reveal something of the virtuosity required of the first violin. Taken together, the last 10 quartets are among Mozart's masterpieces.

Of Mozart's eight string quintets, three rise to supremacy. The *String Quintet in C Major,* K. 515 (K. stands for Köchel, a cataloger of Mozart's works), is a model of strength and delicacy, filled with moods reflecting grace and good humour, but also high dramatic tension. Its companion in G minor, K. 516, is characterized by the same strength but is the embodiment of anguish. Two years later Mozart composed the *Clarinet Quintet,* K. 581; now moods of grace, humour, and cheer prevail. The addition of the woodwind instrument enabled Mozart to achieve a high level of brilliance and colour throughout; the *Clarinet Quintet* is one of the monuments of the literature.

Exactly half of Mozart's 32 violin sonatas were composed before his 10th birthday; in them the violin parts do little more than accompany the piano. The last 16 move gradually to a true ensemble texture, which is fully attained in K. 454, K. 481, and K. 526. Two piano quartets, contrasting greatly in mood, are alike in containing a balance between piano and strings. His seven piano trios are somewhat like the violin sonatas in gradually reaching a true ensemble texture. Of the seven, one in B flat major (K. 502), one in E major (K. 542), and one in E flat major for clarinet, viola, and piano (K. 498) rise to greatness in variety of moods, balanced forms, and perfection of detail.

The backbone of the repertory

In the works of Ludwig van Beethoven (1770–1827) chamber-music composition takes a central place. His 17 string quartets constitute the backbone of the repertory. The first six take points of departure from the quartet style of Haydn's later works, but far exceed them in strength, occasional boisterousness, and variety of material. Five quartets of Beethoven's middle period represent a great increase in size, depth of expression, and formal freedom. The six last quartets include works that transcend conventional forms and textures. Development techniques and contrapuntal devices play more important roles here; forms are imaginative and fluid, movements are often thematically related, and a range of expression that uncovers new depths of the soul is here disclosed.

Beethoven's other chamber music, like the quartets, reveals a gradual increase in the power of the motive to generate thematic sections. This is especially true in the *Three Piano Trios,* Opus 1; the *String Trio in C Major,* Opus 9, No. 3; and the *String Quintet in C Major,* Opus 29. Particularly in the scherzo movements, which Beethoven employs in place of minuets, he generally begins with a one-measure motive, from which most of the thematic material is derived. The *Septet,* Opus 20, together with many of the violin sonatas, the cello sonatas, and a few miscellaneous works, occupy an intermediate stage in this development. Some are based on long melodies that are developed, others on short motives that are manipulated. In virtually every case, however, a masterpiece results.

Early Romantic period, c. 1825–55. Franz Schubert (1797–1828), in about 28 chamber-music works, at first modelled his compositions on those of the Classical period. His restless search for instrumental and harmonic colour soon took him beyond the bounds of Classical style and aligned him with the prophets of Romanticism. Of the eight works in which his mature mastery is so clearly revealed, all but one were composed after 1824. They include the last three string quartets, the *Trout Quintet* for piano and strings, an *Octet* for strings and winds, two piano trios, and the *String Quintet in C Major* with second cello added to the usual quartet.

Schubert's melodic flow

Less concerned with traditional formal structure than other composers of his stature, Schubert relied on unceasing melodic flow coupled with rare harmonic imagination. Typically a melodic section is repeated with changed harmonies, ranging far beyond the usual; the finale of the *Piano Trio in E Flat Major,* Opus 100, is an extreme example. But Schubert also had a keen sense of drama, as the *String Quartet No. 14 in D Minor* (*Death and the Maiden*) exhibits eloquently. Such characteristics (lyrical melody, harmonic variety, and drama) are wonderfully combined in Schubert's last large composition, the *String Quintet in C Major* with two cellos—probably the most perfect work of this composer's short life.

With Felix Mendelssohn (1809–47) a return to Classical ideals of form is seen, coupled, however, with Romantic enthusiasm. Of his about 24 chamber-music works, eight represent the composer at his best; these include five string quartets, two piano trios, and an *Octet* for eight strings. Mendelssohn's contributions include primarily a new kind of light and deft music, heard especially in his scherzos; a rich melodiousness that embraces all sections of the sonata-form movements (hence removing the element of thematic contrast on which musical conflict depends); and scrupulous attention to detail. The scherzo of the *String Quartet No. 4 in E Minor,* Opus 44, No. 2; that of the *String Octet in E Flat Major,* Opus 20; and the finale of the *String Quartet No. 3 in D Major,* Opus 44, No. 1, are among the finest representatives of Mendelssohn's enchanting style.

Robert Schumann (1810–56) represents the best aspects of early Romanticism; these include an interest in tone colour, melodiousness, a free approach to details of form, and subjective expression in which enthusiasm plays a large part. Twelve chamber-music works reflect those aspects in varying degrees. A set of pieces entitled *Märchenerzählungen* (*Fairy Tales*) for piano, clarinet, and viola illustrates the search for new tone colours; the *Piano Quintet,* in which the piano is combined with two violins, viola, and cello (possibly for the first time in the 19th century), does likewise. Three string quartets are melodious, dramatic, brusque, and dreamy in turn. In three piano trios, as in one piano quartet, Schumann's tendency to let the piano dominate the strings is sometimes seen. And in all those works his characteristic impulsiveness and tendency to alternate between forthright and moody expression is characteristic.

Late Romantic period, c. 1855–1900. In chamber music of the last half of the 19th century, only a few dozen works by composers other than Brahms survive in the repertory of the period. A piano quintet, one string quartet, and a single violin sonata by César Franck reveal that composer's fondness for cyclical form, in which successive movements are thematically linked, and for a structural scheme that is based on harmonic manipulation rather than melodic development. Bedřich Smetana (1824–84), in two string quartets and one piano trio, tended toward autobiographical expression in which Czech folk dances played a part. His first quartet, *Z mého života* (*From My Life*), is supplied with a program.

The work of Antonín Dvořák (1841–1904) represents a combination of the finest Romantic writing with a decidedly nationalistic flavour. Of about 30 works of chamber music, nine held an important place in the repertory; these include two string sextets, three quartets, two piano trios, a piano quartet, and a piano quintet. One of the string quartets, the *American,* Opus 96, purports to express Dvořák's impressions of American (including Indian) music. Another work, the *Piano Quintet,* Opus 81, marks a high point in the composer's use of attractive melody and rhythmic vitality; it, too, has Czech overtones. And the *Dumky Trio,* Opus 90, contains six dumky (a dumka being a Ukranian folk music form with moods alternating between melancholy and wild abandon); here the element of contrast is stressed to the utmost.

Aleksandr Borodin (1833–87), in the second of his two quartets, combined traces of Russian nationalism with expressions of pure lyricism. Peter Ilich Tchaikovsky (1840–93), with three string quartets (one of them containing the famous "Andante cantabile"), a string sextet, and a big-scale piano trio, often brought moments of orchestral sonority into his chamber music. The *Piano Trio,* Opus 50, is a virtuosic work in two movements—one a lengthy sonata form, and the other a set of brilliant variations—and is primarily elegiac in mood.

Preeminence of Brahms

It was Johannes Brahms (1833–97), however, who dominated the period. All of Brahms's 24 chamber-music works are highly successful; in all these works Brahms's characteristic balance of emotional and intellectual expression is clearly revealed. Rich sonorities, thick textures, and rhythmic complexity are present everywhere, and the forms are those of the Classical period, somewhat modified in the light of Brahms's temperament and expressive requirements.

Eloquent melodic writing is most characteristic of his earlier works, notably the *String Sextet No. 1 in B Flat Major,* Opus 18; the *Piano Quartet in G Minor,* Opus 25; and large portions of the *Piano Quintet,* Opus 34. Later works, by contrast, reveal Brahms's increasing concern with motivic and rhythmic development; as a consequence, lyricism plays a smaller role in such works as the two string quartets Opus 51, and the four late works with clarinet, namely the *Clarinet Trio,* Opus 114, the *Clarinet Quintet,* Opus 115, and the two sonatas Opus 120.

The 20th century. As in all times of stylistic change, considerable overlapping of styles occurred at the turn of the 20th century. In chamber music, several composers born in the 19th century carried the modified Late-Romantic style into the 20th. Among the French composers were Gabriel Fauré (1845–1924), who, with 10 works, is remembered primarily for a refined and controlled style that is rhythmically subtle; and Vincent d'Indy (1851–1931), represented by about eight works, who reflected the style of César Franck. Likewise the Hungarian Ernő Dohnányi (1877–1960) revealed the strong influence of Brahms in about six works noted for their outspoken melodiousness and contrapuntal excellence. The German Max Reger (1873–1916), with about 36 works, was primarily an exponent of chromatic writing in forms that are derived essentially from the 19th century.

The first step toward the new styles of the 20th century were taken in France by Claude Debussy (1862–1918); his one string quartet (1893) and three sonatas (late works) represent the Impressionistic style based on whole-tone harmony, of which he was an exponent. Somewhat similar are the string quartet and piano trio by Maurice Ravel (1875–1937), with a rich array of tremolos, forms based on repetition of melodic fragments, and many astringent harmonies. In England, on a different path are a string quartet and piano quintet by Sir Edward Elgar (1857–1934) and two string quartets, a string quintet, and a song cycle (*On Wenlock Edge* for tenor, string quartet, and piano) by Ralph Vaughan Williams (1872–1958). Elgar reveals an intensely personal style; Vaughan Williams uses English folk song, elusive harmonies, and strong rhythms.

Three major influences

The musical styles that have dominated the later 20th century are largely the work of three composers and their respective followers. The most influential was Arnold Schoenberg with his development of the "12-tone style"; but his earlier works were not yet representative of that style. A string sextet, *Verklärte Nacht* (*Transfigured Night*), transferred the form and content of the symphonic poem to the field of chamber music; two string quartets, Opus 7 and 10, are similarly post-Romantic in style, and the second includes a part for soprano voice. A set of 21 short poems for quasi-reciting voice and five instruments, *Pierrot Lunaire,* marked an intermediate stage; and four later works, including the third string quartet, saw the full development of the 12-tone style. In a fourth quartet and a few smaller works the system was carried to completion.

In the *Lyric Suite* for string quartet (1927) Alban Berg (1885–1935), also an Austrian and one of Schoenberg's pupils, brought elements of Romantic expression into the system. And another Austrian pupil, Anton von Webern (1883–1945), sought to develop utmost refinement and consistency, along with brevity. A string quartet, a quartet for violin, clarinet, saxophone, and piano, and a chamber concerto for nine instruments are the principal works that illustrate his methods of extreme economy in the use of

all materials. Webern's approach has been of maximum influence on many composers of the present day, and has led to the development of serial writing.

A completely different path was taken by the Hungarian Béla Bartók in six string quartets and a trio, *Contrasts,* for piano, violin, and clarinet. In those works the main thrust has been on harmony (including acrid dissonances that border on atonality), greatly rhythmic drive with many irregular rhythmic patterns (some of them based on eastern European folk song, in which field Bartók was an avid worker), and the development of new instrumental effects. Coupled with such technical elements are fervent expressiveness and, in the slow movements, great repose. The Bartók quartets are among the major chamber-music works of the 20th century.

The third principal influence, that of the Russian-born Igor Stravinsky (1882–1971), was felt perhaps less in chamber music than in orchestral, for Stravinsky composed fewer than a dozen works in the field. Five song cycles for voice and small groups of instruments, several short pieces for string quartet, and a pantomime, *The Soldier's Tale,* for narrator and seven instruments are varied in content and style. An *Octet* for wind instruments (1923) represents a deliberately impersonal style that requires no subjective interpretation on the part of the performers. And a *Septet* for three winds, three strings, and piano (1952) marks Stravinsky's adoption of serial writing, a style that he had consciously rejected earlier.

Other major contributions

The German Paul Hindemith (1895–1963), with seven string quartets and more than two dozen sonatas and other works, favoured polyphonic textures, an expanded harmonic scheme, and great rhythmic drive. His style in later works became less dissonant, more lyric, and was characterized by a general lightening of the thick counterpoint that had distinguished his work of the 1940s. His seven works called *Kammermusik* are for larger groups and so do not come within the scope of this article. The French composer Darius Milhaud, in about 18 string quartets, four quintets for various combinations, and a number of other works, for a time espoused the principles of polytonality, the device of employing several keys simultaneously. Characterized by moods that are often pungent, humorous, and even satirical, his works reveal a mixture of dissonant counterpoint, rhythmic flexibility, and graceful expression. His 14th and 15th quartets, independent works in their own right, may be performed simultaneously to form an octet.

Two Russian composers, Sergey Prokofiev (1891–1953) and Dmitry Shostakovich, are represented in the repertory by about 20 works adhering, in the main, to the forms and textures of the 19th century. Both men embrace the new harmonic techniques without departing entirely from Romantic expressiveness. Many of their compositions reveal a sense of humour. Of British composers, Sir William Walton, Lennox Berkeley, Alan Rawsthorne, and Benjamin Britten have made significant contributions to the medium.

The chamber music by American composers has in general reflected the international styles mentioned above. One exception is seen in two quartets, a piano trio, and several violin sonatas by Charles Ives (1874–1954), who maintained a style of great originality through his long lifetime. Another exception may be noted in the work of Ernest Bloch (1880–1959), Swiss by birth, but identified with the United States since about 1917. In five string quartets, two piano quintets, and a few smaller works, Bloch brought his Jewish heritage to expression in styles that are robust and varied.

American composers

Among the more prominent American composers, a few may be singled out for their notable contributions. Walter Piston, with four string quartets, a piano trio, a quintet for flute and strings, and a piano quintet, is perhaps the most eclectic; his works are basically Neoclassical and are distinguished by elegance and vitality. Roger Sessions, represented principally by two string quartets and a string quintet, has written in an austere, reserved, and strongly dissonant style. Quincy Porter (1897–1966) composed 10 string quartets, several quintets for various combinations, and smaller works; they are characterized by warm expressiveness achieved in textures that employ considerable repetition of short motives. The works of Roy Harris are distinguished by forms that depart from 19th-century models; three string quartets and a piano quintet are among his most significant works.

Aaron Copland may be mentioned for a piano trio; a sextet for clarinet, piano, and strings; a piano quartet; and a violin sonata. Those works include variously nationalistic allusions (including Jewish and Latin American), unresolved dissonance, and elements of serial style. William Schuman in four string quartets and smaller works discloses a strongly dissonant style that remains, nevertheless, within the tonal system; his works are rhythmically vital and express great energy.

Elliott Carter, Jr., is best represented by a cello sonata and two string quartets. He employs elements of serial writing, composes in a virtually free rhythmic manner, and employs new instrumental effects in the manner of Bartók; yet his style is a completely individual expression. Leon Kirchner has composed two string quartets, a violin sonata, and a piano trio; unmetrical rhythm is a striking characteristic of his style, along with a variety of harmonies ranging from purely diatonic to atonal, and warm expressiveness is usually present.

Latin-American composers

Among composers representing the countries of Central and South America, three have risen to international prominence. Heitor Villa-Lobos (1887–1959) was the outstanding exponent of Brazilian national idioms, including those of the indigenous Indians. In his many chamber-music works (10 string quartets, several piano trios, and a few sonatas are representative) Villa-Lobos gave expression to those idioms. Carlos Chávez (1899–1978) worked similarly with the idioms of Mexican Indians, but in several of his relatively few chamber-music works, Neoclassical style elements are prominent. Alberto Ginastera (1916–83), representing Argentina, stressed the element of rhythm to a high degree in a style that is thoroughly contemporary.

Structural elements. *Form.* A major distinction must be drawn between the prevailing musical forms of the period before about 1750 and those after that date. The earlier forms included primarily the *sonata da chiesa,* which emerged from the instrumental canzona, and the *sonata da camera,* which owed its origin to the dance suite. In the first of these, the several sections that had been taken over from the canzona were gradually extended, cadences (harmonic devices analogous to punctuation marks in prose) were confined largely to ends of sections, and the single-movement form soon dissolved into a set of movements of varying length, tempo, and metre. Toward the 1640s a tendency arose to standardize the number of movements and regularize the contrasts between them; soon a pattern of four movements arranged in slow–fast–slow–fast sequence, with textures based to a large extent on imitative or fugal writing, emerged. The Italian violinist-composer Arcangelo Corelli, with about 38 *sonate da chiesa,* was the most consistent in employing that pattern after about 1680.

Chamber and church sonatas

The other form, *sonata da camera,* remained less regular. Its parent, the dance suite, had most often contained four movements, but works of three to eight or more movements exist also. When the dance suite adopted the trio-sonata instrumentation and gradually became the *sonata da camera,* it at first maintained that irregularity. Soon, however, it was altered to include a nondance first movement (prelude, preamble, or *intrada*), after which a number of idealized dance forms followed. In keeping with its origin, the *sonata da camera* revealed a relationship to dance rhythms in its several movements (except the first), and homophonic style (*i.e.,* with a single melodic line supported by chords) dominated. The work of Corelli, embodied in 34 *sonate da camera,* again served as a model for later composers.

Toward the end of the 17th century the two forms began mutually to influence each other. The *sonata da chiesa,* with its serious moods set usually in contrapuntal texture (*i.e.,* employing counterpoint, the intertwining of independent melodic lines), adopted some of the lighter and more rhythmic aspects of its rival. Likewise, the *sonata da cam-*

era, light in its total mood and based on dance rhythms, often embodied contrapuntal devices and contained movements that were essentially imitative or fugal in texture and serious in mood. By the end of the 17th century the distinctions between the two types tended to disappear; soon the terms *chiesa* and *camera* were dropped, and the term *sonata a tre* or "trio sonata" prevailed to about 1750. The situation in regard to solo sonatas (for violin and continuo, for example) was similar; they, too, took on common characteristics derived from the contrasting trio-sonata types, and contained both dance metres and contrapuntal textures.

Pattern of the string quartet

The post-1750 forms, on the other hand, were based on different patterns. A standard pattern of a string quartet consisted of four movements, the first of which was most often cast in sonata form—three-part form containing an exposition of two contrasting melodic ideas, a transition (later elaborated to create a "development section"), and a recapitulation of the first part with changed harmonies. The second movement was generally in slow tempo and could represent one of several forms: another sonata form, a set consisting of theme and variations, or the like. Then followed a movement in triple metre (at first a minuet and later a faster version of that dance called a "scherzo") derived from the dance field and consisting actually of two such idealized dances; the second, called a "trio," usually lighter in texture, was followed by a recapitulation of the first dance. The last movement was a rondo (consisting of a regular alternation of two or more musical ideas, in the form A B A B A or A B A C A), or a set of variations, or even another sonata form. The whole represents a compound form called a "sonata," although post-1750 and pre-1750 sonatas have few structural elements in common.

The term sonata (in the post-1750 version) can be applied to most of the forms within the field of chamber music as well as to several outside that field. As seen in the compositions of a line of composers from Haydn in the late 18th century to Brahms in the late 19th and beyond, the piano trio, violin sonata, string quintet, and the others are all based essentially on the pattern that characterizes, above all, the string quartet. Even the symphony and the concerto of the post-1750 period are, in effect, sonatas for orchestra. Internal differences exist, of course; the piano trio and the violin sonata, for example, do not always include a dance-derived third movement, which the string quartet and symphony generally do. Conversely, the exposition of the symphony's first movement often contains more than two contrasting themes, and is often preceded by a massive introduction; and the recapitulation is often followed by a large concluding section or coda (literally, "tail"). Similarly, the first movement of a concerto (for piano and orchestra, say) is generally characterized by two expositions—one for the orchestra, the other for the solo instrument. In most other respects, the majority of the larger instrumental forms of the post-1750 period are closely related in their total structure.

Melody. The years about 1600, marking roughly the date when chamber music emerged as a separate branch, also mark one of the major turning points in the evolution of music. Virtually all the factors of music were affected by the developments of the time. A new system of melodic organization (the tonal system, with its major and minor scales) soon assumed a preeminent position; the principles of harmony were expanded and systematized; a texture based on the polarity between melody and bass (as opposed to one that had been largely the result of writing intertwined and independent melodies) came to the fore; and the figured bass or continuo was invented (albeit, a few decades earlier) to deal with the new texture. In those new developments all the musical factors continued to be mutually related; but they are considered separately here for the sake of clarity.

The melodies of the canzona, or sonata, at first continued to imitate vocal melodies; easily sung intervals, relatively slow tempos, and undulating stepwise contours were characteristic. Gradually composers began to consider the nature of the instruments they were using and to write melodies appropriate to those instruments. Soon the concept of instrumental idioms was developed; each instrument was given melodies appropriate to its structure. That development is seen most clearly in the many trio sonatas written by Corelli after about 1680.

Harmony as a system

With the emergence of systematized harmony, in which specific functions were given to chords according to their relationships to the tonic (the basic, or root, tone of a given scale), melodies became harmonically directed, moved from one harmonic goal to another, and began to take on regular periodic structure (in units of four measures, eight measures, and so on). Slow movements often adopted elements of vocal style, in which sharp contours were avoided, and the melody followed purely musical or aesthetic laws rather than the laws of textual declamation. The ever-increasing use of harmonic dissonance was reflected in melodic writing through the 18th and 19th centuries. Extreme leaps, angular contours, irregular rhythmic shapes—such characteristics became the common property of all composers.

Influence of tonality

Harmony. The complex of chords gradually evolved into the system of tonality. Central to that system is the idea that the triad on the first tone of the scale (*i.e.,* the tonic and the third and fifth intervals above it) determines the key or tonality (C major, D minor, and so on) around which other chords are grouped. Modulations (shifts to other key centres) became regularized: those to the dominant (the fifth note of the scale) and subdominant (an interval of a fifth below, or the fourth note of the scale) became the most important. In the period immediately before and after 1800, especially in the works of Beethoven and Schubert, modulations to the mediant and submediant (an interval of a third above and below the tonic, respectively) became characteristic. And throughout the 19th century, modulation to ever more remote keys was practiced assiduously. Further, chromatic tones—tones not related to the key centre (F sharp or D flat in a C major context, for example)—appeared in increasing numbers; and tones not part of the chord at a given moment (F in a triad on C, for example) were treated more freely. The consequence was a system in which tonality became so ambiguous that it ceased to serve any real function through long passages in the music. Chromatic harmony dominated much music of the late 19th century, and the steps from chromaticism to the atonal and serial systems of the 20th century, in which tonality was entirely abandoned, followed as a matter of course.

Texture. Similarly, the element of texture underwent a series of changes. Much music was composed in homophonic style, with a melody supported only by a few chords built above the continuo. Gradually, especially in the trio sonatas, an inner part came to imitate the upper melody to some extent; bits of figuration gave the two upper melodies a degree of independence, and eventually polyphonic texture, composed of two or more intertwining melodies, was restored. That texture reflected the harmonic developments of the time and came under the control of the tonal system with its dissonances, modulations, chromatic embellishments, and all the rest. Mixed textures, partly homophonic and partly polyphonic, became common also; but in general the uppermost melody dominated the structure well past the middle of the 18th century.

Toward the 1770s, with the string quartet an established grouping, increasing attention was given to the inner and lower parts. Viola and cello were occasionally given thematic material, the violins at times played accompanying parts, and detailed writing for all four instruments compensated for the absence of the continuo. The practice of improvising harmonies at the keyboard came to an end, and all parts were obbligati (that is, obligatory). Continued refinement in the writing and equal distribution of musical responsibility to all four instruments resulted in the so-called quartet style, in which the distinction between melody and accompaniment disappeared and no instrument dominated the others. From that point forward, the idea of a soloist in chamber music lost whatever validity it had had earlier; the performers in a chamber-music work became members of a group of equals.

Style. In style, too, there has been a continuing series

of changes. "Style" may be defined in this context as the sum of the devices—melodic, structural, harmonic, and all the rest—that a composer consistently employs, that a class of works regularly exhibits, or that a particular age finds most useful for its aesthetic purposes.

In this sense, the majority of chamber-music works composed before 1750 are monothematic in style; those after about 1750 are polythematic. The typical fast movement of a trio sonata, say, consists of a series of phrases largely similar in contour and mood and differentiated primarily by harmonic considerations; whereas the typical sonata-form movement is characterized by having two or more themes embodying sharp contrasts of mood and shape, and further contrasted by means of texture, instrumentation, and harmonic colour. Alternation of dramatic and lyric moods, further, is most often characteristic of post-1750 chamber music.

With the emergence of the string quartet and sonata form toward the middle of the 18th century, thematic materials most often took the shape of relatively long melodies—whatever their contour or mood. Those melodies were then manipulated or repeated in accord with harmonic principles and constituted sections in tonic, dominant, and so on. In the 1780s, and specifically in the quartets Opus 33 by Haydn, certain melodies were so constructed that they could, in effect, be broken apart into fragments or motives, each motive with its own distinctive shape. In the appropriate sections of sonata-form movements—namely, those that connected one thematic section with another, and the large transition that comprised the midsection of the form—the motives were treated separately, manipulated, combined in new ways, served to suggest yet other ideas to the composer; in short, they were "developed."

Thematic development

Such treatment of the motives led to the principle of thematic development and to the practice of motive manipulation. Begun by Haydn, carried forward notably by Beethoven and Brahms, and employed by virtually every other instrumental composer of the 19th century, the principle of thematic development is one of the chief distinguishing marks of late Classical and Romantic instrumental music. Beethoven, however, and after him many other major composers, employed the process somewhat differently from Haydn; he often began with a melodic or rhythmic motive, then let the themes themselves grow out of the motive manipulation.

The repertory of works for piano and strings also grew considerably from the late 18th century onward, and there was considerable modification in the role of the piano in that repertory. The keyboard instrument had entered the field, it will be remembered, after having played a century-long role as the improvising member of the continuo team, in which it provided accompaniments to the other instruments. When it emerged in its new role with written-out parts to play, it at first assumed a dominant position—in violin or cello sonatas and in piano trios alike. Many of the piano trios by Haydn are essentially sonatas for solo piano with accompaniments furnished by violin and cello; the latter often do little more than double the parts given to the pianist's right and left hands, respectively.

Evolution of role of piano

Gradually the string parts acquired a degree of independence and became obbligato parts. The final steps toward complete equality were taken across the interval from about 1790 to 1840, especially in the piano trios and quartets of Mozart and Beethoven and in Schumann's *Piano Quintet,* Opus 44 of 1842. In many of those works, particularly the later ones, the piano emerged as one-half of the tonal body with the two, three, or four stringed instruments providing the other half. Again, as in the string quartets, the concept of soloist versus accompanist has no validity in chamber music with piano. A keyboard player does not "accompany" the strings; he is an equal partner in the ensemble—which marks a major change from the role he played in the 17th and the first half of the 18th centuries.

Chamber music in the later 19th century became ever more affected by developments in the orchestral field. The rise of professional quartets in the time of Beethoven had the effect of moving chamber music from the confines of the home to the public concert stage. Composers took advantage of the virtuosic attainments of the best performers and wrote music with which the nonprofessional performer could not always cope. Effects requiring consummate technical ability became common; true virtuosity became a general requirement. Further, orchestral effects depending upon sheer volume of sound were often employed; the string quartets and piano trio of Tchaikovsky are examples. And with the rise of descriptive or program music in the orchestral field, extramusical or nationalistic elements sometimes entered chamber-music works; Smetana's autobiographical string quartet, *Z mého života* (*From My Life*), and certain of Dvořák's compositions containing Czech folk idioms and representing the Czech spirit are typical.

The overwhelming majority of chamber music composed before about 1900 consists of works that employ instruments in conventional ways. Tones are limited to the pitches in the chromatic scale (*i.e.,* a scale consisting of half steps, C, C sharp, D, D sharp, E, and so through all 12 tones), stringed instruments are used in the traditional manner, and the piano likewise. A few notable exceptions may be mentioned: in the *Piano Trio No. 1 in D Minor,* Opus 63, by Schumann the strings play a short passage *sul ponticello* ("against the bridge")—that is, play closer to the bridge of the instruments than usual in order to produce the higher overtones and give the pitches an ethereal or veiled quality; in the same composer's *Piano Quartet in E Flat Major,* Opus 47, the cello must retune its lowest string downward a whole step in order to supply a longheld tone beyond the normal range of the instrument. And, in a few works of the time, harmonics are called for: a string is touched lightly at its midpoint or at one of the other nodal positions at one-third or one-quarter of its length, and the harmonic (overtone) thus produced adds a distinctive quality to the music. Such effects, plus the traditional pizzicato (in which the string is plucked rather than set in motion by the bow) are virtually the only exceptions to normal writing.

In 20th-century chamber music, however, the number of purely instrumental effects has been increased; the Hungarian composer Béla Bartók in several of his quartets became the leading exponent of such devices. In his *String Quartet No. 4* (1928), for example, glissandi are required; in such cases the player slides his finger up or down the string to cover the span of an octave or more, and produces a wailing effect. Pizzicati are directed to be performed so that the string slaps back against the fingerboard, to add a percussive effect to the pitch. In works by other composers employing the clarinet, the performer is required to blow through the instrument with its mounthpiece removed while opening and closing the keys at random; this produces the effect of a high-pitched whistling wind along with a semblance of pitch changes. Or again, in the case of brass instruments, the composer's directives call for the player to tap his hand against the mouthpiece, to create a hollow percussive sound.

Pitches themselves are altered on occasion, for tones lying between those of the chromatic scale are sometimes employed; among early exponents of the quarter-tone practice, the contemporary composer Ernest Bloch may be mentioned. In his *Piano Quintet,* and elsewhere, the string performers are required to play certain tones a quarter step higher or lower than written, thereby departing from the scales that had served music for many centuries. Other composers carried the quarter-tone practice further and developed a kind of microtonal music that employs intervals even smaller than quarter-tones.

Use of quarter-tones

All such developments give evidence that 20th-century composers continue to seek new means of expression and expand their available resources—thus continuing a practice characteristic of composers in all periods. Two further aspects of that search remain to be considered: the development of new systems of tonal organization and the increasing use of instruments that embody the results of contemporary technology.

Early in the 20th century a number of composers led by Arnold Schoenberg experimented to reach beyond the confines of the tonal system. In a series of chamber music and other works, Schoenberg gradually arrived at a system

in which all 12 tones of the chromatic scale are used as independent entities; concepts of tonic and dominant, of major and minor, and of key centres themselves no longer apply in those works. The 12 tones are arranged in a self-determined series called a "tone row"; certain sections of that row, used vertically, form the chords that supply the harmonic material; the row may be manipulated in accord with self-imposed rules; and the row may be arranged differently for each composition. The system of composing with 12 tones, as Schoenberg referred to his invention, has been modified and enlarged by later composers, the relevant principles have been applied to other elements of music (notably the rhythmic factor); and under a new term, "serial composition," the system has become one of the most influential of the present day.

Electronic synthesizers

The other aspect concerns the use of various electronic sound-generating devices called "electronic synthesizers," and of magnetic tape recorders to transmit the results. The composer working with a synthesizer has virtually complete control over the shape and sound of the tones he wishes to produce. He can select tones with characteristics unlike those produced by conventional instruments, noises (that is, sounds with irregular vibration rates) to which a semblance of pitch has been given, or rapid changes in pitch, loudness, duration, and quality beyond the ability of any human mechanism. The new tonal materials, then, can be combined with voices and conventional instruments, or can be used alone. Devices such as the synthesizer have given the composer access to a new world of tonal resources; he still faces the problems of selection, combination, organization, and expressive purpose that have plagued composers since music began. Since his medium of performance is a tape recorder, since human participation in the performance may not be required, and since his composition may contain a few strands or a hundred strands of tone, it becomes impossible to make distinctions between chamber music, orchestral music, or any other genre. Electronic music is, thus, on the way to becoming a completely new type to which traditional classifications do not apply (see below *Electronic music*).

Audiences. For well over a century after its inception about 1600, chamber music was supported primarily by the nobility. Aristocratic establishments customarily employed groups of musicians who served as composers, conductors, and performers of a variety of operatic, orchestral, and chamber music; and traditionally the audiences were restricted to the patrons and their guests. Chamber-music concerts were instituted in London in 1672, and seem to have been exceptional for their time, for regularly established professional chamber-music groups did not emerge until about 1810, apparently first in Vienna.

Meanwhile, primarily at certain German university towns in the 1700s, the establishment of collegia musica (music societies) marked the beginning of a movement that brought nonprofessional participation in its wake. Eminent musicians directed those societies in many cases; the Collegium Musicum at Leipzig, for example, was founded by Georg Philipp Telemann and had Bach as its director for a decade after 1729. Audiences were at first restricted to university students; later the general public was admitted, and the rise of the modern chamber-music audience began.

Famous quartets

Since the mid-19th century, chamber-music concerts have been a staple of musical life. Many of the best known string quartets (for example, the Joachim Quartet from 1869 to 1907, the Kneisel from 1885 to 1917, the Flonzaley from 1902 to about 1928, the London from 1908 to 1935, the Budapest from 1918 to 1968, and the Juilliard, Paganini, Amadeus, and Fine Arts quartets of the present day) have travelled to countries around the world performing the standard and contemporary repertories of their day.

Parallel to this has been the continuing activity of informal, nonprofessional groups in virtually all musical centres of the Western world. An international association of amateur chamber-music players exists, whose members grade themselves (in a directory) according to technical ability and experience. The colleges and universities of the United States often stress ensemble activity in their music curricula, and many schools of music are centres of activity in the field.

The sheer amount of music being composed makes it virtually inevitable that chamber music will continue to receive the attention of major composers—especially in view of the economic factors that make performance of new orchestral works hazardous at best. One may hope that chamber music will play as vital and significant a role in the future as it has played in the last three and a half centuries. (H.U.)

FUGUE

Although the statement is debatable, it is often said that the fugue is the most complex and highly developed type of composition in Western music. The term fugue, derived from *fuga*, the Latin word for "flight," was first used about 1330 by Jacques de Liège, the author of *Speculum musicae*, an important medieval treatise. At that time it referred to a technique of musical writing based on strict imitation. Later, after its emergence as an independent musical form in the 17th century, the fugue became a composition in counterpoint based on a generating theme, in which different parts, or voices, enter successively in imitation, as if in pursuit of each other. The heir of all the compositional techniques that had developed earlier, it differs from its ancestors (the motet, the ricercare, the canzona) in having a more specifically tonal character, unity of form, and a greater economy.

The fugue is written in counterpoint, two or more lines that sound simultaneously. Counterpoint's laws and techniques have developed from the 10th century to the Renaissance, a period during which Western music was essentially polyphonic. One of the main problems was the harmonic aspect of the meeting of the voices, and the rules of counterpoint are always precise regarding the use of consonance and dissonance. Counterpoint deals also with movement between the parts. It includes various techniques of development, among which imitation is probably the most remarkable feature of polyphonic music. There are many kinds of imitations. The strictest is the canon, in which the melody stated by the first voice is later reproduced by the second voice. A good example is the song "Frère Jacques." Other common types of imitation include inversion of all the intervals, augmentation (in which the rhythmic values are doubled), diminution (in which they are reduced), or even retrograde imitation, in which the last note of one voice becomes the first note of the next. All these techniques are used in fugal composition, which is characterized more by its "language" than by its form.

Types of imitation

Elements of the fugue. The fugue is written for a certain number of voices, or instrumental parts. The most frequent are fugues for three or four voices, but there are also fugues for two, five, or more voices. Although the fugal form varies from composer to composer, there are certain common elements.

The subject is the theme of the fugue. It is stated alone by the first voice before being taken up by the others. In the course of the fugue, it will be stated in different keys, and it will be sometimes slightly modified or inverted. Some of its elements may be developed separately.

The second voice brings in the answer, generally stated in the key of the dominant (the fifth degree of the major or minor scale). If it reproduces the subject exactly, it is called a real answer. But in most cases, in order to preserve the tonal unity of the fugue, the answer has to undergo a "mutation" that alters some of its melodic intervals and makes the modulation to the dominant key smoother. This is called the tonal answer.

The countersubject accompanies the answer. If it is maintained throughout the fugue, it is called sustained or obbligato countersubject and will follow the subject like its shadow for each new statement. Subject and countersubject are the two principal "actors" of the fugue, and theoretically all the musical substance must be derived from them.

The first part of the fugue, which includes the successive entrance of the voices, in subject–answer alternation, is called exposition. This progressive enrichment of the

polyphonic web is one of the most striking traits of the fugue. In some fugues, after the exposition, the composer brings in the answer followed by the subject. This is called counterexposition.

An episode is any passage, developed or not, that links two statements of the subject. It is characteristically written in imitative style. Generally it uses a motive from the subject or the countersubject, but sometimes a new element is introduced. There is a great variety of episodes.

When the subject overlaps the answer (or the answer the subject), it is called a stretto. This device, whereby the entries are drawn more closely together, is often used at the end of the fugue, where it achieves spectacular effects.

Once past the exposition, the plan of the fugue depends on the will of the composer and the resources of its thematic elements. For instance, the Danish composer Dietrich Buxtehude often presents the subject and the answer only in the principal and dominant keys, in short expositions linked by small episodes. With J.S. Bach, the tonal plan becomes more elaborate and includes a journey to the principal neighbouring keys. Since the composer adapts his plan to the character and to the potential of his themes, the itinerary is always different. That is why in his hands the fugue becomes the most versatile of musical forms; each fugue of Bach brings a new solution to the problem of the relation between form and content.

Versatility of the fugue

Theorists created an ideal plan of the fugue and gradually perfected it, in the 19th century, as fewer and fewer real fugues were being written. They devised a tripartite form consisting of the exposition, the development, and the stretto.

Varieties of fugue. The simple fugue is monothematic, without a maintained countersubject (such as the *Fugue in D Major* of Bach's work *The Well-Tempered Clavier,* Book I, No. 5). More elaborate fugues use one or more countersubjects. In a counterfugue, the answer imitates the subject by inversion. There are beautiful examples of this technique in Bach's work *The Art of the Fugue,* numbers 5 to 7.

There are two ways of writing a double fugue; either the two subjects may be presented simultaneously, in which case the fugue is not very different from a fugue with countersubject (Bach, *Fugue in B Minor on a Theme of Corelli,* BWV 579), or else the second subject has a special exposition. The latter yields, in general, a tripartite scheme: exposition and development of the first subject, exposition and development of the second subject, and finally combination of the two elements, which are devised so that they can be superimposed. A splendid example is given by Bach's *Toccata and Fugue in F Major* for organ, BWV 540. The same principles apply to a triple or quadruple fugue.

The fughetta is a miniature fugue but strictly written, whereas the fugato starts like a fugue but gives up its discipline once past the exposition.

The choral fugue plays a considerable role in works for chorus and orchestra. Generally the chorus sings in strict counterpoint, while the instruments play an expressive or decorative accompaniment. The composition techniques of the fugue can also be used in forms as universal as the prelude, the aria, the chorus, the overture, the concerto, and others.

Literature of the fugue. Since vocal polyphony was based on a text that had to be sung by each of the parts (either simultaneously or, more frequently, in imitation), it was not very much concerned with the problem of form. That is why theorists and musicians concentrated on questions of texture.

At first the term *fuga* applied to strict imitations (which would now be called canons); the concept evolved in a more general sense when it was realized that a freer use of all kinds of imitations offered much more stimulating opportunities. Besides the purely vocal polyphony, the first independent forms of keyboard music (the ricercar, the canzona, the capriccio, the fantasia) testify to the remarkable development of what can be called the fugal style of the 16th and 17th centuries. In this evolution, the role of the Italian composer Andrea Gabrieli and of the English virginalists was preponderant. The two great precursors of the fugue proper were the Dutch composer J.P. Sweelinck and the Italian composer Girolamo Frescobaldi. Both greatly influenced the keyboard music of the 17th century, in particular through their students Samuel Scheidt and Johann Jakob Froberger. In Germany, a generation of musicians dominated by Buxtehude gave the fugue its modern form by putting it in a tonal perspective and abandoning the fragmentary style of their predecessors. Almost all the composers of the 17th century contributed to the history of the fugue.

The genius of J.S. Bach found particular expression in the fugue, perhaps because it allies the strictest economy of language to a relative freedom of form. Each of his fugues amazes by the freshness of its inspiration, the wonders of its writing, or by its gigantic proportions, all marvellously represented in the two volumes of *The Well-Tempered Clavier* (1722–44), two sets of 24 preludes and fugues going through the cycle of the 24 major and minor keys. Some of his organ fugues tend toward development, some toward symmetry, and some toward virtuosity; others take the form of double fugues.

His last work, *The Art of the Fugue,* is a collection of 14 fugues and four canons, all based on a theme in D minor and its inversion. All the resources and procedures of the fugue are demonstrated in what constitutes the most inspiring treatise on fugue, a treatise without words, in which music speaks alone. After being long slighted as a purely theoretical work, *The Art of the Fugue* has won a high place in the hearts of music lovers, who see it as Bach's musical testament. Bach's cantatas, passions, and oratorios abound in admirable fugues.

Bach's *Art of the Fugue*

Handel's fugues are less erudite than those of Bach and sometimes employ looser counterpoint, but they touch the listener by their vitality and their harmonious proportions. The great fugal sections of his oratorios are more important than his keyboard fugues.

After Bach the fugue lost much of its importance. With the appearance of the sonata, the musical taste changed, and composers tended to consider counterpoint as an archaic discipline. Nonetheless, the fugue retained a place in choral works, and fugal methods were kept in the sonata form, particularly in the development section.

A great passion for the music of Bach led Mozart to a more contrapuntal style. This influence is obvious in the *Fugue in C Minor,* for two pianos, K. 426, which, though pure Mozart, is nonetheless a homage to Bach. In ingenuity and mastery, Mozart rivalled the greatest contrapuntists in, for instance, the great choruses of the *Mass in C Minor,* K. 427, or in the final development of the *Jupiter Symphony.*

Beethoven resorted more and more to fugal technique in his last works. He confessed that he wrote his fugues with the greatest difficulty, and it is true that his counterpoint gives an impression of effort. Most of the fugal passages integrated into his last sonatas and quartets create a dramatic tension. Far from being a scholastic technique, the fugue was for Beethoven a means to reach the expressive limits of an idea. He used this language in particular circumstances. The strange and desolate atmosphere of the opening fugue of the *String Quartet in C Sharp Minor,* Opus 131, brings to mind the 20th-century fugue in the first section of the *Music for Strings, Percussion and Celesta* of Béla Bartók. The Promethean side of Beethoven asserts itself particularly in the *Great Fugue* from the *String Quartet in B Flat Major,* Opus 130, and the noble fugal section of the *Missa Solemnis.* Unlike Mozart's classical fugues, Beethoven's are rather irrational in form but are justified by their creative power alone.

Compared with the fugues of Beethoven, those of Felix Mendelssohn defer to traditional rules. Critics sense in them a nostalgia for Bach, sometimes weakened by a touch of sentimentalism. A more authentic romantic breath animates the fugues of Robert Schumann on B.A.C.H. (the German letters for the notes B♭–A–C–B♮), but the fugue is not his natural language. The genre is more suited to César Franck, as may be seen in his *Prélude, fugue et variation,* or in his *Prélude, chorale et fugue.* His harmonic sensitivity enriches a contrapuntal technique while not breaking with tradition. The fugues of Franz Liszt are

entirely different: once past the exposition, he cannot renounce symphonic developments. There is an original use of the fugato before the re-exposition in his *Piano Sonata in B Minor.* The fugal style was used to varying degree by the major composers of the 19th century, including Brahms in his *German Requiem,* Richard Wagner in his opera *Die Meistersinger,* and Verdi in his *Requiem* and at the end of his last opera, *Falstaff.*

Among the post-Romantics, who cultivated their own exaggerated form of counterpoint, mention must be made of Max Reger, whose admirers took him as the heir of J.S. Bach. Though that appears to be going too far, his counterpoint does possess vitality in works such as the *Variations and Fugue on a Theme by Mozart,* for orchestra, or the fugue on the chorale melody "Wachet auf, ruft uns die Stimme," for organ.

Bartók's use of fugue

As an autonomous form, the fugue played only a modest role in the first half of the 20th century. The most beautiful example is the already mentioned fugue of the *Music for Strings, Percussion and Celesta* of Béla Bartók, a born contrapuntist. This is a true model of fugal treatment in a post-tonal style. The methods of the fugue are also found in his *Sonata for Two Pianos and Percussion* and in his admirable quartets.

Stravinsky, though influenced by the composers of the 17th and 18th centuries, showed no particular interest in the fugue. Although the second part of his *Symphony of Psalms* can be considered a double fugue, it does not strike the listener as such.

In his collection of interludes and fugues, called *Ludus Tonalis,* Paul Hindemith seems to have drawn his inspiration from Bach's *Well-Tempered Clavier.* Although an interesting work, it did not herald a rebirth of the fugue. A new conception of counterpoint appeared in the works of Arnold Schoenberg and Anton von Webern. The serial techniques of composers like Pierre Boulez can, to a certain extent, claim some kind of kinship with fugal language, and a work such as the *Passion According to St. Luke* of Krzysztof Penderecki testifies to the permanence of a musical form the history of which is probably unfinished.

(L.A.R.)

SYMPHONY

The term symphony (literally, "sounding together"), though it has many meanings in musical literature, is commonly understood to refer to a lengthy composition for orchestra, often employing a sonata form (see below) in one or more large sections called "movements." Symphonies of this sort began to be composed during the so-called Classical era in European music history, *c.* 1740–1820 (the early part of this period and the decade immediately preceding it are sometimes called pre-Classical, as are the symphonies written before about 1750). During the 19th century, which included the Romantic era, symphonies grew longer, and composers concerned themselves with ways of unifying the movements; extramusical programs and new approaches toward tonality (the major–minor system of chord progressions) were among the solutions to the problems of large-scale symphonic form. Late in the century, symphonies—and orchestras—had grown to such an extent that reaction set in, culminating in the Neoclassical movement of the early 20th century, in which composers turned again toward principles of balance and formal discipline, using new techniques to achieve dynamic coherence. Economic considerations forced a reduction in the size of orchestras and amount of rehearsal time available to mid-20th-century composers, further justifying a return to less extravagant symphonic thinking. But throughout the 19th century a number of outstanding symphonists were able to reconcile the demands of fashion with strict musical logic: these composers represent the mainstream of symphonic activity, and their works remain models for much 20th-century activity in the genre. Throughout the following section two concerns predominate: a survey of the chief symphonic works and composers and consideration of the evolution of symphonic thought.

The concept of symphony before c. 1750. The word *symphōnia* was used by the Greeks in reference to notes sounding together in harmony and by extension meant an "ensemble" or "band" rather than a musical form. The word implies a pleasant concord of different notes and has been used in fields other than music to denote a pleasing combination of various elements. In the New Testament Gospel According to Luke (King James Version), *symphōnia* is translated as "musick," as distinct from *choroi,* "dancing." In the Middle Ages the name was given to several musical instruments, among them a double-headed drum, bowed stringed instruments, a large hurdy-gurdy, and bagpipes. Mention is made in 1582 of *eine Symphonie,* evidently a stringed keyboard instrument.

Vocal and instrumental works

From the mid-16th century, symphonia (and related spellings) is a term often found in titles in which it simply indicated ensemble music, whether for instruments with voices or either alone. A collection of madrigals published in Antwerp in 1585 is entitled *Symphonia angelica . . . raccolta per Huberto Waelrant.* Later notable examples are the *Sacrae symphoniae* of the Venetian composer Giovanni Gabrieli (Book I, 1597; Book II, 1615), collections of elaborate vocal and instrumental music, often for multiple choirs; and the *Symphoniae sacrae* of his celebrated German pupil, Heinrich Schütz (1629, 1647, 1650). Schütz's collection reveals his debt to the colourful and brilliantly orchestrated Italian style in works ranging from several voices to large polychoral compositions with solo parts and instruments. His countryman Samuel Scheidt's 70 *Symphonien auff Concerten-Manir* (1644) likewise combine instrumental and vocal ensembles to enrich the texture and heighten the drama of his music.

Symphonies for instruments alone during the early Baroque era (*c.* 1600–30) occur as independent pieces and as introductions or interludes in theatrical productions. The Italian Biagio Marini's Sinfonia *"La Orlandia"* (1617) is a duet for violin or cornetto (a wind instrument with finger holes and cup-shaped mouthpiece) and continuo in five brief contiguous sections, distinguished by contrasting metres and new melodic material in each section. (The continuo is a harmonic accompaniment improvised over the written bass line, usually played on a keyboard instrument and a bass viol or other bass melody instrument.) Early operas often include instrumental symphonies. Jacopo Peri's *Euridice* (first performed 1600) includes a sinfonia for three flutes; Claudio Monteverdi's lavish musical drama *Orfeo* (1607) is punctuated with five richly scored sinfonias, while a *sinfonia da guerra* ("sinfonia of war") accompanies a staged battle in his *Il ritorno d'Ulisse in patria* (*The Return of Ulysses to his Country*; 1641). Each act of Stefano Landi's opera *Il Sant' Alessio* (1632) opens with a sectional sinfonia. Many other opera and oratorio composers used short descriptive or introductory sinfonias, often of sectional form with contrasting metres and tempos.

Characteristics of Italian and French overtures

It remained for a Neapolitan, Alessandro Scarlatti (1660–1725), to formalize the overture to his operas as a fast–slow–fast *sinfonia avanti l'opera,* as in his opera *Dal male il bene* (*Good from Evil*; 1681). The so-called Italian overture of this and later works, scored for strings and continuo, has been widely considered to contain the germ of the later three-movement symphony. In contrast with the more contrapuntal French overture, which begins with a pompous slow movement and continues in a fugal section (involving imitation of a melody among several voices), the Italian style is immediately tuneful and predominantly homophonic (chordal) in texture. The first fast movement may be trivial; its symmetrical phrasing is unexpressive. The contrasting second movement may be more lyrical, perhaps anticipating tunes heard later in the opera. The last movement, sometimes a minuet, is an exuberant curtain raiser. This format spread quickly outside Italy, even to France. Jean-Philippe Rameau's *Zoroastre* (1749), for example, includes such a fast–slow–fast overture. Rameau, indeed, was considered an exponent of the Italian style, particularly in his lucid harmonic treatment. This late-Baroque concern with tonal clarity prefigured the attitudes of early Classical symphonists. Among the devices used to assure clarity are melodies constructed of arpeggiated ("harplike," or broken) chords and passages in unison or in parallel thirds or sixths (sequences of harmonies formed

by thirds, such as C–E or D–F, or sixths, such as C–A or D–B). These features are not common in Baroque music that is strictly contrapuntal (based on interwoven melodic lines) in texture.

While the opera overture settled into a form that eventually inspired early symphonists, the term sinfonia, or symphony, as yet had no formal definition. As late as 1771 *Encyclopædia Britannica,* reflecting ancient Greek usage, defined symphony merely as ". . . a consonance or concert of several sounds agreeable to the ear, whether vocal or instrumental, called also harmony." Sinfonia was used interchangeably with concerto, consort, overture, suite, and so on. Commonly a brief instrumental interlude, as in a song, was called a symphony, even into the 19th century. In the late Baroque era (*c.* 1700–50) the term was applied to such dissimilar pieces as J.S. Bach's didactic *Three-Part Inventions* for keyboard, called *Sinfonien* in the 1723 copy, and the orchestral "Pastoral Symphony," a quasi-descriptive interlude in Handel's *Messiah* (composed 1741), said to have been based on an Italian shepherd bagpipe tune and very much in the tradition of earlier descriptive symphonies in opera.

Bach's *Sinfonia VII in E minor* and *Sinfonia XI in G minor* are interesting in that in each piece the opening material recurs at the end. In *VII* this repetition is merely suggested, but in *XI* the last eight measures of the piece virtually duplicate the first eight. The whole intermediate body of these pieces develops the motivic material presented at the beginning, and the initial material is transformed contrapuntally and harmonically. In the closing bars the tension thus aroused resolves and the rhythmic drive reins in. This suggestion of an expository unit moving from the home key to a different key, followed by an extended development that explores still more remote keys and the motivic and contrapuntal implications of the beginning, concluding with a recapitulation in which the energy of the development is somewhat dissipated by a return to the opening material, prefigures the sonata form of the Classical symphonists. Bach uses this technique in some of his instrumental concerto movements; the concertos have other elements in common with early symphonies, especially in the mood of their lyric slow movements and fast duple-metre finales.

Exploitation of key relationships

The word sinfonia was applied to a trio sonata for flute, oboe, and continuo in Johann Joseph Fux's *Concentus Musico-instrumentalis* (1701), a collection of suites each comprising a number (as many as 15) of bipartite (two-section) dances and descriptive pieces. An intellectual and influential Viennese court composer, Fux departed in this sinfonia from the typical 17th-century suite, which is merely a collection of contrasting dances in the same key. The work falls into two major divisions, both comprising three short movements; the key scheme is F major, D minor, F major—F major, D minor, F major, and the last three movements have programmatic titles. Here is not merely a collection of various dances but a conscious attempt to relate movements tonally and thereby create larger hierarchic units. F major and D minor are closely related keys, and it would not be possible to omit a single movement without destroying the symmetry of the whole (not that either group of three, or even each dance, does not sound good by itself). By means of this simple, balanced harmonic structuring Fux advanced beyond the looser architecture of the typical suite; and by framing a minor-key movement between two movements in the same related major key he anticipated the overall form of many early symphonies.

Importance of tonal harmony

Both Fux and Bach were products of the evolution of tonal harmony, a system of key relations which brought with it the possibility of basing large-scale forms not only on melodic variation or counterpoint, as earlier, but on harmonic tension and modulation. (Modulation, unlike simple change of key, implies the establishment of a new tonic, or tonal centre, by means of progression through a number of related keys.) The wide-ranging modulations and affective harmonic progressions of German Baroque composers depended on equal temperament, a system that permits exploration of keys distant from the tonic without the necessity of retuning to accommodate the remote harmonies. Bach exploited this system to the utmost, as did many of his North German contemporaries; but their rich harmonic palette was foreign to the south, where many important symphonists arose. Concerned less with powerful emotions (*Affekten*) and more with clarity, the southerners avoided intricate counterpoint and convoluted harmonic progressions, preferring a restricted chord vocabulary and clear-cut symmetrical phrasing dominated by tuneful melody.

Besides the suite and opera overture, the short humorous intermezzo, which originated in Naples and flourished *c.* 1685–1750, strongly influenced pre-Classical symphonists. Neapolitan composers, headed by Alessandro Scarlatti, concerned themselves in the intermezzo with dramatic, comic interplay between two singers in two or three short acts made up of arias, recitatives, and duets. Because the texts demanded clear articulation and careful declamation, they influenced the melodic phrase structure, giving rise to repeated-note figures and brief rhythmic or melodic motives. These phrases normally fall into two-measure units. Counterpoint was abandoned, for it tended to obscure the text; and harmonies became simple and slow-moving. Intermezzo melodies abound in ornaments, sudden accents, syncopation (displaced accents), and playful leaps reflecting the text declamation and lack the broad, spunout arch and driving rhythm of typical Baroque melodies. Rather, they are made up of short motives joined one to another and give rise to frequently articulated phrase groups. This word-derived idiom furnished the melodic impulse of the early symphonies.

The symphony proper. *Early Classical period.* Chord-generated melodies (those arising from arpeggiated triads) abound in 18th-century symphonies, among which a number of stereotyped "theme families" can be distinguished. These furnished raw material for further development. In fact, a composer's originality found expression not so much in his original theme as in his realization of the implications of the theme later in the composition. Certain tunes are by nature not highly implicative; they are perfect closed units that cannot be easily developed and so are superficially inappropriate for symphonic use. Such, for example, are many folk tunes; and this explains why great symphonists rarely use folk tunes without at least distorting them so as to open them to development. On the other hand, motivic melodies, such as those in the intermezzi, coupled with slow harmonic motion, lend themselves well to fragmentation, recombination, extension, elision, reharmonization, and other developmental techniques. By the 1740s, Italian symphonists had learned to sustain interest by these means and to obtain contrast by dramatically apposing tunes of different character in different keys (usually the tonic, or home key, and the dominant, located five tones above the tonic, or related major or minor keys).

Early uses of sonata form

Among Italians influenced by these factors was Tomaso Albinoni (significantly, a composer of 48 operas). The third movement of his *Sinfonia in D Major,* fifth of the *Sei sinfonie a quattro* (1735), displays a simple sonata form (also known as "first movement form," though not so limited). Sonata form, crucial in the symphony's evolution, is based on the dramatic apposition and eventual reconciliation of contrasting keys. In essence it consists of an exposition in which one or more themes are presented, the first (often forceful in character) in the tonic key and the second (often lyric) in the dominant. Sometimes a third, closing theme follows in the dominant. The two key areas contrast not only harmonically and melodically but often in instrumentation, loudness, and texture. So-called monothematic sonata movements lack a contrasting second melody; indeed, it is not so much the character of the tunes but the dynamism of the opposed key areas that is essential to the dramatic structure. The transition between tonic and dominant areas was to become a focus of interest to later composers, but in early symphonies the transitions were brief and simple.

The exposition, often marked to be repeated, comes to a close on a key other than the tonic (usually the dominant) and is followed by a development section, beginning on the dominant, in which themes previously heard are re-

harmonized, fragmented, or otherwise reshaped. Again it is not melodies so much as harmonies that arouse tension in the development. The composer confronts the problem of returning to the tonic via more distant chords, and this is sometimes accomplished by modulations that bear no thematic relation to the exposition. In early symphonies this process is only tentatively exploited, and developments are brief, sometimes involving merely transposition of the original first theme to a new key. Later the development assumed the character of the meat in the sandwich, as it were.

Following the development comes a recapitulation of the exposition, this time all in the tonic key (before *c.* 1770 the recapitulation sometimes retained the key scheme of the exposition, except for the closing bars), resolving the harmonic tension of the development. The recapitulation may be simply a virtual repetition of the exposition, with appropriate key changes, or may be truncated, expanded, or otherwise varied so as to continue developmental processes. Many early symphonies take advantage of the implications of a varied recapitulation, literal repetition being abhorrent to imaginative composers. It will be observed that when both themes appear recapitulated in the tonic, the function of the transition between themes differs from that in the exposition, in which it leads from one key to another. After the 1750s, however, the first theme was often omitted in the recapitulation. Obviously, the recapitulation's tonal scheme allows extended treatment of the tonic, but sometimes a coda (tail) is added after the recapitulation to consolidate further the focal nature of the tonic.

It is important to understand that sonata form was subject to great variation and deviation from "textbook" norms throughout the symphony's history. Ideas of a "typical" sonata form did not evolve until *c.* 1830. Nevertheless, the vocabulary of exposition, development, recapitulation, transition, and so on is capable of wide application and will simplify the remainder of the present section.

Albinoni's *Sinfonia in D Major* as a whole is forward-looking. The orchestra lacks a continuo, harmonic orientation replaces counterpoint, and the movements are of larger scale than typical Baroque dance movements. The central minuet-and-trio movement, surprisingly modern-sounding, contrasts lightheartedly with the sonata form. Minuets and song-form movements relieve the dramatic tension of sonata movements; and from this time on minuets appeared frequently in symphonies. Gradually losing dance character, they moved from the last or middle position to penultimate place when, later, a fast fourth movement appeared as finale.

The symphonies of Sammartini

A leading early symphonist, the Italian Giovanni Battista Sammartini, is known from some 77 extant symphonies, some of them available in modern editions. A prolific composer of instrumental chamber music, his use of incipient sonata form, restricted harmonic vocabulary, and motivic, not highly ornamented melodies pointed to the future. Though dependent on Baroque models for inspiration during his first period of activity (to *c.* 1740), he had abandoned the continuo by about 1760, filling the harmony instead with horns or trumpets—which, however, were restricted in their ability to play in certain keys and therefore operated to constrict the available harmonic vocabulary. More than many contemporaries, Sammartini infused inner parts with contrapuntal life, especially in earlier works, although he rarely used extended imitation. His rhythmic energy was appreciated by operawriting contemporaries, from whom (especially the Italians Niccolò Jommelli and Rinaldo di Capua) he perhaps drew inspiration for the long, expressive cantabile (singing) phrases that, along with a firm grasp of modulation, characterize his later works. His slow movements are especially rich. Another late characteristic is the extended role of wind instruments, which are given independent, idiomatic parts. Sammartini wrote for oboes, flutes, and bassoons among the woodwinds (bassoons doubling the bass line); clarinets were also in use at this time, usually interchangeably with oboes. Significantly, Mozart heard Sammartini's music during a visit to Milan.

A third Italian, Padre Giovanni Battista Martini, renowned as a teacher and music historian, left 24 symphonies dating roughly between 1736 and 1777. There is remarkable consistency among this corpus. All but one are in the then-normal three movements (Sammartini wrote a number in four), and all have outer movements in a major key, whereas the middle slow movements are nearly always minor. Music of the Classical period greatly favours major keys; according to one investigator all but about 2 percent of 18th-century symphonies are major (excepting their expressive slow movements). Martini, although trained in counterpoint, avoided it in these works, favouring instead a treble-dominated texture over a simple, slow-moving bass. His chord vocabulary was restricted, his orchestration elementary. His melodies reflect a number of banal formulas in current use, but his manipulation and development of these formulas was skillful. Mozart visited Martini several times in Bologna in 1770.

In the hands of these and other Italian composers, symphonic style evolved considerably by 1740, and there was continued fruitful experimentation through the 1750s. That Italians influenced contemporary and later German and, especially, Austrian symphonists cannot be doubted; but the extent of indebtedness and mutual influence cannot now be fully determined because of the scarcity of available scores. Relatively few of the surviving early symphonies have appeared in reliable modern editions, and those known to survive in manuscript represent but a fraction of the thousands composed. The early history of the symphony remains, therefore, a matter of speculation and debate, despite the enormous progress in research and publication in the mid-20th century.

The Mannheim composers

Germany and Austria were important centres of symphonic composition after about 1740. In Mannheim, Germany, the Bohemian Johann Wenzel Stamitz developed a remarkably well-trained orchestra that by 1756 comprised (in addition to 30 strings) four horns, pairs of flutes, oboes, clarinets, bassoons, trumpets, and timpani. With this ensemble, independent wind writing and creative orchestration flourished. Stamitz—himself a violinist and composer of more than 70 symphonies, chiefly mature works—and his contemporary Ignaz Holzbauer evolved a bold style born of the confluence of Italian melody and German seriousness. Counterpoint is abandoned; expression arises from orchestral crescendos and diminuendos (anticipated by Jommelli), characteristic melodic effects such as sighing appoggiaturas (falling figures) and rocketing arpeggiated (broken) chords, and strong dynamic, thematic, and textural contrasts. This style degenerated into mannerism with Stamitz's son Karl (composer of about 80 symphonies) and Johann Christian Cannabich, who enlarged the Mannheim orchestra.

Mannheimers paid special attention to their development sections, which have been described as a "mosaic of fragments." They tended toward incomplete recapitulations, wrote tender slow movements, extended the number of movements to four: allegro (lively), andante (slow), minuet, and presto (rapid). Insisting on disciplined and precise performance, they wrote all parts out in full instead of leaving some to be realized by the players. With the rise of independent wind parts after *c.* 1770, the continuo became redundant and was abandoned; in outdoor music and in huge orchestras it had become inaudible anyway. Musical textures, which in early works were equally appropriate for string quartet or orchestra, became truly symphonic. Holzbauer occasionally features bassoon solos (as in the *Symphony in E Flat Major*, Opus 4, No. 3), liberating that instrument from simply doubling the bass. The elder Stamitz and Holzbauer were particularly highly regarded in Paris and strongly influenced symphonic activity there.

In Berlin and northern Germany another school arose, dominated by Carl Philipp Emanuel Bach (a son of J.S. Bach), Johann Gottlieb Graun, and other musicians reared in a tradition of rigorous counterpoint and formal conservatism. Retaining three-movement format and avoiding strongly contrasting themes, they maintained contrapuntal interplay in the prevailingly homophonic texture. Even more than the Mannheimers, they concerned themselves with melodic development and ornamentation and with emotional expressiveness—an aesthetic approach

they termed *Empfindsamkeit* (sensitivity). C.P.E. Bach's set of six symphonies commissioned by Baron Gottfried Bernhard van Swieten (completed 1773) aroused enthusiasm for their humour, technical challenge, and novelty of harmonic invention. Even more intensely passionate are the late *Orchestral Symphonies for Twelve Obbligato Parts* (1780), with their clever instrumentation and affective harmonies punctuated by unison passages. Reflecting the literary *Sturm und Drang* (storm and stress) movement, the Berliners powerfully influenced Haydn and Mozart and even Beethoven.

Another son of J.S. Bach, Johann Christian, the so-called London Bach, was perhaps yet more important for the future, influencing Mozart, who met him in London (1764) and again in Paris (1778). His 50 or so symphonies lack the passionate gestures of the Berliners' but are finely wrought and sophisticated in melody and orchestration. The *Sinfonias for Double Orchestra*, Opus 18, reflect in their *style galant* tunes the influence of his study with Martini in Italy, as well as French and Mannheim characteristics (*galant* was the 18th-century term for modern, light, elegant style). Numbers two and three of the set served as opera overtures. Simple in form, complex in texture, J.C. Bach's works are now considered to epitomize elegant, fashionable chamber music.

The Viennese school

The style most influential on Haydn, Mozart, and Beethoven was that of the Viennese school, headed by Georg Matthias Monn and Fux's pupil Georg Christoph Wagenseil. The Viennese experimented further with orchestration and tone colour, emphasized the violin's melodic role, and displayed popular influence in their playful minuets. Monn, though perfectly at ease with counterpoint, ignored it in his symphonies. His four-movement *Symphony in E Flat Major* for pairs of oboes and horns, strings, and continuo is noteworthy for its wide dynamic range and gracious melody so characteristic of Viennese music. The first movement's first theme recurs in the recapitulation transformed into a virtuoso horn duet, reflecting the skill of the players at his disposal and the liberation of horns from a mere harmony-filling role. Elsewhere in the movement are found the slow, repeated-note bass and inconsequential viola part common in early symphonies. As yet the development is quite short and thematically limited, and the movement's scale is small—only a little more than three minutes. But as is often the case, the first movement is the most extended of the four, first movements having gained importance beyond the first movements of opera overtures. In later works Monn dropped the continuo and extended the role of the winds. Together with Johann Stamitz he has been considered highly influential in establishing modern symphonic style, although perhaps Wagenseil, an experienced keyboard player and opera composer, was a more successful composer, especially notable for skillful thematic construction and manipulation, working ornamentation into structure. Also active in Vienna was Haydn's friend Karl Ditters von Dittersdorf, who contributed no fewer than 115 symphonies.

The Viennese style became widely disseminated in Europe. As many as 25 Viennese composers migrated to Paris; others moved to Dresden, Mannheim, and Munich and even as far as Dublin, St. Petersburg, and North America. Their style thus became truly international, and the innovations of these minor masters paved the way for the fully developed symphonic style of Haydn and Mozart. The music of the Viennese composers, mainly intended for elite entertainment, reflects the virtuosic attainments of many private orchestras and the cultured taste of aristocrats who commissioned a constant stream of symphonies and lighter chamber music.

The mature Classical period. Joseph Haydn, despite his isolation from urban musical centres for much of his life, was revered throughout Europe, beloved by Mozart and Beethoven, and widely published and copied—so much so that the authenticity of many works attributed to him remains in question. One hundred and eight symphonies are thought to have been written by him; one of these is lost. Few composers show such remarkable growth as Haydn: from his insignificant youthful pieces, entirely dominated by the style of his pre-Classical elders, to the towering achievement of his last works, his symphonies display an evolution in form and content that had tremendous effect on his followers.

Viennese in style, some of his early symphonies display originality in the use of nonstandard phrase lengths and in their monothematic tendencies. *Symphonies Nos. 1* and *2* are in three movements, lacking a minuet. These works require a continuo (the slow movement in *No. 2* consists only of a bass and treble part), and horns and oboes are as yet not independent. *Symphony No. 3* and others incorporate contrapuntal movements. The sonata recapitulations are subtly altered; but unlike Stamitz', they are generally complete. Melodically, Haydn drew on folk music for inspiration, especially in minuets but also on *galant* and operatic styles. His work reveals a gradual growth in appreciation of the idiomatic qualities of wind instruments, especially in trios of minuets (*e.g., Symphony No. 22, Symphony No. 40*); in *Symphony No. 5* he included winds in the slow movement, unusual at this time, and in *Nos. 6–8* he wrote independent wind solos, recalling the instrumental dialogue found in the Baroque concerto grosso. *Symphonies Nos. 6* and *11* begin with slow introductions, a characteristic which became common in Haydn's symphonies after *No. 84*.

With his appointment to the service of Prince Esterházy in 1761, Haydn's individuality began to emerge, partly because of his opportunity to experiment with the Esterházy orchestra. The bulk of his symphonic production dates from these years before 1771. Although humour and good nature pervade these works, stronger emotions and tension also begin to appear, as in the minor-key *Symphonies Nos. 26, 39,* and *49*. The *Farewell Symphony (No. 45)*, with its adagio (slow) coda, displays Haydn's wit and is one of the best of his symphonies from the decade before 1780. This transitional period shows him striking out into more remote keys, introducing new themes in development sections, and growing more confident in formal craftsmanship and orchestration. Powerful and concentrated, the symphonies of the so-called *Sturm und Drang* period recall the *Empfindsamkeit* of C.P.E. Bach. By turns rigorously contrapuntal and lucidly witty, the vitality evident in the forms reflects Haydn's overflowing adventurousness. Contredanse (country dance) melodies may have inspired some of his themes, for example in the finale of *Symphony No. 88*.

Haydn's later works

The late *London* and *Paris Symphonies* reflect the influence of Mozart and show Haydn at the height of his power. No two movements are alike; the "mosaic" of theme elements pervades even transition sections and codas; each instrument shares in the melodic development; minuets grow in fire or dignity while finales exploit varieties of rondo form (see below). His slow movements, often straightforward sets of variations, engage in artful modulations prefiguring the romantic aspect of Beethoven. *Symphony No. 103* is especially thematically economical, and its movements are related by thematic resemblances, foreshadowing the cyclic nature of many 19th-century symphonies.

Haydn, though by no means the "father of the symphony," contributed enormously to a definition of the harmonic basis of Classical form, the dramatic role of key relationships, and the expressive capabilities of the winds. Major–minor contrasts, wide-ranging modulations, and reconciliation between counterpoint and homophony underlie his unambiguous moods, so different from those of Mozart. An eclectic architect, he amalgamated all the styles of his time in uniquely free and expressive shapes.

Use of rondo-form movements

Rondo form (in which a recurrent theme alternates with other material, as A B A C A) had been found especially in Italian opera and French instrumental music before *c.* 1770; in the 1770s and '80s it became second only to sonata form in symphonic importance. Exploited already by C.P.E. Bach, Stamitz, and others, rondos became a favourite last-movement form with Haydn and Mozart after about 1773. Haydn wrote a number of slow movements as rondos (*Symphonies Nos. 73, 74, 76*) and employed rondos 12 times in his last 17 symphonies. Mozart avoided the rondo in his last symphonies, perhaps because

of the light nature of the form. Its vogue seems to have been brought about by the public's demand for structural simplicity and repetitive tunefulness. In the hands of Haydn and Mozart, however, the rondo increased in complexity, demonstrating in the so-called sonata-rondo the characteristics of sonata form, such as developments of earlier-stated material by means of fragmentation and modulation.

Wolfgang Amadeus Mozart raised the symphony to heights never surpassed. Of his 50-odd symphonies, produced between 1764 and 1788, the earliest ones are conventional but precocious, reflecting influences of J.C. Bach, Sammartini, and Haydn. An invigorating first movement predominates, followed by a light cantabile movement and a fast finale or minuet (minuets in his symphonies date mostly after 1767). The *Symphony in B Flat Major,* K. 22 (1765; Köchel numbers are the standard way of identifying Mozart's works) contains a lovely chromatic slow movement in the key of G minor.

Mozart's synthesis of Italian and German structures

Mozart's exposure to Europe's main musical currents led him to synthesize the playful Italian homophonic and operatic style with serious German polyphony. This is evident in the agitated *Symphony in G Minor,* K. 183 (1773)—a *Sturm und Drang* work and his first minor-key symphony—and in the cheerful *Symphony in A Major,* K. 201 (1774). In these works the balance of interest shifts to the last movement. The addition of codas ("tails," extended closing sections reaffirming the tonic), the increased length and scope of slow movements and minuets, and a growing orchestral sensitivity all point toward maturity. In contrast with those of Haydn, Mozart's slow movements lean toward the sonata form with its inherent drama.

Mozart, unlike Haydn, was not a formal experimenter; he re-used successful structural formulations in later works. It was his treatment of melody that set him apart. He preferred to ignore monothematic structure; and his first and second themes, neither folklike nor mosaic-like, contrast strongly. His harmonic range is narrow compared with Haydn's, but within his range he constantly transformed thematic material. Development sections expand with the introduction of new thematic material and modulations over a wider tonal field. His recapitulations tend to be straightforward. In this mature period, Mozart's symphonies became unified thematically and expressively, using fuller imitation, more singing figuration, freer instrumentation (the *Paris Symphony,* K. 297, in D major, introduces clarinets). Mozart rejected Mannheim gesture in favour of better integrated dynamics.

Mozart's last 10 years saw him further exposed to Haydn's influence and very aware of J.S. Bach's music. The monumental last six symphonies reflect his experience as an opera and chamber music composer. The *Symphony in C Major,* K. 425, has a rare, slow chromatic introduction, while K. 504 in D major (*Prague Symphony*) dispenses with the minuet, has all three movements in sonata form, and uses canonic development (development by means of exact imitation). The last three symphonies (K. 543, in E flat major; K. 550, in G minor; K. 551, in C major, or the *Jupiter Symphony*), summits of the Classical genre, are bold in their harmonies and counterpoint; the serious minuet of K. 550 foreshadows the scherzo of Beethoven's *Fifth Symphony.* (The scherzo is a rapid, rhythmic, minuet-derived form.)

Mozart was no revolutionary. Receptive to the influence of others, he rejected more than he assimilated, transforming all into a uniquely personal idiom. Several of his symphonies were used as opera overtures, but the best ones are so complete in themselves as to make their use as incidental music unthinkable to modern taste. Mozart's and Haydn's mature symphonies are comprehensive in mood and design. The various movements balance one another so well that those who are accustomed to hearing them would find it difficult to accept the substitution of other movements. This tendency toward intimate relation among the standard four movements reflects the urge of these composers to seek unity on the highest hierarchic level—a trend foreign to most of their lesser contemporaries but a basic factor in the symphony's evolution throughout the next two centuries.

With Ludwig van Beethoven the symphony became no longer entertainment music but an expression of monumental intellect and innermost feeling, as in Haydn's and Mozart's late works. The *Symphony No. 1 in C Major* (completed 1800) is Haydnesque, particularly in the opening theme of the finale (comparable to the finale of Haydn's *Symphony No. 88*), but full of originality. Its four classically structured movements reflect Beethoven's concern with expressive woodwind writing and dynamics. The third movement (Menuetto) is prophetic of Beethoven's later whirling scherzos. The slow introduction to the first movement is remarkable for its avoidance of the tonic, a technique used often in later works to arouse tension.

The *Symphony No. 2 in D Major* (1802) is transitional and, like the *Symphony No. 1,* somewhat diffuse. A long introduction announces a work of grand dimensions. The lyric slow movement is rich in themes that are organically unified. A dynamic scherzo, only slightly dancelike, and an expanded sonata finale (with an enormous coda introducing a new theme) point toward the revolutionary length and structure of the *Symphony No. 3 in E Flat Major* (*Eroica;* completed 1804), a work that many consider to herald the dawn of musical Romanticism. The *Eroica* (Beethoven's title) no longer aims at an elite audience. Its first movement employs a multitude of themes, again drawn together into a cohesive organism and developed in a context of great harmonic tension. The tonic, Eb, is avoided near the beginning for 14 measures. A pathetic funeral march, replacing the ordinary slow movement, is followed by a vigorous scherzo; this leads to a variation finale, based on a theme from his *Creatures of Prometheus* ballet and full of contrapuntal development. The symphony marked a new fusion of old formal structures with Beethoven's dynamic outlook.

The *Eroica* symphony

The cheerful *Symphony No. 4 in B Flat Major* (1806) and fateful *Symphony No. 5 in C Minor* (1808), so unalike in character, were composed side by side. The *Fifth,* like the *Third,* a visionary work, is unified by the famous four-note motive that permeates all four movements in one form or another. The scherzo and finale are joined, and an explosion of C major in the last movement is celerated with three trombones (possibly their first use in a symphony), piccolo, and contrabassoon. This grandiose edifice is constructed with relentless logic and rhythmic drive, hallmarks of Beethoven's mature style.

The *Symphony No. 6 in F Major* (1808), called the *Pastoral,* is in five movements, the first two and last in sonata form, each, according to Beethoven, expressing an aspect of rustic life. The whole has a unity of character that reflects a deeper rhythmic unity. A descriptive "Storm" movement links the scherzo ("Merrymaking of the Peasants") with a calm "Thanksgiving after the Storm" finale, which, incidentally, incorporates a Swiss yodel tune. The relaxed human and poetic qualities of the *Sixth* set it apart from the *Fifth* and from the demoniac *Symphony No. 7 in A Major* (1812), with its expanded scherzo and trio, blazing finale, and spirited first movement preceded by a long modulatory introduction.

The small scale of the first three movements of the *Symphony No. 8 in F Major* (1812) leaves one unprepared for its breathtaking finale. Its minuet is a subtle parody of the classical minuet of Mozart and Haydn.

The *Symphony No. 9 in D Minor (Choral)* found Beethoven deaf at its first performance in 1824. It marked a turning point in music history, not only for its novel inclusion of chorus and vocal soloists in the last movement and the extraordinarily variegated sonata form of that movement—incorporating a Turkish march, double exposition, double fugues, strophic (stanzaic) variations—but for the scope of the whole, a summary of Beethoven's ethical and symphonic achievements.

In his development of motifs and variation of entire themes Beethoven went unchallenged. He expanded the limits of Classical form, particularly in his finales, and increased the length of the symphonic process to more than four times the 15 or so minutes required for a pre-Classical symphony. Further, his orchestral sensitivity allowed all instruments a structural role while simultaneously making new demands on player and listener alike. Besides

widening the scope of the orchestra with extra winds and percussion, he made it more than ever a cohesive single instrument, bequeathing to the 19th century a standard against which composers measured the effectiveness of their own orchestrations. Finally, through the immense concentration of his symphonies he made it impossible for his followers to equal the sheer quantity of production of the Classical composers; far too much effort went into creating a symphony to allow pouring them out by dozens.

So overwhelming was the impact of Beethoven's symphonies, along with that of Mozart's and Haydn's mature ones, on later generations that they utterly obscure the productions of many other worthy symphonists. François Joseph Gossec, an early French symphonist, and Pierre van Maldere came to grips successfully with the dominating German–Italian idiom and were important among the Parisians influenced by Stamitz and his school. Van Maldere was eulogized for his imaginative thematic structures as well as for the unusually serious nature of his compositions, which strongly contrasted with the more lighthearted style characteristic of the Mannheimers.

An English composer, William Boyce, eclipsed by the London Bach, wrote eight sinfonias that betray in design the strong influence of theatre music. Basically merely overtures in French or Italian styles, they show none of the modern characteristics being formulated at the time in Germany; England, in general, was not quick to adopt the new symphonic style.

Revolutionary composers of Eastern Europe

Eastern Europe produced revolutionary composers of whom until recently little has been known. Stamitz, Bohemian by birth, overshadowed such competent composers as Jiří Benda. Benda's symphonies, dating mostly between 1750 and 1765, are generally brief, in three movements, and close to the Italian overture in form and feeling. The sonata form is not exploited, although characteristics such as contrasting themes and contrast within a single theme (a technique used also by Mozart) suggest a Mannheim influence or at least a revolt against Baroque conventions.

Luigi Boccherini, Giovanni Giuseppi Cambini, Michael Haydn (Joseph's brother), Leopold Mozart (father of Wolfgang), and many other important chamber music composers contributed numerous symphonies well worth performance. Later composers included the conservative Swede Franz Berwald and a brilliant but short-lived Spaniard, Juan Crisóstomo Arriaga, influential mostly in their own countries; and Muzio Clementi, Luigi Cherubini, Louis Spohr, and Carl Maria von Weber, who, although better known for work in other genres, were nevertheless popular symphonists. Spohr wrote a number of highly pictorial programmatic symphonies, going well beyond Beethoven's *Sixth*.

The Romantic era. Among 19th-century symphonists several trends can be distinguished. Concerned to some extent with self-conscious emotional expression, they often tended to use looser forms and slower paces than the Classical composers. Sometimes this led to lax discipline but not in the case of the finest composers, among them Schumann, Brahms, and Dvořák, who were all very conscious of their debt to Beethoven, Mozart, and Haydn. With later composers, such as Anton Bruckner, Peter Ilich Tchaikovsky, and Gustav Mahler, the normal balance of form was sometimes upset in favour of romantic license, but they too derived their basic goals from the Classical composers, with a more or less heavy admixture of the influence of Richard Wagner.

Schubert

Franz Schubert is known primarily as a songwriter. His nine symphonies stand in the shadow of Beethoven's but are revolutionary and Romantic in a way utterly different from Beethoven's. Whereas Beethoven wrestled with melodic problems, Schubert was a born melodist and consequently concerned himself more with the harmonic basis of form. He was likewise the more sensitive orchestrator, and in the last three symphonies he greatly expanded the role of the brasses.

His *Symphony No. 1 in D Major* (1813) and *Symphony No. 2 in B Flat Major* (1815) illustrate Schubert's departure from Classical models. Although the first movements are in sonata form, their pace is slower than the ordinary Classical allegro and is supported by long nonthematic passages that expand the harmonic arch. In the youthful sonata-form movements the second theme group is often set in an unexpected key before the music turns to the dominant at the end of the exposition. In recapitulations, too, Schubert shies away from harmonic simplicity and Classical expectation; his phrasing also is often irregular. Schubert's slow movements, scherzos, and minuets are not as strikingly original. Clear references to movements and themes of Beethoven occur in these early works, and in key scheme and major–minor contrast Schubert often betrayed his indebtedness to Beethoven. He was unembarrassed to borrow melodic material, which he transformed in an utterly personal way. This is particularly the case in the *Symphony No. 4 in C Minor* (the *Tragic*; 1816). The *Symphony No. 5 in B Flat Major* (1816), scored for a smaller orchestra, more strongly recalls Mozart and Haydn. The highly emotional *No. 6 in C Major* (1818) is of larger scale, based as usual more on rhythmic and harmonic impetus than melodic development. The incomplete draft of the *Symphony in E Minor-Major* (1821) has inspired attempts at completion. But it is the last two (the *Symphony in B Minor* or *Unfinished*, 1822, and *Symphony in C Major*, or *Great*, 1828) that raise Schubert to high rank among symphonists. Composed for large orchestras, they nevertheless reflect Schubert's experience in writing for voice and piano.

Schubert's *Unfinished* and *Great* symphonies

The *Unfinished* consists of two complete movements in $\frac{3}{4}$ and $\frac{3}{4}$ time and a sketch for a scherzo. The complete movements form a convincing unity; masterful in harmonic organization and orchestration, they are expressive without being diffuse, a criticism often levelled against passages in Schubert's earlier works. The *Great* is of Beethovenian scale, partly because of extensive repetition. The scherzo and related slow movement, no longer simply rustic pieces, are both sonatas. Irregular phrases, modulatory schemes, and rhythmic force give evidence of Schubert's concern with form based on slowed-down and far-reaching harmonic motion. His rhythmic manipulation was un-Classical, his themes personal and of more than Classical significance.

With the first group of symphonists born in the 19th century the Romantic style was fully fledged. The French composer Hector Berlioz and the Hungarian Franz Liszt contributed large symphonic works that to some extent departed in form from the Classical sonata-centred model. The literary program to Berlioz' *Symphonie fantastique: Épisode de la vie d'un artiste* (1830) was not written until the music was well along toward completion. The symphony was thoroughly planned out thematically and formally and stands as a musical unity without regard to the program, which Berlioz himself eventually withdrew. A very personal expression nevertheless, the *Fantastique* introduces a structural *idée fixe*, a theme (representing his mistress?) recurring throughout the five movements in various rhythmic forms, serving to unite the "scenes" musically as well as dramatically.

Harold en Italie (1834; after Byron's poem), like the *Fantastique*, makes use of preexistent material and is unified not only by a program but by a recurrent theme, a viola solo representing Harold. This theme is not subject to the kind of variation given the *idée fixe* in the *Fantastique*; yet from it springs much of the melodic inspiration of the whole work. Berlioz' third symphonic work, *Roméo et Juliette* (1839), rarely heard in its entirety, incorporates chorus and vocal soloists into its five large sections, which are programmatically derived from episodes of Shakespeare's drama. Not coincidentally, Berlioz was a great admirer of Beethoven. Beethoven's unity of moods, thematic development, and dramatic orchestration were models for Berlioz to extend, although he did so outside the formal confines of the sonata and with even more explicit passion.

Liszt owed much to Berlioz, both in his handling of enlarged orchestral forces and in thematic transformation (as opposed to development). The three movements of his *Faust Symphony* (1854) bear the names of Goethe's characters: Faust, Gretchen, and Mephistopheles; and the final movement parodies themes of the first two in a satisfyingly diabolical manner. Characters aside, the music is

highly effective and balanced; Liszt revised the score over several decades. The score is dedicated to Berlioz.

Liszt's other symphonic work, the *Symphony to Dante's Divina Commedia* (1856), depicts the Inferno, Purgatory, and Paradise. Liszt, at times a devout Catholic, portrayed Dante's scenes with great imagination and passion, cleverly suiting his melody—sometimes simple and tranquil, sometimes chromatic and writhing—and harmony to the special characters of the three levels. The symphony is dedicated to Wagner, who suggested the third-movement setting of the Magnificat for female chorus and orchestra. As do many operas of Wagner, Liszt's work uses the leitmotiv, an extension of Berlioz' *idée fixe*.

If Berlioz and Liszt represented a trend toward freedom and extramusical content in symphonic writing, Schumann and Mendelssohn were more conservative though not strictly comparable. All four were deeply concerned with formal discipline, but Schumann and Mendelssohn departed less widely from Classical norms and made less point of extramusical associations.

Mendelssohn's symphonic works

Felix Mendelssohn wrote 16 symphonies and a symphony-cantata. Twelve of the symphonies are immature works; but the remainder fairly exemplify his style: facile, full of light melody and brilliant orchestration, occasionally oversentimental, according to some critics. He is best known for his *Symphonies No. 3* (*Scottish*) and *No. 4* (*Italian*), both in A major–minor. The *Scottish* (also called *Scotch*), completed in 1842, although not programmatic, is expressive of Mendelssohn's poetic nature. Its beginning was sketched during a visit to Scotland in 1829. In structure the work consists of four movements played without pause, with a slow introduction. Its fairylike scherzo, which incorporates part of a Scottish folk song, exemplifies the delicate moods that Mendelssohn excelled in creating. The other movements are well developed, the many contrasting themes integrated contrapuntally and extended with interesting modulations. But although it is full of good music, the symphony is less powerful than its companion, the *Italian* (finished 1833). This happy work, inspired by visits to Rome and Naples, is particularly colourfully orchestrated. It ends with a dance movement incorporating three themes; the minor tonality does not detract from its vivacity. The first movement, too, has three themes, the third introduced in the development section. The second movement, recalling a religious procession, and the third, a quasi-minuet and trio, are picturesque without being descriptive and represent Mendelssohn at his finest—uncomplicated, lush, and vigorous.

Schumann's miniaturist style

Robert Schumann, like Mendelssohn and Mozart, wrote his symphonies at an age when most longer-lived composers are just beginning to mature and wrote only a few truly great ones. Like many first-generation Romantic composers Schumann was essentially a miniaturist, most at home in songs and short piano works. His orchestral style reflects these qualities; rhythmically restless, often repetitive, not sensitively scored, they have been praised more for their harmonic subtleties and wonderful lyric melodies than for development of these ideas.

The *Symphony No. 1 in B Flat Major* (*Spring*; 1841), based on a poem by Adolph Böttger, originally had titles given each movement; these were soon rejected by Schumann and indeed are irrelevant to the music. The first movement, opening with a slow introduction (a tradition since the days of Haydn), incorporates three contrasting themes (the third introduced toward the conclusion of the movement) as well as the opening dramatic figure of the introduction. The slow movement and unusual scherzo (it has two different trios, rather than one) are linked thematically and played without a pause between them. The impulsive progress of the finale is interrupted before the recapitulation by slower passages for flute and hunting horns, perhaps intended by Schumann to be descriptive.

The *Symphony No. 2 in C Major* (1846) is tightly organized and owes something in design to Beethoven. It has been overshadowed by more frequent performances of the last two symphonies, *No. 3 in E Flat Major* (*Rhenish*; 1850) and *No. 4 in D Minor* (1841, rev. 1851). The five-movement *Rhenish* is less "classical" than the *Symphony No. 2*. Inspired by a ceremony at Cologne Cathedral as well as by the appearance of the cathedral itself, the polyphonic grandeur and harmonic richness, especially of the fourth movement, are tempered by the relaxed pace and rustic character of the scherzo and following short, quiet slow movement. The outer movements are related both thematically and in mood, and the last two movements also share material, forming a large cohesive structure.

Even more cohesive is the plan of the *Fourth Symphony* in which all four movements are played, as in Mendelssohn's *Scottish Symphony*, without pause. A single theme recurs in various guises in all four movements; this thematic transformation is a hallmark of Schumann's style, as of Berlioz' and Liszt's. The last movement introduces new material but without destroying the cyclic nature of the whole work. Cyclic structure, which relates separate movements by means of re-use of thematic material, is a feature of much symphonic writing after Beethoven. As composers gradually departed from repetitive forms, cyclic construction became a chief mode of achieving unity over a large time span and greatly enlarged harmonic vocabulary. An advanced form of cyclic construction may be seen in the Belgian composer César Franck's influential single *Symphony in D Minor* (1888).

Traits of Bruckner's symphonic style

Although Johannes Brahms's four symphonies are popularly considered to be no less important than the greatest earlier symphonies, the contribution of his contemporary Anton Bruckner is controversial. Bruckner, a devout Catholic whose church music is among the finest of his generation, is noteworthy not only for the excessive length and heavy orchestration of many late movements but for his Wagnerian harmonies, large-scale repetitions, and (at its best) monumental conceptions of form. Bruckner gathered much from studying late Beethoven and Schubert. Yet his style evolved little in the course of nine symphonies (he was over 40 when he wrote his first symphonies; two other unnumbered early ones are never heard, and his last was incomplete at his death). Entirely personal in expression, his symphonies underwent frequent revision. They are in four movements and are basically unprogrammatic, even conservative. Despite his devotion to Wagner and Beethoven, Bruckner remained provincial; his technique was grounded on traditional studies, and his movement types seem to follow a set of typical formulas that derived from Classical patterns, especially the sonata. Within these formal types he develops themes powerful in their simplicity and monolithic in harmonic expanse. Chords reminiscent of German chorale (hymn melody harmonizations) and tremolo or pizzicato (plucked) accompaniments occur along with organ-like counterpoint and pedal tones (sustained notes against changing harmonies). Hardly imbued with youthful vigour, some scherzos still have roots in the fertile Austrian popular music that nourished Haydn and Beethoven. These movements, however, are not sufficient to lighten the overall impression of density. Unlike those of Brahms, Bruckner's symphonies are not immediately rewarding; yet connoisseurs, including Mahler, respect Bruckner's heroic finales, in which themes from earlier movements are sometimes combined. *Symphony No. 4 in E Flat Major* (1874, first performance of revision, 1881), with a Beethovenian andante and scherzo recalling the hunt, is noteworthy for the use of four themes in the first movement. *No. 7 in E Major* (1881–83, rev. 1885), well received at first hearing, is Wagnerian in orchestration (Wagner tubas play in the adagio) and makes use of contrapuntal techniques developed in the Renaissance. In the last two symphonies the adagio movements occur after the scherzos rather than before.

Individuality of Brahms's symphonies

The symphonies of Brahms, each highly individual, appealing on first hearing, and rewarding to rehear, could hardly be more different from Bruckner's. Yet Brahms, his technique grounded on thorough study of Classical and Baroque works, was no less essentially conservative. He retained the four-movement format and familiar methods of thematic development and rigorous contrapuntal craftsmanship, avoided programmatic content, and was always concerned with aural effect. These concerns are reflected in his orchestration, which is never merely flashy, never astonishing. His entire remarkable skill and attention to detail served the lyrical, spontaneous flow of his melody.

His tunes, Romantic as Schubert's, are developed with consistency, refinement, and a harmonic interest foreign to many lesser contemporaries (especially those seduced by Berlioz and Liszt but without understanding their talent). Brahms is a master of understatement. Finished in 1876, 20 years after it was begun, his *Symphony No. 1 in C Minor* was the fruit of a mature man's experience. It carried on where Beethoven left off, drawing inspiration especially from Beethoven's *Fifth*. The triumph of major over minor, epitomized in the finale, underlies the whole. The key scheme of the movements is cyclic, based on a succession of rising major thirds: C minor, E major, Ab (= G♯) major, C minor–major. The third movement, formally a scherzo with trio, slackens tension as though to prepare for the marvellously developed finale, which is preceded by a broad introduction (as is the first movement) that sets harmonic and thematic goals for the remainder.

Clear goal orientation also characterizes the *Symphony No. 2 in D Major* (1877). Unlike the *First* in mood, it is pervaded in all movements by optimistic calm. The first and last share a three-note motive that is joined by other serene themes in the first movement, which includes a long horn solo near the end. The second movement begins in B major, a third lower than the first, and the fast third movement begins a lower third still, in G major; the finale returns to D. This third-based tonal scheme, like that of the *First*, marks Brahms as a true Romantic, as do the tempo changes within movements, the sensuous modulations that circumscribe harmonic goals, and the intense major–minor conflicts.

Modal tension—major versus minor—characterizes the cyclic *Symphony No. 3 in F Major* (1883), the movements of which are related by material derived from Brahms's "motto" motive, FAF, *frei aber froh* ("free but joyful"). Winds are prominently featured, particularly clarinet and horn, as elsewhere in these symphonies. Brahms retained Classical outlines as usual; but, as in the *First*, the scherzo with trio serves to throw the vigorous, stormy finale into relief. The first movement plunges to the heart of things from the opening chords, harmonizing the motto; there is no introduction, no coyness in exposing the main themes. Chromatic harmony and contrapuntal development are fully exploited.

Brahms's architectural skill is nowhere more in evidence than in the finale of the *Symphony No. 4 in E Minor* (1884–85), an extended chaconne, or set of variations over an (eight-bar) repeated bass melody. This movement is almost Baroque; and elsewhere in the work Brahms employs Baroque contrapuntal techniques, chromatic labyrinths, and modal melody that hovers between major and minor but is neither. In this work particularly, but throughout the symphonies, Brahms epitomized the tendency of the later Romantics to seek a balance between the expressive forms of the early 19th century and older traditional technique, to apply to the wealth of available harmonic and orchestral colour constructive methods consciously founded upon study of Beethoven (particularly *Symphonies No. 4, No. 7,* and *No. 8*), Handel, and other models. These disciplined composers (including Schumann and Mendelssohn) reacted partly against what they felt to be the extramusical emphasis and compositional excesses of Berlioz, Liszt, and lesser figures, who took as their point of departure the less conventional Beethoven of *Symphonies No. 5, No. 6,* and *No. 9*.

Dvořák and Tchaikovsky

Both trends found reflection in the symphonies of Dvořák and Tchaikovsky, composers who were products of growing nationalistic tendencies in music. Antonin Dvořák continued a distinguished line of Bohemian symphonists stretching back to Stamitz. Conscious of his musical heritage, Dvořák infused his music with folk-derived elements, particularly dances; his last symphony, *No. 9 in E Minor* (*From the New World*, 1893), even incorporates American tunes; but these are almost incidental to the strong Slavonic character of the work. An early devotee of Wagnerian sonorities, Dvořák in his later symphonies returned to the more conservative models and orchestrations of Beethoven and Brahms. It is these later works, through which Dvořák is known today, that have led detractors to call him a "second-rate Brahms." In fact, Dvořák's melodic invention, often based on irregular folk-like scale forms, and his captivating irregularity of phrase length, surprising variety of orchestration, and impetuous rhythms are entirely personal.

Peter Ilich Tchaikovsky, on the other hand, was not comfortable working with preestablished formal models but was at his best in ballets and tone poems in which his somewhat extravagant nature found fuller scope for expression. Of his eight symphonies, only *No. 4 in F Minor* (1877), *No. 5 in E Minor* (1888), and *No. 6 in B minor* (*Pathétique*, 1893), actually fourth, sixth, and eighth in order of composition, are well-known. These are controversial works, partly because their novel structures are not easily analyzed (or heard) in standard formal ways. Some feel that Tchaikovsky's freedom and tendency to musical autobiography were inimical to purely abstract musical expression and that understanding of his music depends on knowledge of his state of mind at various times or upon some extramusical imagery or program. This attitude conflicts with an essential determinant of symphonic idiom, which is that the establishment and working-out of tensions in the piece are primarily occasioned by purely musical, formal means; and that extramusical data, interesting though they may be, are not directly relevant to apprehension and appreciation of the symphonic process. If Tchaikovsky's symphonies are to be considered successful as symphonies, they must make purely musical sense—and the three mentioned fulfill this condition.

Tchaikovsky's kind of musical logic, however, is quite different from that exemplified by the main-line German symphonists. Isolated in his formative years from the influence of Brahms and Wagner, he learned instead by hearing Mozart and Italian opera, characteristics of which he fused with elements of non-European melody, harmony, rhythm, and colour; in this he followed Aleksandr Borodin and other Russians. He strongly favoured the minor mode, no doubt partly because of its inherent instability. This unique confluence of stylistic sources produced a new model for later symphonists, particularly in regard to orchestration and a reevaluation of sonata form based on a fresh conception of tonal harmony.

Mahler as the culmination of the Viennese tradition

With Gustav Mahler, the central path, if not the culmination, of Viennese symphony was regained. In importance Mahler's nine completed symphonies (a 10th was left unfinished at his death) stand equal to any corpus since Beethoven's. That this has been so recently recognized may have something to do with historical perspective but is more probably a matter of relevance of his music to the mood of the mid-20th century. Nowhere else in music is found such explicit cynicism, such deliberate distortion of the familiar; by the same token no symphonist exceeds him in desire for reconciliation. Mahler's melodies and harmonies are strongly goal oriented; that his goals are so frequently frustrated or beset with obstacles reflects a truly contemporary outlook.

Mahler's symphonies, like those of Tchaikovsky and Berlioz, suffer from being too often considered solely in the light of extramusical associations. Mahler himself suppressed the programs of his early symphonies and subjected their music to frequent revision. Structurally, the symphonies are entirely logical, even simple, beneath the multitude of themes and wealth of colouristic detail. Mahler was a fastidious and brilliant orchestrator. The seeming superfluity of orchestral resource he called for, especially in the later symphonies, is handled with restraint and sensitivity—Mahler was a conductor as well as a composer and knew well the capabilities of the instruments.

Enormous in time scale, Mahler's symphonies contain sufficient variety and contrast to maintain interest. Underlying this stylistic multiplicity—including parodies of folk song, waltzes, fanfares, marches, text painting (four symphonies include voices), chorales, borrowings from other composers as well as his own songs—was a leaning toward cyclic structure, with themes or motives shared among movements, as in his song cycles and those of Schubert and Schumann. Mahler also experimented with tonal structure to the extent of combining movements in unrelated keys, so that the ear never tires of a single tonal area. *Symphonies No. 5, No. 6,* and *No. 7,* themselves a

huge cycle, show him coming to grips with Classical sonata form, greatly expanded though it is. Unity on a lower level is achieved through extensive counterpoint. These later works show an economy of structure that is foreign to Bruckner, from whom Mahler nevertheless learned much.

Nielsen and Sibelius

The 20th century. Important symphonists of the early 20th century include many non-Germans. Carl Nielsen and Jean Sibelius, the former Danish, the latter Finnish, both owe much to the Viennese symphonists but acquired individual styles that resulted in new conceptions of symphonic form. Nielsen's six symphonies display a kind of unity based on "progressive" or "emergent" harmony, one key moving on to the next in such fashion that the gamut of harmonies in a single symphony (or movement) does not totally relate to a single tonic. His harmonies sometimes fluctuate between two or more goals and incorporate chromatic and modal features. This untraditional harmonic tension is an aspect of the breakdown of normal Classical ways of establishing tonality, for which the 19th century (and Wagner in particular) is largely responsible. (Nielsen, however, was an anti-Wagnerian.) This "destructive" impulse, elements of which may already be heard in Haydn, led to constant re-evaluation of the basis of sonata form and hence of the symphony as a whole. As the traditional harmonic foundation weakened—partly because the enlarged time scale makes long-term harmonic relationships hard to hear—symphonists sought new unifying techniques, among them cyclic forms, extramusical plots, progressive harmony, etc. None of these is incompatible with dramatic sonata form, taken in its broadest sense. Nielsen retained and emphasized key conflict as a dynamic force and experimented with counterpoint and conflicting rhythms (*e.g., Symphony No. 4, The Inextinguishable,* 1916; and *Symphony No. 5,* 1922), joined movements, and the rest.

Sibelius wrote his seven symphonies between 1899 and 1925. Like Nielsen's, they departed from Classical models (notably Beethoven's *Fifth*) and reflected especially the advances of Brahms and Bruckner. Sibelius was a restrained orchestrator, a non-Wagnerian. Although nationalistic, he used no folk songs and incorporated no programs. He had little immediate influence, isolated as he was after World War I, but is highly regarded presently in his native country, and in England and the United States. Sibelius, like Nielsen, is not tied to Classical tonic-dominant opposition. He sometimes introduces modal scales and polar harmonic goals between which the music oscillates. A chief unifying device is a repeated bass line or sustained pedal tone. His themes are often groups of melodic fragments, meaningless when out of context, that are capable of being combined in various ways. The gradual integration of these motifs is an important means of development. In this Sibelius resembles Borodin; the effect is quite unlike that of Mahler's long melodies. Structurally Sibelius is terse and simple. He eliminated transitions and introductions, avoided simple recapitulation, and kept harmonies static or ambiguous over long stretches. Rarely was he merely playful. He was fond of low, dark sounds. Sibelius is hardly unemotional but certainly is not effusively romantic. His symphonies represent a great contrast with Mahler's, and he strikes a new path away from the sonata.

Elsewhere in the early 20th century important symphonic contributions were being made by the Frenchman Albert Roussel, whose four symphonies are elegant and classical in form; the American Charles Ives, who quotes well-known tunes in his highly dissonant four symphonies; and the Englishmen Sir Edward Elgar and Ralph Vaughan Williams. Their works are not often heard outside their native countries, and the extent of their influence on the growth of symphonic thinking remains to be determined. A more important innovator, the Viennese Arnold Schoenberg, considered his *Chamber Symphony,* Opus 9 (1906), "the climax of my first period." Basically still sonata-oriented and tonal, this work departed from the gargantuan orchestrations of Mahler and Richard Strauss and is scored for 15 soloists, 10 of whom play winds. The idiom is highly dissonant and motivic, straining at the limits of traditional tonality and pointing to Schoenberg's formulation of dodecaphony, or 12-tone serialism (deriving melody and harmony from the composer's ordering of the 12 tones of the chromatic scale).

Stravinsky's imaginative force

Igor Stravinsky likewise inherited a living tradition and transformed it with great imaginative force. Like Schoenberg, he was not primarily a symphonist; his early *Symphony in E Flat Major* (1905–07) is no more original than anything of other Russians such as Borodin or Aleksandr Glazunov. But the *Symphony in C* (1940) and *Symphony in Three Movements* (1942–45) are unique. The former, a Neoclassical work, reinterprets in Stravinsky's language the thematic construction and sonata form of the Classical era. The result, far from a simple parody of Classical style (such as in Sergey Prokofiev's *Symphony No. 1 in D Major* or *Classical Symphony* of 1917), was an altogether fresh and revealing insight into the implications of Haydn's work. The *Symphony in Three Movements,* inspired by wartime impressions, is independent of models, yet in outward form the movements appear traditional. Two other of Stravinsky's works deserve mention here: the *Symphonies of Wind Instruments* (1920, rev. 1947) and the *Symphony of Psalms* (1930), which includes chorus. These works are symphonies only in the 17th-century sense of ensemble pieces: in both form and structure they are dissimilar from the other symphonies.

Chief among other Russians are, besides Prokofiev (seven symphonies), Nicolay Myaskovsky (also seven) and Dmitry Shostakovich (15). Shostakovich's large corpus marks him as one of the most important and prolific modern symphonists. His works are uneven in quality. A number are programmatic, dealing with Russian political and social upheavals. Shostakovich at times concerns himself with incorporating popular and folk tunes, giving expression to national feelings, and, more basically, with problems of achieving cyclic unity by such means as leitmotivs and thematic recurrences and joining movements without pause.

The mainstream of American symphonic production resides with Roy Harris, Walter Piston, William Schuman, and Roger Sessions. Important as teachers, these men have influenced younger symphonists such as Easley Blackwood and helped create a distinctive style of composition that resulted in the first important symphonic output in the Western Hemisphere. Although many younger composers on both sides of the Atlantic are turning to avant-garde techniques, including experiments in formlessness, and to small instrumental and vocal ensembles as well as to electronic sources, the future of the symphony seems secure. Extremely large orchestrations are not widely favoured, partly because of the difficulty and expense of mounting a performance; yet Blackwood has written one symphony for an orchestra larger than Mahler's as well as one for chamber orchestra. Audiences tend to favour works in familiar forms. Prizes and commissions assure a steady output of symphonies and many have been written for college and university orchestras. Flourishing amateur orchestras also furnish outlets for the young composer. As regards the masters of the 18th and 19th centuries, there seems no possibility that their symphonies will become museum pieces in the foreseeable future. On the contrary, the recording and broadcasting industry has brought about renewed interest in even the lesser known symphonists. Scholars and public alike have now almost unlimited access to the treasures of three centuries of symphonic production. (La.L.)

SONATA

Deriving from the past participle of the Italian verb *sonare,* "to sound," the term sonata originally denoted a composition played on instruments, as opposed to one that was *cantata,* or "sung," by voices. Its first such use was in 1561, when it was applied to a suite of dances for lute. The term has since acquired other meanings that can easily cause confusion. It can mean a composition in two or more movements, or separate sections, played by a small group of instruments, having no more than three independent parts. Most frequently it refers to such a piece for one or two instruments. By extension, sonata can also refer to a composition for a larger instrumental group having more than two or three parts, such as a string quartet or

an orchestra, provided that the composition is based on principles of musical form that from the mid-18th century were used in sonatas for small instrumental groups. The term has been more loosely applied to 20th-century works, whether or not they rely on 18th-century principles.

Sonata and sonata form

Quite distinct from all of the preceding, however, is the use of the term in "sonata form." This denotes a particular form or method of musical organization normally used within instrumental sonatas, string quartets, and other chamber music, and symphonies written since the beginning of the Classical period (the period of Mozart, Haydn, and Beethoven) in the mid-18th century.

The first concern of this section will be to establish the principles of musical form often associated with sonatas for small and large groups of instruments. They will be approached through an examination of the principle of musical structure called "sonata form." A historical account of the origins and development both of the instrumental sonata and of sonata form will then endeavour to throw light on other meanings of the term. In conclusion, some estimate will be offered of the present and possible future roles of the sonata in musical life.

Structure of the Classical sonata. Sonata form denotes a particularly fertile manner of organizing the musical structure of a single movement. It commonly occurs within the larger context of a multimovement scheme. Maturing in the second half of the 18th century, it provided the instrumental vehicle for much of the most profound musical thought until about the middle of the 19th century, and has continued to figure largely in the methods of composers down to the present day.

The basic elements of sonata form are three: exposition, development, and recapitulation, in which the musical subject matter is stated, explored or expanded, and restated. There may also be an introduction, usually in slow tempo, and a coda, or tailpiece, but these optional sections do not affect the basic structure. Although sonata form is sometimes called first-movement form, the first movements of multimovement works are not always in sonata form, nor does the form occur only in first movements. Likewise, another name for it, sonata-allegro form, is misleading, for it need not be in a quick tempo such as allegro.

At first glance sonata form may appear to be a species of three-part, or ternary, form. The three parts of ternary form are a first section (A), followed by a contrasting section (B), followed by a repetition of the first section (that is, A B A). The parts are interrelated not in terms of basic structure but by purely lyrical or character contrast. Actually, the three parts of sonata form developed out of the binary, or two-part, form prominent in the music of the 17th and early 18th centuries. In binary form the structure depends on the interrelationship not only of themes but also of tonalities, or keys, the particular sets of notes and chords used in each part. Thus, the initial part, which is repeated, leads directly into the second part by ending in the new key in which the second part begins. The second, also repeated, moves from the new key back to the original key, in which it ends. The second part thus completes the first.

Binary form

In sonata form the exposition corresponds to the first part of binary form, the development and recapitulation to the second. The exposition moves from the original key to a new key; the development passes through several keys and the recapitulation returns to the original key. This echoes the motion, in binary form, away from and back to the original key. In relation to binary form, sonata form is complex. It offers, in the exposition, contrasting musical statements. In the development these are treated dialectically; that is, they are combined, broken up, recombined, and otherwise brought into change and conflict. In the recapitulation they are restated in a new light. This organic relationship between parts marks the sonata form as a higher, more complex, type than the ternary form. The occasional designation of sonata form as compound binary form is useful in that it stresses its origins in the earlier form, but notes its added complexity.

The emphasis on contrast, even conflict, is the element that distinguishes the exposition of a sonata-form movement from the first section of an earlier binary form. The first section of a binary movement in a Baroque suite or instrumental sonata, for example, might contain two clearly differentiated themes, but the stress is on continuity and on uniformity of musical texture rather than on contrast. In sonata form the emphasis is more dynamic; there is a stronger sense of contrast within the movement. The terms usually given the contrasting areas are "first subject/second subject" or "principal group/subsidiary group." These are misleading terms, for they imply a simple contrast of themes.

In reality it is contrast of key, or tonal contrast, that characterizes the sonata exposition. Usually the opening of the exposition is firmly rooted in the tonic, or "home," key of the work. The later segments of the exposition move decisively to a closely related but distinct key. The second key chosen is almost invariably one of the two keys most closely related to the home key. If the home key was a major key, the dominant key is chosen; if the home key was minor, the relative major is chosen. (The dominant key is the one whose keynote is five tones above that of the tonic, as C–G; the relative major has a keynote three tones above the relative minor, as A minor–C major.) The exposition thus creates an opposition of tonalities or key areas that the rest of the movement—the development and recapitulation—will strive to reconcile. Compared with the contrast of keys, the question of how many themes the movement possesses is of minor structural significance. Very often, a movement in sonata form has two clearly defined main themes, for example the first movement of Mozart's *Symphony No. 41 in C Major*. It may also have only one, like the first movement of Haydn's *Symphony No. 85 in B Flat Major*. Or it may have more than a half dozen strongly characterized themes, as does the first movement of Brahms's *Fourth Symphony*.

Thematic and tonal contrast

The thematic organization of a movement in sonata form may affect the character of the exposition, and thus of the whole movement, in two specific respects. When two themes or groups of themes are clearly differentiated, their distribution may help the listener to assimilate the cardinal points of the tonal design (that is, the arrangement of keys) of the movement. When, on the other hand, such differentiation between themes is obscured or set at variance with the organization of tonalities, the very tension between thematic design and tonal scheme may greatly enhance the subtlety and interest of the form. Such tension may produce not merely an interplay of melody and key within the movement but an interplay between two interplays. One fairly simple way of achieving this is shown in the first movement of Haydn's *Symphony No. 99 in E Flat Major*. Here, as in *No. 85*, the first theme is restated in the dominant key. This restatement could appear at first to be the second subject. But later it is followed by another distinct motive that, in terms of themes, is the real second subject. At the same time the neat, almost epigrammatic character of the second subject makes it similar to a codetta theme, which is often used to round off the exposition after both main subjects have been stated.

In the first movement of Mozart's *Symphony No. 35 in D Major (Haffner)* this interplay of interplays reaches a higher level of subtlety. The second theme, against which the first persists as a counterpoint, is stated "on" rather than "in" the dominant; that is, its harmonies suggest the dominant key, but remain part of the home, or tonic, key. The second theme is thus heard as a new perspective on the tonic. Later, when the dominant key is firmly established in its own right, Mozart introduces a new subject whose tune is closely related to the first theme. In this richly ambiguous structure, the newly introduced motive would be regarded by the criterion of key, as the second subject; in purely thematic terms, it might almost be said to constitute the beginning of the codetta, or concluding section.

The functions of the other two main sections follow naturally from what has been established in the exposition. Their purpose is to discuss and resolve the conflicts of tonality and theme that the exposition has raised. The development is an area of tonal flux—it usually modulates, or changes key, frequently, and any keys it settles

Modulation and thematic alteration

in are likely to be only distantly related to the keys found in the exposition. It frequently proceeds by breaking the principal themes down into smaller elements and bringing these elements into new tonal or contrapuntal relations with each other. That is, themes or fragments of themes may appear in new keys; they may be combined to form apparently new melodies; they may be played against each other as counterpoint, or countermelody. One of the finest illustrations of the methods of development used in the Classical period occurs in the first movement of Mozart's *Symphony No. 38 in D Major (Prague).* Another resource of development is to seize on an apparently minor feature of the exposition and, by developing it extensively, to demonstrate its hidden importance. Another is to introduce entirely new material. This may provide a moment of relief in the course of a rigorous argument (as in the last movement of Mozart's *Piano Sonata in C Major,* K. 330); or it may allow the composer to expand the scope of a large-scale movement (as in the first movement of Beethoven's *Symphony No. 3 in E Flat Major,* the *Eroica*).

Sometimes such a theme may only *seem* to be new. In the first movement of Beethoven's *Symphony No. 4 in B Flat Major,* for instance, the theme in the development that is usually described as "new" is really a decorated version of a motive already heard in the exposition.

One common tactic in the Classical development is to begin the section with the codetta theme that ended the exposition. The first movement of Beethoven's *Cello Sonata No. 2 in G Minor,* Opus 5, No. 2, is an example.

The impact of this device, and of the development section as a whole, is often obscured by the common tendency among modern performers to ignore the composer's instruction, present in almost all sonata form movements of the Classical period, to repeat the entire exposition. When this repetition is omitted, the thematic balance of the movement is upset and the dramatic effect of the development's sudden departure from an established regularity can be ruined. Music is an art to which the controlled use of time is basic. The temporal structure of a movement cannot be altered without seriously changing the proportions of the whole.

Tension and recapitulation

Like the beginning of the development section, the point at which development passes into recapitulation is one of the most important psychological moments in the entire sonata structure. It marks the end of the main argument and the beginning of the final synthesis for which that argument has prepared the listener's mind. The Classical masters differ in their handling of this juncture. All usually prepare for it with a long passage of gathering tension. In Mozart the return of the tonic key and subject is managed with understated punctuality, the actual moment of recapitulation gliding in almost unnoticed. Haydn and Beethoven tend to celebrate its advent with panoply.

The recapitulation presents the principal subject matter of the movement in a new state of equilibrium. The main subjects of the exposition are heard almost always in the same order as before, but now both subjects are typically in the tonic key, whereas in the exposition the first was in the tonic, the second in the dominant key. As a result of the musical events in the development, the listener perceives the subjects in a new relationship—rather like a traveller who glimpses the constituent parts of a valley separately as he climbs a hill and then, when he reaches the summit, sees the entire landscape for the first time as a whole. The recapitulation can vary greatly in the literalness with which it repeats the elements of the exposition. Sometimes, as in the first movement of Mozart's *Sonata in B Flat Major,* K. 570, a tiny modification in the transition that originally led from the tonic to the dominant key is enough to effect the necessary change of key perspective and keep the second subject in the tonic key. In other cases (the first movement of Beethoven's *Eroica Symphony,* for instance, and many of Haydn's symphonic movements) far-reaching modifications and reshufflings of the original material are made in the recapitulation. As in any living manifestation of a principle of musical form, the methods differ vastly from work to work; but the effect is always to bring about the reconciliation of opposites that is essential to sonata form.

A large-scale sonata movement often creates conflicts of key and theme that cannot be completely settled even by the full process of recapitulation. In this case, the movement may be rounded off with a coda, or concluding section. Beethoven often extends the coda so greatly that it becomes almost a second development section, as in his *Appassionata* piano sonata. But this is no more an essential element of sonata form than the introduction that may precede the main movement.

The form described above is that exemplified in most first movements of sonatas, and of sonata-style compositions, in the Classical period. There are usually two, three, or four movements in the entire work. Two-movement and, more particularly, three-movement schemes are most common in sonatas for one or two instruments. Symphonies and string quartets almost always have four movements, and Beethoven, particularly in his earlier period, sometimes expanded the scheme of the instrumental sonata to four movements too.

The first movement in all of these patterns is usually fast; the second commonly provides the contrast of a slower tempo; and the last in most cases is again fast. When there are four movements, a simpler, dance-style movement of the type also found in the suite is included. This is usually placed between the slow second movement and the finale; in some cases it stands second and the slow movement third.

The forms of these other movements vary much more than that of the first, which in Classical examples is almost invariably the weightiest. Since their function is to complement the experience of the first movement through a new but related range of contrasts, their scope and manner depend on the point to which the issues of the work have already been taken. Simple ternary (A B A) form and variation form (*i.e.,* theme and variations) are among the most common patterns for the slow movement, but rondo and sonata forms are also used. In rondo form a recurring theme is contrasted with a number of intervening themes, as A B A C A. When sonata form is used in slow tempos, the demands of overall proportion frequently cause the omission of the development section. Sonata form, rondo, and, less often, variation form are also used for the final movement. In final movements, also, the simple rondo pattern (A B A C A) is often expanded into A B A-development-B A, with B in the dominant key at its first appearance and in the tonic key at its second. The result is a hybrid form known as sonata-rondo.

The dance movement

In the first part of the Classical period, the dance movement, when it appeared, usually consisted of a minuet in fairly simple binary form (the two-part form from which sonata form evolved). This was followed by a second minuet known as the trio, which tended in orchestral works to be more lightly scored. The first minuet was then repeated, normally without its own internal repeats. The minuet-trio-minuet structure forms an overall ternary pattern. Haydn frequently, and Beethoven still more often, chose to speed the traditional minuet up to the point at which it lost its dance character and became a scherzo, a quick, light movement usually related to the minuet in form. In some extreme cases, such as the ninth symphonies of both Beethoven and Schubert, the binary structures of both scherzo and trio were expanded into small but complete sonata-form structures. In this way, as with the sonata-rondo, the principles of thematic development and key contrast spread during the Classical period as the sonata form began to influence other movements.

Such are the outlines of the most fertile form in Western instrumental music since 1750. Before discussing its origins, growth, and later modification, there should be a warning against phrases like "true sonata form." If sonata form as described is considered the sole "true sonata form," the implication is that instrumental sonatas written in forms other than sonata form are not genuine.

Actually, the principle exemplified in sonata form represents one way of organizing the passage of sound through time. Its scope is enormous; it was the basis for some of the greatest works of Western music; and it still contains the seeds of potential further development. But it is only one episode in a complex chronicle of styles and princi-

ples of musical organization. In contrast to earlier forms, it emphasizes conflict instead of continuity and derives its impact from the explosive power of tonal organization instead of the smoother influence of melody.

History of the sonata. The sonata in all its manifestations has roots that go back long before the first uses of the actual name. Its ultimate sources are in the choral polyphony of the late Renaissance (music having several equal melodic lines, or voices). This in turn drew at times on both liturgical and secular sources—on the ancient system of tones or modes of Gregorian chant, and on medieval European folk music. These two lines were constantly interweaving. Popular tunes, for example, were used as the starting point for masses and other religious compositions from the 15th to the early 17th centuries. Sacred and secular elements influenced the development of both the sonata and the partita (or suite) of the Baroque period.

Earliest origins

The specific musical procedures that were eventually to be characteristic of the sonata began to emerge clearly in works by the Venetian composers of the late 16th century, notably Andrea Gabrieli (*c.* 1520–86) and Giovanni Gabrieli (1556–1612). These composers built instrumental pieces in short sections of contrasted tempo, a scheme that represents in embryo the division into movements of the later sonata. This approach is found not only in works entitled "sonata," such as Giovanni Gabrieli's *Sonata pian' e forte* (*Soft and Loud Sonata*) of 1597, which was one of the first works to specify instrumentation in detail; the instrumental fantasia and the canzone, an instrumental form derived from the chanson or secular French part-song, display a similar sectional structure. Like early sonatas, they were often contrapuntal (*i.e.*, built by counterpoint, or the interweaving of melodic lines in the different voices, or parts). At this stage sonatas, fantasias, and canzoni were often indistinguishable from each other, and from the fuguelike ricercare, though this form is generally more serious in character and more strictly contrapuntal in technique.

In the 17th century stringed instruments eclipsed the winds, which had played an at least equally important role in the sonatas and canzoni composed by the Gabrielis for the spacious galleries of St. Mark's Cathedral, Venice. Claudio Monteverdi (1567–1643) devoted more of his energies to vocal than to instrumental composition. The development of instrumental writing—and of instrumental musical forms—was carried on more and more by virtuoso violinists. One of these was Carlo Farina (flourished *c.* 1630), who spent part of his life in the service of the court of Dresden, and there published a set of sonatas in 1626. But the crowning figure in this early school of violinist-composers was Arcangelo Corelli (1653–1713), whose published sonatas, beginning in 1681, sum up Italian work in the field to this date.

Apart from their influence on the development of violin technique, reflected in the works of such later violinist-composers as Giuseppe Torelli (1658–1709), Antonio Vivaldi (1678–1741), Francesco Maria Veracini (1690–*c.* 1750), Giuseppe Tartini (1692–1770), and Pietro Locatelli (1695–1764), Corelli's sonatas are important for the way they clarify and help to define the two directions the sonata was to take. At this point the *sonata da chiesa*, or church sonata, and the *sonata da camera*, or chamber sonata, emerged as complementary but distinct lines of development.

Church and chamber sonatas

The *sonata da chiesa* usually consists of four movements, in the order slow–fast–slow–fast. The first fast movement tends to be loosely fugal in style (*i.e.*, using contrapuntal melodic imitation), and thus reflects, most clearly of the four, the sonata's roots in the fantasia and canzone. The last movement, by contrast, is simpler and lighter, often differing from the dance style typical of the *sonata da camera* only in that its sections are not repeated. The *sonata da camera* is altogether less serious and less contrapuntal than the *sonata da chiesa*, and it tends to consist of a larger number of shorter movements in dance style. If the *sonata da chiesa* was the source from which the Classical sonata was to develop, its courtly cousin was the direct ancestor of the suite, or partita, a succession of short dance pieces; and in the 18th century, the terms suite and partita were practically synonymous with *sonata da camera*. The two streams represented by church and chamber sonatas are the manifestation, in early Baroque terms, of the liturgical and secular sources found in Renaissance music. The Baroque style flourished in music from about 1600 to about 1750. Down to the middle of the 18th century the two influences maintained a high degree of independence; yet the injection of dance movements into the lighter examples of the *sonata da chiesa* and the penetration of counterpoint into the more serious suites and *sonate da camera* show that there was always some cross-fertilization.

Another characteristic of the Baroque sonata that Corelli's work helped to stabilize was its instrumentation. Around 1600 the musical revolution that began in Italy had shifted emphasis from the equal-voiced polyphony of the Renaissance and placed it instead on the concept of monody, or solo lines with subordinate accompaniments. The comparatively static influence of the old church modes was superseded by the more dramatic organizing principle of the major–minor key system with its use of contrast of keys. Although counterpoint continued to play a central role in musical structure for another hundred years and more, it became a counterpoint that took careful account of the implications of harmony and of chords within the framework of the major and minor keys.

The continuo part

In this context the continuo, or thorough bass, assumed primary importance. The composer that used a continuo part wrote out in full only the parts of the upper melody instruments. The accompaniment, which was the continuo part, was given in the form of a bass line, sometimes supplemented with numbers, or figures, to indicate main details of harmony, whence the term "figured bass." The continuo was "realized," or given its performed form, by a low melody instrument (viola da gamba, violone, or later cello or bassoon) in collaboration with an organ, harpsichord, or lute. The collaborating instrument improvised the harmonies indicated by the figures or implied by the other parts and so filled the gap between the treble and bass lines.

In Corelli's work, "solo" sonatas, for one violin with continuo, are found alongside others for two violins and continuo described as sonatas *a tre* (*i.e.*, for three), early examples of the trio sonata that was the principal chamber-music form until about 1750. The use of "trio" for sonatas played by four instruments is only superficially paradoxical: although trio sonatas were played by four instruments, they were considered to be in three parts—two violins and continuo. Moreover, specific instrumentation at this period was largely a matter of choice and circumstance. Flutes or oboes might play the violin parts, and if either harpsichord or cello or their substitutes were unavailable, the piece could be played with only one of them representing the continuo. But a complete continuo was preferred.

Corelli's importance is as much historical as musical. Perhaps because a vigorous line of Italian composers of violin music followed him, he is commonly accorded the main credit for late 17th-century developments in sonata style. But his undeniably vital contribution should not distract attention from equally important work that was done around the same time outside Italy.

Early development outside Italy

In France Jean-Baptiste Lully's lucrative monopoly of music at the royal court and the immense popularity of spectacular ballets used as courtly entertainments naturally led, through François Couperin (1668–1733), to a concentration on the smaller dance forms found in the ballet and courtly social dance. This concentration gave the French school its preeminence as producer and influencer of the 18th-century dance suite. The French, thus occupied with dance music, had little effect on the growth of the *sonata da chiesa*. But in Germany, where in 1619 Michael Praetorius (1571–1621) published some of the earliest sonatas, the sonata developed from an originally close relation to the suite into a more ambitious blend. As it evolved it combined the suitelike multisectional structure of the *sonata da camera* with the contrapuntal workmanship and emotional intensity of the Italian *sonata da chiesa* form.

One of the first contributors to this development of

the Italian influence was the Austrian composer Johann Heinrich Schmelzer (*c.* 1623–80). In Nürnberg in 1659 he published a set of trio sonatas for strings, following it in 1662 with a set for mixed strings and wind instruments, and in 1664 with what may have been the first set of sonatas for unaccompanied violin. The German composer Johann Rosenmüller (*c.* 1620–84) spent several years in Italy; his *Sonate da camera cioè sinfonie* (*i.e.,* suites or symphonies), published in Venice in 1667, are essentially dance compositions. But 12 years later, in Nürnberg, he issued a set of sonatas in two, three, four, and five parts that vividly illustrate the German trend toward more abstract musical structure and expressive counterpoint. During this period even pieces with dance titles began to lose their danceable character and became compositions meant only for listening.

Meanwhile, the greatest member of this school, Heinrich Ignaz Franz von Biber (1644–1704), published several sets of sonatas—some for violin and continuo, others in three, four, and five parts. In these, from 1676 onward, he took a penchant for expressiveness to extremes of sometimes bizarre but often gripping profundity that contrast sharply with the bland, polished style of Corelli. The titles of some of Biber's sets of sonatas specifically indicate his aim of reconciling church and chamber styles. The 1676 publication, for instance, is entitled *Sonatae tam aris quam aulis servientes* (*Sonatas for the Altar as Well as the Hall*). And being himself, like Corelli, a violinist of extraordinary powers, Biber made a valuable contribution to the development of instrumental technique in a set of sonatas for unaccompanied violin in which the practice of *scordatura* (adjustment of tuning to secure special effects) is ingeniously exploited.

The English composers were achieving a comparable intensification of expression during the 17th century, though in their case the technical starting point was different. In accordance with the characteristic time-lag of the English in the adoption of new European musical methods, the English continued to work with polyphony in the Renaissance manner, while the Italians were perfecting monody and the Germans fruitfully uniting monody with their own contrapuntal tradition. English polyphony in the 17th century attained a remarkable level of technical finish and emotional grandeur. Thomas Tomkins (1572–1656), Orlando Gibbons (1583–1625), John Jenkins (1592–1678), and William Lawes (1602–45) were the chief agents of this refining process. They and their predecessors, notably John Coperario (*c.* 1575–1626), made a gradual transition from the string fantasia bequeathed by William Byrd and other composers during the reign of Elizabeth I (1558–1603) and approached the new kind of musical form associated with the Baroque sonata; but they always stayed closer than their continental colleagues to the spirit of polyphony.

Contribution of English polyphony

When Henry Purcell (*c.* 1659–95), in his three-part and four-part sonatas, submitted this rich English tradition to the belated impact of French and Italian influence, he produced a fusion of styles that was the highest point of musical inspiration yet reached by the emergent sonata form.

The Baroque era. The years from the end of the 17th century to the middle of the 18th represent a moment of equilibrium in the interaction of counterpoint and monody that had created the Baroque sonata. The continuo device, as long as it endured, was a sign that the balance still held—and it did endure as long as the trio sonata kept its central position as a chamber-music medium. During the first half of the 18th century the later Italian violinists, most notably Vivaldi, were prolific creators of trio sonatas. Sometimes they leaned to a three-movement pattern (fast–slow–fast), influenced by the direction the Italian operatic sinfonia, or overture, was taking. More often the old four-movement pattern was preserved. In this well-tested shape, too, Georg Philipp Telemann (1681–1767) produced hundreds of examples that maintained a remarkably consistent standard of musical interest. George Frideric Handel (1685–1759), working for most of his life in England, composed some trio sonatas, and also some valuable sonatas for solo instrument with continuo. In France, Joseph Bodin de Boismortier (1691–1755) and the violinist Jean-Marie Leclair the elder (1697–1764) cultivated both solo and trio genres with charm although with less profundity.

Yet even while the sonata with continuo flourished, the forces of tonality, or organization in terms of keys, developed intensely toward a use of key contrast that would eventually drive the trio sonata from the scene. The continuo itself was being undermined by the growth of interest in instrumental colour, and the figured bass could not long survive the tendency toward scoring for specific instruments and exhaustive detailed musical notation.

Rise of tonal consciousness

Beginning in 1695 Johann Kuhnau (1660–1722) had published the first sonatas for keyboard instrument alone, some of them programmatic pieces on biblical subjects. J.S. Bach (1685–1750), the greatest composer of Baroque sonatas, continued the move away from the treatment of the keyboard in the subordinate, "filling-in" capacity that was its role in the continuo. He wrote a small number of trio sonatas after the traditional scheme, and also a few violin and flute sonatas with continuo; but at the same time he produced the first violin sonatas with obbligato harpsichord parts (that is, obligatory and fully written out, rather than improvised), others for flute or viola da gamba with obbligato harpsichord, and three sonatas (along with three partitas) for unaccompanied violin.

In these works, as in some of Telemann's later sonatas, the power of key or tonality to articulate sections of musical structure, and its ability to provide a harmonically derived eventfulness—a sense of expectation succeeded by fulfillment—began to make itself felt. These powers of key are the seed from which the Classical sonata form originated. But at this point the dualism engendered by tonal and thematic contrast had not yet supplanted the more continuous, unitary processes at work in a composition based on counterpoint. Nor was the consciousness of tonality any more advanced in the otherwise forward-looking work of Domenico Scarlatti (1685–1757). His harpsichord sonatas—555 movements survive, many designed to be played in pairs or in groups of three—are often original to the point of idiosyncrasy in expression. They introduced a valuable new flexibility in the treatment of binary form, and they had a powerful effect on the development of keyboard writing. But in formal terms they still belong in the old world of unity—even their strongest contrasts have an air of being suspended in time, quite unlike the far-ranging effects of conflict through time that are the basis of the Classical sonata.

A later generation of composers completed the transition from Baroque to Classical sonata. One of J.S. Bach's sons, Carl Philipp Emmanuel Bach (1714–88), plunged enthusiastically into the new resource of dramatic contrast. In about 70 harpsichord sonatas, and in other works for chamber ensembles and for orchestra, he placed a new stress on key contrast not only between but, more important, within movements. Correspondingly, he emphasized the art of transition.

Transition from Baroque to Classical

In the development of sonata form in orchestral music, particular value attaches to the work of the Austrians Georg Matthias Monn (1717–50) and Georg Christoph Wagenseil (1715–77) and of the Italian Giovanni Battista Sammartini (1701–75). All three played vital roles in shaping the symphony, which assumed an importance equal to that of the solo or small-ensemble sonata. Their symphonies further stressed the individual characterization of themes and, in particular, the use of the second subject to shape form. Another of Bach's sons, Wilhelm Friedemann Bach (1710–84), made sporadic but interesting contributions to this development, and a third, Johann Christian Bach (1732–82), who settled in London, exploited a vein of melodic charm that influenced Mozart.

The Classical era and later. By about 1770 most of the specific changes that dictated the shift from Baroque sonata to Classical sonata were firmly established. Through the work of the Neapolitan school of opera led by Domenico Scarlatti's father Alessandro (1660–1725), the operatic sinfonia, or overture, had streamlined the traditional *sonata da chiesa.* It omitted the opening slow movement and abandoned the fugal manner that was

the first allegro's link with the past. In the new three-movement pattern, a minuet sometimes replaced the fast, abstract finale. In other cases, the inclusion of both minuet and finale brought the number of movements back to four. The south German Mannheim school of composers —most notably Johann Wenzel Stamitz (1717–57) and his son Karl (1745–1801)—developed the technique of the orchestra, whose resources now provided an ideal laboratory for experimentation with the dramatic effects of tonal contrast.

By this time the Classical sonata proper (*i.e.*, with at least one movement in sonata form), whether in the medium of sonata, trio, quartet, quintet, or symphony, could provide a vehicle for consolidating the process begun nearly two centuries earlier by the revolution from equal-voiced polyphony to monody, with its emphasis on melody and harmony. The Rococo style of the mid-18th century, generally known as *style galant*, had attained a halfway stage in which counterpoint had been virtually dropped and tunes had occupied the forefront of interest. But now, in the mature Classical style of Haydn and Mozart, superficial melodic interest was in turn subordinated. In this style the value of tunes lay in their role as functions of tonality. Key by this time had had assumed a central role as the fundamental articulator of form. As a corollary, musical themes were often, though not always, reduced to the status of mere motives, or tags. The theme's harmonic implications, which contribute to the feeling of key, took precedence over its attractiveness as melody.

Subordination of melody to tonality

The new musical principle—that of contrast of key—reached full expression in Haydn and Mozart through their use of sonata form as a principle of musical organization. Haydn's most valuable work in the sonata form is found in his series of over 80 string quartets, over 100 symphonies, 52 keyboard sonatas, and 31 trios for piano, violin, and cello. Unlike Haydn, Mozart was at his greatest in the fields of opera and of the solo concerto. (The latter, though it shared with sonata form such elements as the central principle of key contrast, was a medium that evolved, through the Baroque concerto grosso, from the fundamentally different source of the solo vocal aria and the vocal-instrumental concerto.) But in the last six symphonies, the last 10 string quartets, about a dozen keyboard sonatas, and several trios, quartets, quintets, and serenades, Mozart achieved outstanding examples of sonata structures. The formerly prominent sonata for violin plays a relatively minor part in both men's output: the violin had been eclipsed by the rise of interest in keyboard instruments. It was reintroduced almost surreptitiously as a distinctly subordinate partner and regained a leading role only toward the end of the 18th century in Mozart's later violin sonatas and then in Beethoven's.

The strikingly individual details in Haydn's and Mozart's handling of sonata form are all features consonant with the general outlines of the form. Examples of different approaches include Haydn's taste for combining dualistic key schemes with monistic thematic material (that is, the use of the same basic theme in both keys). He also frequently set slow movements in keys only distantly related to the key of the first movement. Mozart preferred strongly differentiated themes, and he often reshaped his second subjects drastically when they reappeared in the recapitulation. Beethoven, in his sonata compositions (preeminently, the 32 piano sonatas, the 16 string quartets, the trios, the 9 symphonies, and the sonatas for violin and for cello), retained the basic sonata form. But he vastly extended its scale; *e.g.*, by increasing the importance of the coda, or concluding section, and by using unusual keys in the exposition, which was greatly increased in length. He also introduced extramusical implications of a profound philosophical nature. In his later sonatas and quartets he began to move away from the dualistic sonata principle and back to the monistic approach exemplified in variation form and fugue.

The case of Franz Schubert (1797–1828) is quite different. The first movement of the *Symphony No. 5 in B Flat Major* (written when he was 19) is one among several places that illustrates a changing attitude to sonata principles. In the recapitulation of this movement, the first theme is given in the subdominant key (the key whose keynote is five tones below that of the tonic, or home key, as F–C, just as the tonic's keynote is five tones below that of the dominant key, as C–G). This device enables Schubert to place the second theme in the tonic key (the goal of the recapitulation) without altering the transition between the two themes; for the same passage that, in the exposition, took the music from the tonic to the dominant serves, in the recapitulation, to take it from the subdominant to the tonic. This essentially labour-saving procedure is evidence of a certain lack of patience with the workings of sonata form as hitherto practiced. Up to this time, sonata form, first treated as a textbook study after Schubert's death, was not a set of rules codified by theorists and followed by composers. Rather, it was a principle of composition that grew out of earlier forms and that can be generalized from an examination of the actual work of Haydn, Mozart, Beethoven, and their contemporaries.

19th-century trends

Schubert's interests lay in new directions, and the first steps in two such directions are to be found in the greatest of his instrumental works. His later sonata-form compositions in all media—when they follow the rough traditional scheme of exposition, development, and recapitulation—modify it substantially. He frequently expanded the number of tonal centres (central keys) in the exposition, and sometimes also the number of basic themes, from two to three. This tendency to expansion affects the whole subsequent course of the Austro-German symphonic tradition. It is the direct ancestor of the expositions of Anton Bruckner (1824–96), with their three distinct thematic groups, and of the vastly extended sonata structures of Gustav Mahler (1860–1911). At the same time, Schubert's *Fantasy in C Major (Wanderer)* for piano (1822) exemplifies an opposite 19th-century trend toward contraction, through the fusion of the sonata's formerly separate movements in one closely integrated whole: the four movements of the fantasy are based on transformed versions of a single theme. Similarly, in France, Hector Berlioz (1803–69) in his *Symphonie fantastique* transformed the theme representing the artist's beloved (the *idée fixe*, or fixed idea) so that it took different forms in each movement. In this case the transformation was affected by the program or "plot" of the symphony. This was a departure from the abstract, or plotless, character of the Classical sonata. The tendency to fusion—that is, to thematic unity between movements—was the source of the thematic transformations used in symphonic poems, such as those of Franz Liszt (1811–86), as a basic principle of musical structure. But in these works the program rather than any abstract musical form suggests the particular course of the transformation of the themes. For this reason their specific form does not depend, as did that of the Classical sonata, on the exposition–development–recapitulation principle of contrast, conflict, and reconciliation of keys. A corresponding evolution away from the Classical form of the sonata for one instrument occurs in Liszt's one-movement *Piano Sonata in B Minor* (1853). In this work he used a single extended movement with subdivisions analogous to the sections of sonata form. But the specific use of his four themes, which are transformed and combined in free fashion, departs from the usual order of the classical Sonata.

The influence of program music

Robert Schumann (1810–56) likewise experimented fruitfully, especially in his *Symphony No. 4 in D Minor*, with the Schubertian idea of fusing movements together. The tendency to use thematic transformation in a manner that moved away from the Classical sonata form was complemented by César Franck, who adhered to the basic form but from 1841 utilized a "cyclic" approach; that is, one of fusion, or thematic relationships between movements. Brahms, on the other hand, carried the more familiar Classical sonata form to its highest point of complexity. In addition to making valuable innovations in rhythmic structure, he gave the role of counterpoint a new lease of vigour and interest and used the concept of thematic relationships between movements in a particularly subtle way. Chopin's three piano sonatas are concerned more with lyrical expression than with innovative formal methods. Similarly, the sonata compositions of Carl Maria von Weber (1786–1826) and Felix Mendelssohn (1809–47),

which generally followed the patterns of their Classical predecessors and were highly regarded in their day, contributed little to the evolution of sonata form away from its Classical state. This evolution, illustrated by the works of Berlioz and Liszt, was carried forward by Mahler. In his symphonies expansion, through inclusion of more than two tonal centres and groups of themes, and fusion, or the creation of unity between movements, are combined. This gives rise to expansive compositions held together by complex interrelationships between themes. Arnold Schoenberg (1874–1951), in such works as his *First String Quartet* (1904), carried the idea of fusion of movements to its logical conclusion: this is a one-movement work with contrasting sections in which all the themes used are derived from a few basic motives.

Weakening of the Classical sonata form

Two important 19th-century developments tended to weaken the effectiveness of the Classical sonata form as an organizing principle. One, exemplified by Richard Wagner (1813–83), was an increasing use of chromaticism; that is, of notes and chords foreign to the key in which a passage of music is written. Chromaticism, when used extensively, broke down key feeling. Instead of being heard as a contrast to, or special modification of, the key, it became so prominent that the key itself was not heard strongly enough to establish itself in the listener's mind. Secondly, Liszt and his followers weakened the sonata form by using in their symphonic poems musical organizations based on program rather than on contrast of keys. But although the effectiveness of key as a basis for musical organization was weakened by the late 19th century, Mahler and Carl Nielsen (1865–1931) provided a modification of the sonata form that made use of tonality in a new way. This innovation, progressive tonality, used the home key as a goal to be worked toward from more or less distant key regions, so that a work ends in a different key from the one in which it began. Mahler and Nielsen arrived at the same notion independently at the same time. Nielsen's *First Symphony* and Mahler's *Second Symphony* (both 1894) are the first to use progressive tonality, and both composers forged highly individual new forms from it.

Most compositions written in sonata form after Wagner's era, however, lack a certain sense of vitality. Frequently, because the effectiveness of key or tonality has been weakened, such compositions centre on melody without the strong contrast of tonality that underlay the Classical sonata. Some composers made stylistic compromises. Schoenberg's *Fourth String Quartet* used his 12-tone (dodecaphonic) approach to composition, an approach that began with a "row," or series, of the 12 tones of the chromatic scale, chosen by the composer to serve as the melodic and harmonic basis for the composition. In this work he fits the 12-tone style into the outlines of sonata form. The result is based on contrasting themes, rather than on the Classical sonata principle of key contrast, because 12-tone music, being atonal, deliberately avoids the creation of a sense of key. In a comparable way, though in the context of a different style, some of the sonatas of Sergey Prokofiev (1891–1953) use the outward formal divisions of the classical sonata form but stress the interest of melody as such, leaving tonality—still present in this case—to play a decorative rather than a structural role.

New principles

Other modern composers developed new principles of musical form. Although these principles appear in genres traditionally associated with the sonata, such as instrumental sonatas, string quartets, and orchestral works, they vary in the degree to which they are or are not related to the Classical sonata form.

One of the more useful of such principles has been the technique of constructing large-scale compositions from transformations and developments of a single germinal motive, often merely two or three notes. Like Schoenberg's approach, in which a 12-tone row is transformed, this is actually the application at a more radical and consistent level of the 19th-century principle of thematic transformation. The symphonies of Jean Sibelius (1865–1957) are based on this method. So are those of Ralph Vaughan Williams (1872–1958), who also used some of the features of sonata form but imaginatively reshaped them and transformed their proportions to suit his purpose. In the nonsonata works of Schoenberg and his pupils Alban Berg (1885–1935) and Anton Webern (1883–1945), the 12-tone method produced legitimate new forms of the highest historical importance; but when forced into an uncomfortable liaison with earlier schemes of organization such as the sonata, its effectiveness diminished. In the works of Béla Bartók (1881–1945), passages built on folk music scales, rather than on the major and minor scales of 18th- and 19th-century keys or tonalities, are used alongside atonal passages. His musical structure frequently takes the form of a combination of elements of sonata form with a simple "archlike" structure such as A B C B A. Paul Hindemith (1895–1963) contributed copiously to the sonata medium with works for almost every known instrument, but as far as the form was concerned his innovations were of minor significance. Sir Michael Tippett in his *Second Symphony* and sonatas (*e.g.*, for piano; for four horns) uses tonality in a fresh and valid way, and he has effected a stimulating rapprochement of the sonata form with the equal-voice polyphony characteristic of the English fantasia and madrigal (a genre of part-song) of Elizabethan and Jacobean times. The *Second Symphony* of Wilfred Josephs shows yet another potentially valuable reinterpretation of the fused-movement approach to the sonata: its long first movement serves the function of exposition, three intermediate movements act on one level as development and on another level as a combination of slow movement and scherzo, and a brief finale serves as a kind of recapitulation.

Other musical approaches use metre and instrumental tone colour to mark important musical points much as traditional sonata form used contrast of keys. Elliott Carter has combined a use of germinal motifs with a new rhythmic technique known as "metric modulation," a controlled change of metre foreshadowed in Brahms by such passages as the end of the *Second Piano Concerto*. Carter's *Sonata for Cello and Piano* is an example of this use of metre. Carter also uses the idea of sharply differentiating the musical subject matter given to the individual instruments of an ensemble—a resource found earlier in the *Second String Quartet* of Charles Ives (1874–1954). Some of the many styles of Igor Stravinsky (1882–1971), particularly after his late adoption of the 12-tone approach, make ingenious use of germinal motifs; but his music really bases its structure on the juxtaposition of large blocks of distinct musical character, rather than on "development" in the sense traditionally associated with the sonata.

Music in the latter half of the 20th century is too various in form, medium, esthetic attitude, and social function to allow any confident predictions. But all of these examples suggest that the sonata, and its special manifestation, the sonata form, can still provide composers with fertile areas of activity. As in the time of Haydn, Mozart, and Beethoven, success will continue to reward those who develop musical forms that grow naturally from the specific principles of composition used in their works, much as the sonata form grew out of the principle of contrast, conflict, and resolution of tonalities that characterized the sonatas, symphonies, and chamber music of the 18th and 19th centuries. (B.Ja.)

CONCERTO

Since about 1750 the term concerto has been applied primarily to the solo concerto; *i.e.*, a musical composition for instruments alone in which an orchestra and a soloist interrelate by alternating, competing, or combining on a more or less equal footing. In this sense the concerto, like the symphony or the string quartet, may be seen as a special case of the generic musical form embraced by the term sonata. Like the sonata and symphony, the concerto is typically a cycle of several contrasting movements integrated tonally and often thematically. The individual movements are usually based on certain recognized designs, including sonata form, A B A (the letters refer to large distinct musical sections), variations, and rondo (such as A B A C A).

But the concerto tends to differ from the sonata, too, in certain ways that set it apart. Thus, in the sonata form

of the concerto's first movement, the exposition often remains in the tonic key while played by the entire orchestra the first time through. The expected departure to a nearly related key and the introduction of the soloist are reserved to a characteristically more elaborate repetition of the exposition. Moreover, to meet a felt need for a more brilliant ending in the same movement, the concerto provides or at least invites an improvised cadenza near the end of the movement—an extended, free flourish that may go on for as long as several minutes. A shorter cadenza may also occur at a strategic point in one or more of the other movements. In addition, the concerto has followed much more consistently than the sonata the plan of three movements, in the order fast–slow–fast. The second movement leads, often without pause, into the finale, or last movement, and the finale has shown a more consistent preference for the rondo design. But, importantly, all of these distinctions of musical form are secondary to the dialogue inherent in the concerto's interrelationship of soloist and orchestra. This dialogue influences the very nature of the solo part by almost forcing the soloist into a virtuoso's role so that he can compete on an equal footing with his adversary, the orchestra. The dialogue, furthermore, influences not only the construction of individual musical phrases but also the musical textures chosen. In addition, it affects the ways of developing musical material (*e.g.*, themes, rhythms) according to the logic of musical form, and even the broader blocking off of sections within forms, as in the concerto's repeated exposition, with its sections for full orchestra (tutti) and soloist.

Dialogue between soloist and orchestra

The literature of the concerto since 1750 is extensive in all categories, although the standard repertoire is limited to scarcely more than a few works for each main solo instrument. Being a prime ingredient of popular concert fare, the concerto is subject, much as is opera, to the exigencies of the box office. The film and phonograph industries have helped further to give disproportionate promience to a few highly successful and undeniably effective examples like those for piano by the Norwegian Edvard Grieg (in A minor) and the Russians Peter Ilich Tchaikovsky (in B flat minor) and Sergey Rachmaninoff (in C minor).

Taking music's commonly accepted eras for its framework, this examination of the concerto starts in the late Renaissance (16th century), with the origins and first uses of the term. It proceeds to the Baroque era (about 1580 to 1750), which was the first main era of the concerto, including the vocal-instrumental concerto in the late 16th and 17th centuries and, especially, the concerto grosso in the late 17th and early 18th centuries. The discussion progresses next to the Classical era (about 1730 to 1830) and the Romantic era (about 1790 to 1915), which mark successive though dissimilar heydays of the solo concerto partially discussed above. Lastly it reaches the modern era (from about 1890), which has witnessed further vitality in the solo concerto and a renaissance of the older concerto grosso principle of contrasting instrumental groups. Within each era examined, the prime considerations of the discussion are the meanings of "concerto" as then current; the concerto's place in the social life of the time: its scoring, or particular use of musical instruments and voices; its means of achieving opposition and contrast (if any); its musical structure; and its output by chief regions and masters.

Origins of the concerto. The word concerto has given trouble to music historians concerned with word origins because within a century after its first known applications to music, in the early 1500s, it had acquired two meanings that would seem to be mutually exclusive. One meaning still current in Italian is that of "agreement," or, as in English, of being "in concert." The other is that of "competing" or "contesting," from the Latin *concerto, -are, -atus* ("to contend"). Probably derived from the same Latin word are such related terms as the Italian *conserto, concertato,* and *concertante;* the Spanish *concierto;* the French *concert* and *concertant;* and the English consort. Yet it is this dual meaning itself that offers the most tangible thread of unity throughout the four-century history of the concerto in its various forms. In other words, the concerto, in whatever guise it assumes, reveals a continuing need to resolve the antithetical ideas of concord and contest. The balance between contest and concord is the concerto's particular solution to the problem of variety within unity that must be resolved in all dynamic art forms.

Original dual meaning of concerto

In the 16th century the word concerto embodied several meanings. As early as 1519 in Rome it referred simply to a vocal or instrumental group (*un concerto di voci in musica*). By 1551 it was used with implications of musical texture, specifically of the contrast of soprano voice with bass and alto ("soprano in concerto col basso & alto"). By 1565 the cognate word concertato was being used in reference to both voices and instruments. And by 1584 a Venetian title, *Musica . . . per cantar e sonar in concerti,* brought forth the meaning of group presentations or concerts.

Although in 1578 "concerti" was used to mean the music itself, for both voices and instruments (rather than performers or concerts), the first formal musical title of this sort appeared in 1587. This was the *Concerti . . . a 6–16 voci* (*Concertos . . . in 6 to 16 Parts*), a collection of vocal and instrumental music by the Venetian composer Andrea Gabrieli and his nephew Giovanni Gabrieli. No formal title concerto is known to be given to strictly instrumental music before 1621, and then the word means both "concerted" or "playing together" and "technically [or even 'virtuosically'] elaborated." This title, with significant implications of a new style—that of the virtuoso soloist—is the *Sonate concertate in stilo moderno* (*Concerted Sonatas in the Modern Style*), by an Italian, Dario Castello, a collection for a violin and for a bassoon that elaborates on the basso continuo part. (The basso continuo, a constant device of Baroque music, calls for a low, sustained-tone instrument—*e.g.*, cello, viola da gamba, bassoon—playing the bass line, plus one or more chordal instruments—*e.g.*, harpsichord, organ, lute—that improvise harmonies above the bass line. Small numbers, or figures, are often placed above the bass line music as a guide to the harmonies, hence the term figured bass.)

Means of contrast

In these early, loosely titled collections by the Gabrielis and by Castello, there can be found at least five of the means of contention or opposition that later became closely identified with the *stile concertato* or concerto. Listed in their approximate order of evolution, they include opposition between voices and instruments; between one choir and another (whether of voices or instruments); between the essential basso continuo and its melodic elaboration; between simple, straightforward parts and more decorative, virtuoso parts; and between two or more voices or instrumental parts engaged in imitative or motivic interplay.

Within the span of a century and a half the Baroque era saw the word concerto change from a broad general term applied on several musical levels to a fairly specific term whose meaning had two senses: that of an instrumental group and that of a musical structure or process. Thus in the Gabrielis' early Baroque "Concerti" the title referred to a collection consisting of church motets (Latin choral compositions) and madrigals (similar Italian compositions) for six to 12 voices in one or two choruses, without and with instruments; a piece for eight voices imitating a battle; and a "Ricercar per sonar" for eight instruments (a ricercar is a piece often based on melodic imitation; *sonar* means to play instrumentally). By contrast the more than 460 late-Baroque "Concerti" composed by the Italian Antonio Vivaldi from the first half of the 18th century are purely instrumental works, mostly three-movement cycles (fast–slow–fast) for one to four soloists and strings with or without other orchestral instruments.

Sonata, symphony, and concerto

The same century and a half saw a similar narrowing of definition in two closely allied terms: sonata and sinfonia. Before sonata, sinfonia, and concerto became clearly defined and attained a degree of mutual exclusion, they often overlapped and were sometimes even equated in meaning. The full title on one musical manuscript by the Italian Alessandro Stradella, for example, reads, *Sonata di viole, cioé per concerto grosso di viole, concertino di due violino e leuto* (*Sonata for Viols, that is, for Full Complement [concerto grosso] of Viols, and Small Group [concertino] of Two: Violin and Lute*). Another reads, *Sinfonia per violini*

e bassi a due concertini distinti (*Sinfonia for Violins and Basses in Two Distinct Groups*). Many so-called trumpet sonatas of the same period, especially those by Domenico Gabrielli and Giuseppe Jacchini, simply equate the three terms without distinction. When Tommaso Antonio Vitali entitled his Opus 4 *Concerto di sonate* . . . (published 1701), he evidently meant no more than "A Collection of Sonatas," for there was only a violin part, a basso continuo part, and the *concertate* cello part that so often elaborated on the basso continuo. But later, when "Concerto" was crossed off a harpsichord solo by the German composer Johann David Heinichen, copied posthumously in 1731, and "Sonata" was entered in its place, the intention was probably to choose a title more identified with the performing instrument, although the work may well have been transcribed from a concerto.

It is no wonder, then, that even the traits most basically identified with the concerto can be found in works of other titles. G. Gabrieli wrote works for as many as five opposed choirs of instruments under the title of "Sonata." The "sonatas" of the German composers Johann Joseph Fux and Georg Muffat have passages actually marked "T." and "S." for tutti and soli (soloists) groupings, and, indeed, the tutti–soli principle of contrast still operates strongly in the classical symphonies of Haydn and Mozart. These cross-influences are important reminders that any full history of the concerto idea must take into account not only the concerti in the literature but many works with other titles. Yet in a more concise, encyclopaedic summary it is necessary to stay close to the evolution of the term concerto itself, and there is a real significance in observing how the word acquired definition. The evolution of the word in effect reveals the composers' own developing concepts of it. Concerto was the last of the three terms (sonata, sinfonia, concerto) to attain clear definition. In part this was because the word first had to grow free of its original association with music for both voices and instruments.

Cross-influences

The Baroque vocal-instrumental concerto (c. 1585–1650). As already suggested, the first category of music to be associated significantly with the term concerto was that of the vocal-instrumental concerto. If this category is sometimes incorporated only incidentally into overall accounts of the concerto, the reasons lie, first, in its lack of clear identification with any one type of musical form and, second, in the longer, more vivid association of all later categories of the concerto with music exclusively for instruments.

Both the early association of the word with vocal-instrumental combinations and the lack of a clear, identifiable musical form are apparent in the important discussion of the concerto in 1619 by the German composer and theorist Michael Praetorius in his *Syntagma Musicum* ("Writings on Music"). Praetorius classified the concerto, along with the motet and the *falsobordone* (or simple harmonization of a liturgical reciting tone), among vocal pieces that have a sacred or serious secular text. He recognized the two general, and related, types that were to prevail in the vocal-instrumental concerto. The multivoice type was in more than four parts and typically subdivided into opposing choirs, especially low versus high choirs. The few-voice type was for one to four parts; often solo parts, and basso continuo; according to Praetorius, this type, which permitted the text to be understood better, was then replacing the madrigal in Italy. Aside from implications of modernism and greater appeal in the concerto and conservatism and greater weightiness in the motet, Praetorius found no distinction between *concert, concertos ecclesiasticos, sacras cantiones, sacros concentus,* and *motettas.*

Praetorius found that the concerto was performed especially in the church and, particularly the few-voiced type, in the monastery. Today one surmises from titles and prefaces to published concerti, from contemporary paintings, and even from the kinds of instruments specified, that the main social breeding ground for the vocal-instrumental concerto was the chapel, above all the court chapel, and the chapel's resources of musicians and instruments were in fact largely those called for by the concerti of the time.

The distinction that Praetorius drew between the multi-voice, polychoir concerto and the few-voice, soloistic concerto proved to be the most significant distinction throughout the course of the vocal-instrumental concerto. Yet the two types were not independent of each other but were interrelated in their common derivation from the late-Renaissance, polyphonic madrigal and motet. Moreover, they were interdependent. On the one hand, the few-voiced concerto thrived not only on the desire to make the text more understandable and hence more appealing but also on a practical need, in the smaller, less fortunate chapels, to reduce the larger vocal and instrumental groupings to such resources as were available locally (as, for example, during the economizations in Germany brought on by the Thirty Years' War, 1618–48). On the other hand, the polychoir and other larger groupings thrived not only on the desire for more massive, imposing sound but on the opportunity that larger, better staffed chapels provided to expand compositions written for the smaller groupings, whether by adopting alternative scorings that the composer might provide or by improvising other dispositions to suit the immediate place and occasion.

Freedom in use of singers and instruments

There is a clear instance of expanding the scoring in one Gabriele Fattorini's . . . *Sacri concerti a due voci* . . . (. . . *Sacred Concerts for Two Voices* . . .). This work appeared originally in 1600 merely "with a basso continuo for the greater convenience of organists" and only two years later was republished "with a new addition of some four-part ripieni [or *tutti* groupings] to sing in two [opposed] choirs." A good hint of the improvisatory practices is offered in the *Vezzo di perle musicali* (1610; *Necklace of Musical Pearls*), by Adriano Banchieri. Banchieri explains that his pieces are arranged so that "the same concerto can be altered in six ways over the *basso seguente* [a composite bass line taken from the lowest notes in whatever parts], with one or more parts, whether vocal or instrumental."

The natural consequence of this much interdependence and interrelationship of the two types, multivoice and few-voice, was their fusion in vocal-instrumental concerti that provided the massive oppositions of the larger groups, the subjective intensity of the soloists, and the opposition between group and soloist. This fusion, especially in Protestant Germany, often with the incorporation of a Protestant chorale, or hymn, substantially influenced the subsequent development of the German cantata, which was frequently based on a chorale and, like the vocal-instrumental concerto, included vocal soloists, choir, and instruments.

A more specific idea of the Baroque vocal-instrumental concerto might best be given by a brief description of the scoring and nature of six successive, representative examples, running from shortly after the pioneer collection by the Gabrielis in 1587 to a late collection (1650) by the German composer Heinrich Schütz. Banchieri's *Concerti ecclesiastici,* published in Venice in 1595, consists entirely of eight-part motets for double chorus, with a "score" added for organ. This "score" for this double-chorus collection consisted of the soprano and partially figured bass parts of the first chorus only—a partial score enabling the keyboard player to orient himself. Unlike the Gabrieli collection of concerti, Banchieri's is composed exclusively of sacred texts. By contrast, Lodovico da Viadana's popular and influential *Cento concerti ecclesiastici a 1, a 2, a 3, e a 4 voci, con il basso continuo per sonar nell'organo* (*100 Ecclesiastical Concertos* [*i.e.,* motets] *for One, Two, Three, and Four Voices, with the Basso Continuo to be Played on the Organ;* Venice, 1602) exploits the new style, simpler and more intimate, yet florid and expressive, and including actual monody (solo vocal melody accompanied by expressive harmonies, a type of music new with the Baroque Era). These "concerti" achieve opposition mainly through the polarity of upper part(s) and bass, including such dispositions as two tenors and bass, tenor and two trombones, or two sopranos and two basses. In an important preface, especially treating of the organ part, Viadana argued that the reduction from the multivoice type of motet to these new few-voice "concerti" was made possible by the device of the basso continuo and its realization (*i.e.,* the improvised harmonies), which serve as a filler in lieu of the missing parts. Similar oppositions of high and

Influences of the Protestant chorale

low parts, but with secular texts and still greater variety, appeared in the *Concerto, Settimo libro de madrigali a 1, 2, 3, 4, & 6 voci, con altri generi de canti* (*Concerto* [*i.e.*, ensemble or concert consisting of the], *Seventh Book of Madrigals in 1, 2, 3, 4, & 6 Voices* [plus basso continuo], *with Other Kinds of Songs;* Venice, 1619), by the celebrated composer Claudio Monteverdi. Along with two pieces in homophonic, or chordal, style, labelled "Sinfonia," for five unnamed instruments, the book contains both compositions for smaller groups with virtuosic tendencies in the vocal parts and large pieces employing melodic imitation and suggesting Renaissance polyphony, with its independent melodic lines. An example of the larger type is *Con che soavità* [*With What Gentleness*], *concertato a una voce e 9 instrumenti* (making up three choirs of instruments specified for the viola family and a corpus of bass and filler instruments).

German developments

In the same year (1619), in Wolfenbüttel, Germany, there appeared one of several pertinent collections by Praetorius, *Polyhymnia caduceatrix & panegyrica* (named after the muse Polyhymnia), "containing 40 concertos of solemn peace and joy" for one to 21 or "more voices, arranged in" two to six choirs, "to be performed and used with all sorts of instruments and human voices, also trumpets and kettledrums." As Praetorius made clear in his detailed, prefatory instructions and in broader remarks about his concerti in his *Syntagma Musicum,* his concerti comprise a virtual compendium of the vocal-instrumental concerto in all its uses of voices and instruments and styles of opposition and in all its applications of the Protestant chorale, as well. The German composer Johann Hermann Schein acknowledged the influence of Viadana's more intimate concerti in the first set of his "sacred concertos," *Opella nova I* (1618; *Little New Opus*). But in his second set (Leipzig, 1626), he turned more to the larger scale styles of Praetorius for three to six voices and basso continuo. Representative is No. 12, *Hosianna dem Sohne David* (*Hosannah to the Son of David*), for two sopranos, two tenors, two basses, three *bombardi* (bass shawms), and basso continuo, with alternating sections of instrumental episodes, tutti in chordal style, and melodic imitation. In addition there are passages for three instrumental or vocal soloists, a combination often already encountered in the popular Baroque trio setting of two high parts over a low part. The last main landmarks of the vocal-instrumental concerto were the three sets of Schütz's *Symphoniae sacrae,* or *Sacred Symphonies* (Venice, 1629; Dresden, 1647 and 1650), works that reveal all the variety of treatment to be found in Schein's sacred concerti, except for Schein's interest in the chorale. The first two of Schütz's sets consisted of few-voice settings, mostly one to three voices with one or two obbligato (required solo) instruments and basso continuo. The third set extended to as many as eight parts (some of them optional) and basso continuo; in style it showed a considerable return to the concept of oppositions between choirs, chiefly between vocal and instrumental choirs.

The composers cited here were the main exponents and the Italian and German chapels were the main centres of the early-Baroque, vocal-instrumental concerto. After giving birth to the genre, Italy soon turned to opera, oratorio, and more independent instrumental forms. The Germans, whose derivation from the Italians was direct and unequivocal, developed the idea further and longer before it largely gave way to the Protestant cantata around the mid-17th century. Yet echoes of the vocal-instrumental concerto are still strong in the cantatas of J.S. Bach and his predecessor Dietrich Buxtehude.

The Baroque concerto grosso (c. 1675–1750). Late in the 17th century, within a generation after the vocal-instrumental concerto had last flourished in Germany, the concerto grosso began to assume a clear identity of its own in Italy and soon after in Germany and beyond. Its main ingredients have been noted earlier—the opposition of choirs or choir and soloists, the exchanges of melodic imitation, the trio setting of soloists, and even the use of "concertate" in a title of a purely instrumental work (by Castello). Other purely instrumental precedents of the mature concerto grosso exist in the considerable literature of music for opposing instrumental choirs in numerous "sonatas," "sinfonias," and "canzone" (instrumental pieces in several sections), starting with the works of Giovanni Gabrieli. Such anticipations, including the *Sinfonia à 8* (*i.e.*, in eight parts; 1618) of one Francesco Usper—a fortuitous, miniature concerto grosso in all but the name—accumulated during the 17th century. Good examples are the orchestral "trumpet sonatas" written in Bologna, Italy, during the second half. But not until the 1670s did the term concerto grosso itself come into general use. It indicated the larger of two contrasting instrumental groups within a composition, and in this sense the term was opposed to concertino (the smaller group), and signified the relation of full orchestra to one or more soloists. By 1698 it appeared as an actual title itself, in the published *Concerti grossi . . .* , by an Italian, Lorenzo Gregori. That this title did indicate a composite concept (*i.e.*, of opposing instrumental groups) is evidenced by frequent distinctions in prefaces and tables of contents between it (or its shorter equivalent, "Concerti") and the sinfonia or sonata. As one example, the *Sinfonie a tre e concerti a quattro* (*Sinfonias in Three Parts and Concertos in Four Parts,* Opus 5; 1692), by the Italian violinist and composer Giuseppe Torelli makes a distinction not only in the number of parts but in the style: between a dense, polyphonic, older style in the sinfonias, often performed with only one player to a part, and a newer, more open style in the concerti, suitable to multiple (orchestral) performance of the parts. As another example, whereas the German Georg Muffat had already called attention to the tuttisoli dispositions in his five orchestral "Sonate" of 1682, when he republished these in 1701 with revisions he changed the title of each to "Concerto."

Place in society

The social function of the concerto grosso was explicitly stated in 1701 by Muffat, who was as articulate about the secular concerto grosso and its performance as Praetorius had been about the sacred vocal-instrumental concerto:

> These concertos [in his *Ausserlesene . . . Instrumental-Music* or, *Selected . . . Instrumental Music*], suited neither to the church (because of the ballet airs and airs of other sorts which they include) nor for dancing (because of other interwoven conceits, now slow and serious, now gay and nimble, and composed only for the express refreshment of the ear), may be performed most appropriately in connection with entertainments given by great princes and lords, for receptions of distinguished guests, and at state banquets, serenades, and assemblies of musical amateurs and virtuosi. (As translated in Oliver Strunk's *Source Readings in Music History,* W.W. Norton and Company, Inc., New York, 1950, p. 449.)

The breeding ground of the concerto, therefore, was no longer the chapel but the court. From the standpoint of the local court administrator the concerto grosso offered certain economic as well as functional advantages, advantages that might even help to account for its predominance in Baroque instrumental music. The opposition of a full orchestra, playing relatively simple parts, to a few soli, playing more difficult, even virtuosic parts, made it possible to entrust the full-orchestra parts to relative novices in the court entourage, often to servants who could play in addition to their other duties. Thus, only a few solo parts had to be played by experts hired primarily as professional musicians. This practical advantage can be argued only while the distinction between simple and difficult parts prevailed. The distinction became less clear as the concerto matured, at least in works with one or more soloists.

Fundamental not only to the scoring but to the style, and even the musical structure of the Baroque concerto, was the opposition between the full orchestra, or *concerto grosso* (also called tutti, or *ripieno*), and the *concertino* (also called soli, or *principale*). A full complement of strings, usually two to four on a part, often sufficed for the "full orchestra," in addition to the one to three instruments needed to play and realize the basso continuo. Usually at least a low melody instrument, bowed or blown, and a chordal instrument, plucked or keyed, were used for the basso continuo. The same trio setting that had been popular from the start of the century, typically two violins and a cello, often served as the concertino. When the concertino was not playing soli passages it figured as part of the *concerto grosso.* Illustrative of these typical settings is the celebrated *Christmas Concerto* (Opus 6, No. 8; 1714),

Early examples of concerti grossi

by the Italian violinist and composer Arcangelo Corelli. The basso continuo sometimes rested while the concertino played (a frequent procedure in Vivaldi's concerti). One significant consequence of the tutti–soli relationship and its opposition of weighty and light masses of sound was a tendency to sharpen the contrast with the popular Baroque device of "terrace dynamics," or blocks of contrasting loud and soft sound. This occurred especially in the echo effect of a soli passage played piano after a tutti passage played forte. To this dynamic contrast might be added the rhythmic contrast between steady, solid beats in the tutti and more intricate, quicker figures in the soli, growing out of that same tendency toward simplicity, on the one hand, and virtuosity, on the other. Furthermore, not only all of the melodic ornamentation but also most of the passagework were ordinarily given to the soli rather than the tutti. When the tutti strings were augmented by wind instruments and the concertino was reduced to two players or only one (resulting in the first solo concerti), all these oppositions became that much more pronounced. Attention may be called, too, to the artful highlighting of the contrasts through different spacing—that is, through varied alternations of the two groups, now frequent, now less frequent after longer passages.

Opposition and contrast

These several means of contrast provided by motive interplay hardly exhaust the sources of variety to be found in the Baroque concerto grosso. Much variety is achieved in another of its basic kinds of opposition or competition. This is the motivic (or imitative) interplay between parts that is so characteristic of the *stile concertato,* or concerted style.

Such interplay may occur either between tutti and soli choirs or entirely within a succession of single instrumental parts in the full orchestra. In fact, there are numerous Baroque "concerti" that thrive primarily on the latter style of continuity, without any tutti–soli designations at all (for example, Bach's *Brandenburg Concerto No. 3*). The employment of motivic interplay offers certain inherent contrasts of its own. These include shifts from one high or low range to another within a texture of interwoven melodies: rhythmic conflicts based on patterns that do not necessarily coincide with the regular musical metre; and an almost continuous change of key. The last is achieved by rapid successions of modulations (bridges from key to key) and drives to the cadence; *i.e.,* building up of tension in the harmonies used, culminating and relaxing in the cadence, or stopping point. In fast movements, when the propelling force is not such motivic interplay, it is likely to be a force achieved by outright statements of musical figures based on chords and scales. Or it may be an unfolding succession of figures together with the harmonic drive to the cadence. In slow movements it is likely to be compelling progressions of chords, enhanced by melodic ornamentation and enlivened by continual suspensions, dissonances, and resolutions (*i.e.,* by suspending single notes while the harmony around them changes; this creates dissonance, the tension of harmonies that seem to clash; the tension is "resolved" when the harmonies change again).

In spite of all this variety there are consistencies of style in the scoring and musical textures just described. In addition, certain additional rhythmic and melodic traits help further to bring a sense of overall unity to the concerto grosso. With regard to rhythmic traits, a steady motoric pulse is likely to prevail throughout the fast movements. Also, true to the nature of the ever-present basso continuo, a steady running bass line is likely to underlie both the slow and the fast movements. With regard to melodic traits, one cannot ordinarily speak of "main and contrasting themes" as in the classical and later concerto. One reason is the lack of individuality in the main thematic ideas. Corelli's and Vivaldi's themes, vigorous as they may be rhythmically, hardly stand out melodically from the remaining music. Like the musical context in which they occur, the themes themselves are likely to consist of chord notes, scales, or simple repeated notes. Frequently they are announced in unison (all parts playing the same notes) and thus lack a strong initial association with the harmonies of an accompaniment. Bach is exceptional for the individuality of his themes, especially in the finales, where they are usually out-and-out tunes, memorable and fetching (as in his *Violin Concerto No. 2 in E Major,* BWV 1042). The less a melodic idea stands out, the less it functions as a true "theme" or unifier when it recurs and the less it can contrast with any of the other melodic ideas.

Concerto grosso themes

Such relatively neutral themes and motives, which unfold more as supplements than as contrasts, seem to have satisfied most Baroque, especially North German, tastes, including the express preference for limiting any one piece or movement to but one "Affekt" (or characteristic emotion). In addition, and more important for musical continuity, the themes, such as they are, do tend to recur, not only at the more local level of melodic imitation and motivic interplay but also at certain strategic points in the musical structure. Their recurrence, most often at the three or four main tonal landmarks, imparts at least a vague overall outline of formal musical structure. In fact, these strategic recurrences, plus the melodic imitations, the passagework, and the adjunct musical themes that separate them, produce in a loose way the most prevalent structural principle of the fast movements. This is the rondo principle, which is based on the alternation of a refrain, or "ritornello," with contrasting musical passages. In the more tuneful finales, or final movements, the sense of a rondo "ritornello" is most distinct (as in Handel's Opus 6, No. 11). Generally, the alternations of refrains and intervening episodes tally with alternations of the tutti and soli groups, respectively.

Recurring melodic ideas account for two other of the most frequent principles of musical structure in the concerto grosso, those of fugue and of variation. A fugue is based on the polyphonic treatment (through extensive melodic imitation) of a recurring subject, or theme. In fugal sections of a concerto grosso, tutti and soli unite as one group or alternate in expositions (statements of the subject) and episodes (passages in which the subject appears only fragmentarily, if at all). The fugal style occurs largely in fast movements and varies from loose applications, especially among the Italians, to strict ones, especially among the Germans. The variation process depends on continual variation of a constant factor, such as a theme or a group of harmonies. In the concerto grosso it occurs largely in slow movements; its constant factor is a simple, freely recurring bass line, or ostinato (a short, repeated motive or melody). The ostinato often sounds alone in the tutti and may be played in unison at the beginning and end of the movement. It serves as a foil for the soli parts, which sometimes enter successively on long tones and gradually unfold into decorative, expressive passages (as in Bach's *Violin Concerto No. 2.*) When the ostinato's recurrences are free enough and the bass line and treble melody of the tutti stand out enough, the effect is that of an expressive aria (solo song, as in an opera) with a firm prelude and postlude (as in Vivaldi's Opus 3, No. 8), providing one of the many hints of operatic influences in the concerto grosso. To these structural types—rondo, fugue, and variation—may be added especially the binary design, with each half repeated, that prevails in Baroque dances. In binary form, the music of the first half moves from the tonic key to a closely related key. The second half begins in the new key and progresses back to the original key. Dances abound in concerti grossi, not only in those that are primarily orchestral suites or groups of related dance pieces (as are many by Handel) but in others as well. For instance, the finale of Corelli's Opus 6, No. 3, although headed only "Allegro," is a fine example of a binary gigue (a courtly dance ultimately derived from the jig).

Fugue and variation

The number of movements in the concerto grosso varies more than in the later solo concerto or in the sinfonia, symphony, and sonata at any time after the concerto grosso's emergence. But the average may be put at from three to five. Corelli and other Italian pioneers had led off with more movements (insofar as separate movements can be distinguished from mere sectional changes in their concerti). Vivaldi reduced the number, mostly by omitting an initial slow movement that his predecessors had probably derived from the French overture. Instead, Vivaldi largely settled on and, in fact, standardized the cycle at three movements in fast–slow–fast order. He may have been in-

fluenced by the same cycle in the Italian opera sinfonia (or overture). The Germans seem to have varied the number more, with the most movements likely to be made up of relatively short dances. Bach's six *Brandenburg Concertos* do follow the fast–slow–fast plan except that Number 1 adds two dances and No. 3 leaves out the slow movement, simply substituting in its place two slow chords that create a feeling of suspension. Handel's *Twelve Grand Concertos* in Opus 6 contain four to six movements that vary considerably in order and type.

Unity among movements

As usual in tonal music (music based on the system of major and minor keys), additional variety within unity is achieved in the cycle of concerto grosso movements through departure from and return to the home key. Much more often than in the suite, a slow inner movement is placed in a nearly related key. In the shortest, freest slow movements the tonality, or key orientation, sometimes remains uncertain and in flux, giving the sense of a bridge from the previous to the following movement (as in Vivaldi's Opus 3, No. 10). Unlike the Baroque suite and sonata, in the concerto the use of interrelated musical themes is not a frequent means of linking the movements. But the concerto grosso is like these other cycles in its dynamic tendency to progress from the more serious to the lighter movements. Infrequently a "program"—a story or nonmusical image—lends further unity to the cycle, as it does in the four concerti of Vivaldi's Opus 8 that are known collectively as *The Four Seasons.* Each of these concerti is tied closely to a sonnet describing one of the seasons. More often a special unity results from some unusual trait of musical style or use of an instrument. An example is the brilliant solo part given, exceptionally, to the "cembalo concertato" (*i.e.,* a harpsichord that participates with the other instruments in the melodic discourse rather than, as is normal, confining itself to the realization of the basso continuo) in Bach's *Brandenburg Concerto No. 5.*

Like the vocal-instrumental concerto before it, the concerto grosso originated and reached a first peak in Italy, then attained a further peak in Germany. French and English centres responded more than they contributed to it. Again, some of the main landmarks may be briefly noted. The 12 concerti grossi in Opus 6 by Corelli were not first published until 1714, the year after he died. Although they were preceded in print by other pioneer examples, like those of Torelli (from 1698), Tomaso Albinoni (from 1700), and even Vivaldi (from 1712), some of them may have been among the "several concertos" by Corelli that Muffat had already heard in Rome by 1682. Corelli still made the loose distinction, best known in the 17th-century sonata, between *da chiesa* and *da camera*—that is, church and court-style, or serious and light. The first eight of his concerti grossi are *da chiesa* (church-style), in four to seven movements, the last four *da camera* (court-style), in five movements. A trio setting of two violins and cello is specified for the *concertino,* and two violins, viola, and bass for the *concerto grosso,* "which may be doubled as desired." Between the two groups the opposition is not an antiphony of musical ideas but only a change of musical texture and sonority in the continuous unfolding of the short, tasteful, well-proportioned movements.

Vivaldi's more than 460 "Concerti" (written from about 1710 to 1740) bring the Italian contribution to full maturity, and they rank Vivaldi with his contemporaries Bach and Handel among the greatest masters of the concerto grosso. The maturity is marked by larger forms and broader musical architecture, including tighter organization of the rondo principle, and by more distinctive, energetic musical themes, at least rhythmically if not melodically. There is also greater brilliance and exploitation of idiomatic instrumental techniques, including *bariolage* (quick shifts from string to string) and broken chords for the solo violin. Another characteristic is the standardization, as noted earlier, of the three-movement cycle, fast–slow–fast. But if the cycle becomes standardized, with only infrequent exceptions, very little else is predictable about Vivaldi's imaginative, resourceful concerti. Least predictable of all is the scoring, which makes highly varied combinations of string and wind instruments—for example, a tutti of strings with cello and bassoon as the soli; or two oboes, two horns, bassoon, and violin as the soli; or viola d'amore (a violin-like instrument) and lute as the soli.

Starting with Muffat's concerti done under Corelli's immediate guidance, the spread of the instrumental concerto from Italy to Germany was as direct and wide as that of the vocal-instrumental concerto had been. French influences in Germany were considerable, too, especially where the suite touched the concerto. This was often true in the large, resourceful, and highly varied output of the German Georg Philipp Telemann. In Bach's approximately 25 concerti (about 1720–35) Italian influences are especially evident, quite apart from his unusual setting for harpsichord alone specifically entitled *Concerto in the Italian Style.* Again, Italian influence is reflected in the many concerti by Vivaldi and others that Bach transcribed and reworked for harpsichord or for organ. A rare opportunity to learn what mattered most to Bach in concerto structure is provided by a study of his changes in the Vivaldi models. Such changes include themes sharpened melodically and musical textures enriched by the addition of new melodic entries to contrapuntal passages or by more intensive interplay of musical motives. The designs of the musical forms themselves are pointed up by insertions of new musical material, deletions, and altered timing of phrases and entries. Bach summed up the Baroque concerto as he did the cantata, fugue, and other Baroque genres. Besides the transcriptions and the magnificent six *Brandenburg Concertos,* with all their own varieties of scoring, he left concerti in which the solo requirements are one violin; two violins; flute, violin, and harpsichord; violin and oboe; one harpsichord; two harpsichords; three harpsichords; and four harpsichords. The majority of the harpsichord concerti are further transcriptions and reworkings, some not yet tracked to their sources. For example, two of seven solo harpsichord concerti come from Bach's own solo violin concerti, and the concerto for four harpsichords comes from Vivaldi's Opus 3, No. 10, for four violins. These concerti, like the *Brandenburg Concerto No. 5* already noted, emphasize Bach's priority in giving the harpsichord prominence as a concerto solo instrument.

Bach's concerti grossi

Handel left around 35 concerti in all (about 1715–50), including three sets of organ concerti with oboe and strings; one set for strings and winds (Opus 3); one set in the tutti–soli setting for strings alone (Opus 6) that Corelli had used; and several concerti not in sets. Among the last are two works more properly classified in his day as trio sonatas (works usually for two violins and basso continuo but sometimes for orchestra). Transcriptions and reworkings figure in many of Handel's concerti, as in Bach's. Handel's concerto style, like that of his chief contemporary in England, the Italian violinist-composer Francesco Geminiani, is more progressive than Bach's in its frequent French dance influences and in its more open, less complex musical textures. Although imposing fugues can be found, the prevailing atmosphere in Handel's concerti is more often that of light, wide-spaced chamber music. Thanks to his unmatched skill, imagination, good timing, and almost childlike enthusiasm, there is also a feeling of extraordinary vitality, robustness, and breadth in the concerti, especially in the finest of the sets, the *Twelve Grand Concertos* (that is, concerti grossi as translated then), Opus 6. The exploitation of the tutti–soli opposition is less in Opus 3, although the instrumental scoring is more restricted in Opus 6. But in both sets the variety of instrumental combinations is exceptional, even from movement to movement. In Opus 3, No. 2, for example, the soli change from two oboes and two violins to solo oboe, then to two oboes doubling two violins and a viola, further to two oboes and two violins not doubled, and finally to two oboes and cello. Much as Bach had transcribed concerti for organ alone to serve as introductions to cantatas, so Handel played his own original and transcribed concerti for organ and orchestra as introductions and entr'actes in his oratorios. These organ concerti were widely copied by minor followers of Handel in England. Nothing in France close to Handel's level can be pointed to until near the end of the era, when a violinist and composer, Jean-Marie Leclair, produced his solo concerti.

Handel's concerto style

In the opening of this section "concerto" was defined as

it is thought of first today—that is, in the sense that has prevailed since about 1750. Essential to that definition is the interrelation of orchestra and soloist, not soli. Whereas a *concertino* of soli had been the norm before 1750, with a single soloist being a variant or reduction of the concertino idea, the single soloist became the norm after 1750. As a result two or more soloists became the exception in what has since become known as "double concerto," "triple concerto," and so on. Because the concerto since 1750 has been likened to the sonata (again, as in the opening definition), it is often distinguished as the "sonata concerto," although the same could have been done with at least as much justification, especially because of the confusions of terms noted earlier, for the concerto before 1750. More justified, in spite of all the exceptions, might be the designations "solo concerto" for the later type and "orchestral concerto" (or concerto grosso) for the earlier type. The concerto grosso may be said to have dissolved into the solo concerto and the sinfonia concertante. The second term was Mozart's designation for certain concerti with more than one soloist, but it has also been used for symphonies that still reveal the imitative interplay of the concerto grosso or that employ the tutti–soli rondo principle. There are differences between the earlier solo part, which was a minimal concertino, and the later solo part, which was a self-sufficient adversary to the orchestra. There is also a difference in scoring between the two types of concerto, for at the time that the concerto grosso was being replaced by the solo concerto the basso continuo was falling into disuse. In addition there is a difference of degree, with a sharp increase of independence and virtuosity in the soloist's part in the later form of the concerto.

The Classical concerto (c. 1750–1830). Since 1750 the concerto has found its chief place in society not in church or at court but in the concert hall. Some of the excitement it could arouse in classical musical life is recaptured in the Mozart family letters. Mozart's introduction of a new piano concerto (K. 456?) in a Vienna theatre concert was reported by his father on February 16, 1785:

The solo concerto

> . . . your brother played a glorious concerto, . . . I was sitting [close] . . . and had the great pleasure of hearing so clearly all the interplay of the instruments that for sheer delight tears came into my eyes. When your brother left the platform the Emperor waved his hat and called out "Bravo, Mozart!" And when he came on to play there was a great deal of clapping. (As translated by Emily Anderson, *The Letters of Mozart and His Family,* 2d. ed. The Macmillan Co., New York, 1966.)

The solo concerto was the main concert vehicle for composer-performers such as Mozart and for itinerant virtuosos like the Italian violinist Antonio Lolli, whose incessant crisscrossing of all Europe scarcely can be reconciled with the incredibly bad travel conditions that still prevailed. A secondary place for the solo concerto has been in the realm of musical instruction. Although the category of "student concerto" to which certain works have been relegated seems largely to associate with the 19th century, a good many classical concerti evidently served that purpose too. Thus, Mozart, who wrote his latest, finest, and most difficult concerti for his own concert appearances, earlier wrote easier ones to be used mainly in teaching. The concerto also had an occasional place in the theatre, as evidenced by the fact that the Italian composer Francesco Maria Veracini played concerto movements as entr'actes during operatic performances.

The strings remained the nucleus, though less often the whole, of the tutti in the solo concerto. But now the more equivoice setting of the string quartet gradually superseded the polarity of the basso continuo and the melody or concertante parts. Moreover, the tutti was no longer reinforced by the solo instrument in the tutti passages, as it had been in the concerto grosso, for the solo became exclusively a solo part. Though optional instrumentation disappeared insofar as the choice of instruments for the old basso continuo was concerned, the free use of what instruments were available still applied to the wind parts of the usual concerto tutti throughout most of the 18th century. The instrumental colour of solo concerti, up to Mozart's mature works, was therefore relatively neutral, without particular refinement or individuality caused by specifically exploiting the tone colours of the instruments. On the other hand, the solo part became increasingly individualized in the solo concerto as a result of the further exploitation of spectacular playing techniques. Accordingly, the music of the solo part became highly idiomatic for the chosen instrument; that is, it was calculated to take most advantage of the characteristic sound and techniques particular to that instrument. Solo violin parts in particular had already reached heights of virtuosity during the overlap between the Baroque and Classical eras. Such works were scarcely surpassed before the most brilliant writing of the violin virtuoso Niccolò Paganini and his successors in the Romantic era. Examples may be found in abundance in the solo violin concerti of Leclair and the Italians Pietro Locatelli, Veracini, and Giuseppe Tartini. Most of these works, especially Tartini's, have real musical distinction, rooted as they are in an important heritage from Torelli, Albinoni, and Vivaldi in Italy and Johann Georg Pisendel, Telemann, and Bach in Germany.

The rise of the piano

Yet, from the 1780s and the peak of the Classical era, and despite a continuing if limited output of concerti for the cello, flute, oboe, clarinet, bassoon, and horn, it was no longer the violin or any of these instruments that ranked first among solo instruments of the concerto. Rather it was the newly emerging piano, which was rapidly superseding the harpsichord and clavichord. Mozart, who with the London-centred, Italian-born Muzio Clementi was one of the first great pianists, wrote not only some of the first but some of the greatest concerti the instrument has yet known. Two generations earlier, Bach's more limited exploitation of the keyboard in his harpsichord concerti had already shown what a stalwart adversary a keyboard instrument could be in the concerto contest. Now, with the greater independence of the solo part and the greater self-sufficiency of a keyboard part, both the drama and the variety of the tutti–solo opposition could be increased considerably. As for the variety, either orchestra or soloist might perform alone, either might carry the theme while the other accompanied, or the two might share in the theme by doubling, by antiphony (alternating with each other in playing phrases of the theme), or by more rapid interchange and alternation. Thus, Mozart's popular *Concerto in A Major,* K. 488, begins with an extended orchestral tutti without soloist, after which the solo piano enters on a restatement of the main theme, lightly and intermittently accompanied by the strings alone. Another tutti, this time short, leads into a modulatory (key-changing) bridge consisting of rapid piano scales that elaborate on harmonies given in simpler notes in the tutti. The piano now enters alone on a second theme, then decorates snatches of the theme as the orchestra restates it an octave higher. So the work unfolds in a kaleidoscope of ingenious, fresh settings.

Movement cycles and forms

The standard cycle of three movements, fast–slow–fast, became even more standardized in the Classical era. It occurred without notable exception in the concerti of that era's three greatest masters, Haydn, Mozart, and Beethoven. Furthermore, the outer movements are generally predictable, too, at least in their overall plans. "Sonata form" is approximated in the opening movements. In the finales, apart from an occasional minuet (a dance form) in Haydn's concerti, the prevalent forms are rondo and sonata-rondo (which combines the recurrent refrain of the rondo with the exposition-development principle of the sonata). The middle movements are only a little less predictable, with A B A design being far in the majority (as in Mozart's *Concerto in D Minor,* K. 466). Forms such as the dialogue-like fantasy in Beethoven's *Piano Concerto No. 4 in G Major,* Opus 58, or the free variations in his *Violin Concerto* are late-Classical or pre-Romantic exceptions. But, of course, these masterworks are no stereotypes. They find their variety and distinctions in the details and working out of the forms. At most, "sonata form" in the Classical era was not yet the conscious concept or crystallized design that later textbooks have made it out to be. Its thematic organization in particular was still fluid and certainly not bound to any fixed number of themes or any fixed dualism of "masculine" and "feminine" themes. Textbook discussions of the solo concerto say that the tutti

plays the exposition first, all in the tonic key, after which the soloist joins to repeat it, this time more elaborately and with the contrasting theme in a nearly related key. But that concept of the strict "double exposition" is honoured as much in the breach as the observance.

Actually, the application of "sonata form" was likely to be freer, even looser, in the concerto than in the symphony or string quartet. In part this was because of the extensive passagework that is inherent in the virtuosity and idiomatic treatment of the solo instrument. This passagework and the loose treatment of the musical form reach their extreme in a terminal cadenza of the first movement, more so than in the shorter cadenzas likely to be found at one or more focal points in the other movements. The cadenza had already been introduced in late-Baroque violin concerti, undoubtedly influenced by singers' florid, improvised embellishments of arias in current opera, although early instrumental precedents exist, too. The concerto's cadenza was generally improvised by the performer until Beethoven insisted on the use of his own short cadenzas as supplied in *Piano Concerto No. 5 in E Flat Major,* Opus 73. Many later performers have found too little opportunity for technical display in other cadenzas that the masters previously had left for optional performance in some of their own concerti. The dissatisfied performers often substituted more brilliant cadenzas in such cases. But the structural looseness of the cadenza becomes less tolerable when the virtuoso performer goes to later sources or composes new cadenzas that are anachronistic in their technical and harmonic style, out of proportion in length, and inadequately related to the musical themes of the movement.

Improvised and written cadenzas

As with both the vocal and the instrumental concerto of the Baroque era, the starting point for the solo concerto in the Classical era lies in Italian music. But this time more weight must be attached to the evolution of the concerto in Germany and Austria. In these countries, there lies the more significant development, that of the piano concerto, as cultivated by the chief Classical masters.

The transition to the lighter texture and more fragmented musical thoughts of the pre-Classical "gallant style" may be credited in part to the Italian string concerti, notably those of Tartini, Giovanni Battista Sammartini, Luigi Boccherini, and Giovanni Battista Viotti. But the one piano concerto that Boccherini may have left about 1768, along with several cello concerti, and the very few concerti that Clementi in England supposedly converted to solo piano sonatas hardly make any niche for Italian composers in the history of the piano concerto. The full exploitation of the piano in the concerto and the creation of more substantial, consequential concerti for it must be credited primarily to two of J.S. Bach's sons and to the high-Classical Viennese triumvirate of Haydn, Mozart, and Beethoven. Whereas Wilhelm Friedemann Bach had largely followed his father in his half dozen concerti for harpsichord, strings, and basso continuo, Carl Philipp Emanuel Bach opened new paths in about 50 keyboard concerti, as well as some violin concerti and flute concerti. This is especially true of his later concerti intended for the piano (1772) rather than the harpsichord. Original instrumentation, dialogue between piano and orchestra, bold flights and expressive recitatives, are among the characteristics of Emanuel's concerti. So also are final movements that resemble in character the lively musical and dramatic development at the end of an act of opera buffa (Italian comic opera).

By contrast, Johann Christian Bach's 37 harpsichord or piano concerti from the same period are lighter, more fluent, easier works aimed at amateur skills and tastes. Most of them, like his sonatas but unlike most of his 31 sinfonie concertante, have only two movements, the finale often being a minuet or set of variations. The anticipations of Mozart's style are unmistakable.

Haydn left 36 concerti that can be verified, spanning the years from about 1755 to 1796; for violin (four); cello (five); bass; horn (four); hurdy-gurdy, or wheel fiddle (five); trumpet; flute; oboe; baryton, a cello-like instrument (three); and keyboard (11, whether for organ, harpsichord, or piano). In 1792 he also wrote a sinfonia concertante for violin, oboe, cello, bassoon, and full orchestra that returns to the tutti–soli relationships of the concerto grosso. The keyboard concerti bear witness in their unenterprising, sometimes pedestrian handling of the solo part that Haydn was no distinguished keyboardist. Even the best known of them, the *Piano Concerto in D Major* (1784), is heard today more in education than in concert circles, in spite of its musical strengths, especially in the "Rondo all'Ungherese" ("Rondo in the Hungarian style"). The one concerto by Haydn that is widely performed in today's concert world is an admirable, sonorous work for cello, in D major (1783, once attributed to the German cellist Anton Kraft). Cast in the usual three movements, with clear thematic ties between them and accompanied only by the usual orchestra in eight parts (four strings, two oboes, two horns), this work is variously songful, brilliant to a taxing degree, and dancelike. Another important contribution by Haydn was his last concerto (1796), a resourceful and difficult work in E-flat major that exploited the new keyed trumpet, which unlike earlier trumpets was capable of playing diatonic (seven-note) and chromatic (12-note) scales.

Haydn's concerti

During his short career, Mozart left about 45 verifiable concerti dating from 1773 to his last year, 1791. These do not include five early piano concerti arranged from concerto or sonata movements written by Emanuel and Christian Bach and two lesser composers. Out of the total, there are 21 for piano, six for violin, five for horn, two for flute, and one each for oboe, clarinet, bassoon, flute, and harp, two pianos, three pianos, and two violins (called *Concertone*). Two further examples, entitled "Sinfonia concertante," are for violin and viola, and for a concertino of oboe, clarinet, horn, and bassoon. Best known and most played are five of the last eight solo piano concerti (K. 466, 467, 488, 491, and 595), which rank among the finest of his works and the best of the genre. Highly valued and often played, too, are the *Sinfonia concertante in E Flat Major for Violin, Viola and Orchestra,* K. 364, E. 320d, and the *Concerto for Two Pianos,* K. 365, E. 316a. Two of the violin concerti are well-known (K. 218 in D major and K. 219 in A major), although more so to students than to concertgoers. Among those five solo piano concerti, that in D minor (K. 466) reveals a new urgency and compactness in Mozart's writing, reflecting the atmosphere of the *Sturm und Drang* ("Storm and Stress") period in German art, except in the naïvely charming "Romance" that is the middle movement. One among many instances of the striking tutti–solo contrasts in this work is the reservation of certain material, including the soloist's initial theme, for the soloist alone. The *Concerto in C Major,* K. 467, is a more cheerful work, broad and stately in its opening ideas, bubbling with intriguing melodic figuration, and capped by one of Mozart's most delectable rondos. The *Concerto in A Major,* K. 488, is rich in wistful songlike melodies. The spun-out line of the middle movement, in the rhythm of the siciliano (an Italian dance), makes an ideal foil for the gay, tuneful "Presto" that follows. Like the D-minor concerto, that in C minor (K. 491) is an intense work, more extended but even more driving. Mozart's last concerto for solo piano, that in B-flat major (K. 595), is another masterpiece, ever fresh in its ideas, yet with an air of sweet resignation in its almost neoclassical simplicity.

The concerti of Mozart

The much smaller output of concerti by Beethoven, anticipating the still smaller outputs by his 19th-century successors, is not surprising in view of the wider range of expression, further exploration of instrumental resources, and greater size of his concerti. There are nine complete works in all. These include seven with piano—the so-called standard five (1795–1809) plus one more from his boyhood and another, using chorus as well as orchestra, that is seldom performed, oddly constructed, and almost unclassifiable (*Choral Fantasia,* Opus 80, first performed 1808). Further, there is the *Violin Concerto in D major* (1806) and a worthy, but much less successful, *Triple Concerto in C Major for Piano, Violin, and Cello,* Opus 56 (1804). One could hardly find a wider range of expression than that between the third, fourth, and fifth (*Emperor*) piano concerti. Reduced to capsule, subjective terms, the third, in C minor, must be characterized as compelling drama, hushed serenity, and feverish drive in its respective

Beethoven's concerti

movements; the fourth as joyous lyricism, stark tragedy, and scintillating gaiety; and the fifth as heroic grandeur, noble dignity, and victorious rejoicing. The opening tutti sections may be taken as samples of the wide variety of musical structure in these same three concerti. In the third, the tutti extends the exposition of the themes by developing or discussing each after it is first stated. The solo enters almost at once, with only a short flourish, on the main theme. In the fourth concerto, the piano begins alone with a short, refreshingly simple pronouncement of the main theme, followed immediately by a surprising, tangential entrance of the orchestra. There unfolds a full exposition that discusses each theme even more than in the third concerto. This time the solo enters for the repeated exposition only after a more extended flourish, lasting 15 measures. In the last concerto, the soloist begins by embellishing each of the three primary harmonies in the orchestra with a separate cadenza. Only after this opening does there begin a complete tutti exposition that, in its discussion of the themes, is still more developed than in the fourth concerto. Not until the orchestral exposition is ended does the solo enter again to begin its highly virtuosic elaboration in a repeated exposition. It is such development throughout all parts of the musical forms, and not only in the "development sections," that accounts for the great lengths of *Piano Concerto No. 5* and the *Violin Concerto.* Notable are the exceptional technical difficulties in these two peerless masterpieces, which grow as much out of their musical complexities as out of the composer's evident desire to reveal new ways to utilize his solo instruments (especially the rapidly advancing piano, with its wider range, heavier action, and bigger tone).

The Romantic era (c. 1790–1915). Between the Romantic and the Classical concerto there occurred no such marked, relatively abrupt changes in form or style as were observed earlier here between the Classical and the Baroque concerto. The onset of the Romantic era was not signalled by any shift in the concerto's musical structure. Thus there was no stylistic change equivalent to the shift from the polyphonic interplay of short motives in the concerto grosso to the solo concerto's grouping of longer musical phrases in homophonic style (based on chords). Nor was there any shift in instrumental texture equivalent to that from the polarity of basso continuo and melody parts to a more equal distribution of voices or parts. Nor again was there any shift from the piano to another instrument as the preferred solo vehicle.

Gradual evolution of the genre

As with much other Romantic music, the Romantic concerto was marked by an extension or expansion of those same Classical trends in all directions. This development led eventually to their exaggeration and ultimately to their extremes or breaking points. The concerto as a genre became more than ever the ideal showpiece at public concerts, doing much for the composer's profit, the performer's triumph, and the listener's delectation. Indeed, Franz Liszt, the dominant composer-pianist of his time, distinguished between the concerto and the sonata, calling the first a public showpiece and the second a private, personal expression (in 1838, while questioning a publisher's title, *Concerto Without Orchestra,* for the Opus 14 of Robert Schumann, a title changed to *Piano Sonata No. 3 in F Minor*). Over the century, several 19th-century concerti won more popularity than was accorded to any earlier concerti. Time has influenced that preference but little, to judge from a listing, in order of popularity, of the 15 piano concerti most played in major U.S. concerts in the late 1960s: Beethoven No. 5, Tchaikovsky No. 1, Brahms No. 2, Beethoven No. 3, (Prokofiev No. 3, Modern era), Schumann, Rachmaninoff No. 2, Mozart K. 595, Grieg, Beethoven No. 4, Camille Saint-Saëns No. 2, Brahms No. 1, Chopin No. 2, Beethoven No. 1, and Liszt No. 1 (from statistics compiled by Broadcast Music Industries).

Concerto orchestration

Another expansion of Classical trends is seen in the concerto orchestra, with the larger number, greater variety, and more discriminating use of its instruments. It is true that only the thinnest possible "support" for the soloist sufficed for composer-performers such as the pianist Chopin, the violinist Paganini, and others whose musical thinking ranged but little beyond the spheres of their own instruments. But the orchestra developed the status of a genuine if not superior adversary of the soloist in newly resourceful orchestrations by composers of wider instrumental perspective. Examples of this exploitation of the orchestra include *Harold en Italie* (1834), a symphony with solo viola, by the French composer Hector Berlioz; *Piano Concerto No. 1 in E Flat Major* (published 1857), by Liszt; and *Burleske* (completed 1885) for piano and orchestra, by the German Richard Strauss. At the same time, the piano, as the ideal Romantic instrument, secured ever more firmly its Classical preeminence as the preferred solo vehicle of the concerto. Although the total output of violin concerti in particular was very great, there was a decided preponderance of piano concerti among all concerti that appeared on printed public concert programs. In turn, the use of the piano in concerti was one main incentive for further advances in piano construction. By the mid-19th century the instrument reached a peak very close to the sonorous, seven-octave, triple-strung, cast-iron framed behemoth that is the modern "concert grand." With its perfection came also the extension of keyboard technique to the last reaches of athletic dexterity. Evidence of such technical development includes the unreasonably difficult requirements of the three etudes ("studies") that comprise the huge unaccompanied *Concerto,* Opus 39, Nos. 8–10, by the French pianist-composer Alkan (Charles-Henri Morhange). It is also apparent in the more reasonable but no less difficult requirements in Rachmaninoff's *Piano Concerto No. 3 in D Minor,* Opus 30 (1909). The wind instruments used in concerto solos underwent mechanical advances, too, and both they and the stringed instruments enjoyed analogous exploitations of their technical possibilities in this century of virtuosos—not only of Liszt (and so many more) on the piano but of others such as Paganini on the violin, Alfredo Piatti on the cello, and Domenico Dragonetti on the double bass.

Romantic innovations

The most significant extension or expansion of the concerto principle in the Romantic era might in one sense be called a contraction, for it concerns a continuing effort to consolidate, interrelate, and fuse the over-all cycle, both within and between the movements. Certain composers, mostly forgotten perfunctories, yet including as important and successful a figure as Chopin, were satisfied to pour new wine into old bottles. Thus many concerti accepted without question the movement forms and cycle that by then had become self-conscious stereotypes, especially "sonata form" in the first movement. Brahms largely preferred to accept the traditional cycle and forms, too, but with the masterful individuality, flexibility, and logic that were needed to revitalize them. On the other hand, most of the Romantics whose concerti are still played sought to modernize and advance the traditional structural principles. These changes may be summed up in six categories.

First, there is the elimination, in the opening movement, of the long initial tutti section. This innovation corresponded to the elimination in the sonata of the previously customary repeat of the exposition, a change that had begun in Beethoven's late sonatas and had soon become general. Such is the pattern in Schumann's *Piano Concerto in A Minor,* Opus 54 (1845), in which the soloist enters at the outset and proceeds promptly to an almost constant interrelationship with the orchestra as the exposition unfolds but once.

Second, there is the interlocking of the movements, achieved by leading not only from one movement to the next without appreciable pause in time or sound but also without either a definitive cadence (stopping point made clear by the harmonies) or full break in the continuity of harmonies or tonality. Thus in the *Violin Concerto in E Minor,* Opus 64 (1844), of Felix Mendelssohn, a lone bassoon suspends one note of the final chord of the first movement. Preventing a pause in time or sound, it leads directly into the middle movement. Again, between the middle and final movements a brief interlude, midway in tempo, mood, and intensity, supplies the continuity and avoids any full break.

A third Romantic innovation is the effort to bind the cycle more positively through the use of related themes and motives in the successive movements. Such themes and

motives can be only melodic nuclei, as in the so-called basic motive employed by Brahms. Or they may be more extended melodic thoughts, such as are subjected to "thematic metamorphosis" by Liszt or "cyclical" treatment by the Belgian César Franck. (Both terms refer to the practice of transforming a theme melodically and rhythmically in various ways throughout the cycle of movements.) Among well-known examples is the tight thematic organization, with its final retrospective summary, in the four interconnected movements of Liszt's *Piano Concerto No. 1* (*Triangle Concerto,* published 1857), a work Liszt himself claimed to be innovational on this account.

Fourth, there are certain other, more incidental, yet effective means of unifying the cycle. These include the sense of culminating joy or triumph in those many concerti that change from a minor home key to its tonic major (for example, from A minor to A major) for the finale; or the consistency of musical textures caused by making all the movements similar in weight and style; or the stronger sense of return achieved by a finale that follows a middle movement characterized by a marked sense of departure or contrast.

"Program" concerti and fusion of movements

The remaining two categories of changes concern Romantic developments that go somewhat beyond expansions (or contractions) of Classical concerto traditions. As a fifth category, there is the extramusical unification of the cycle by means of a program—that is, a story or image. Unlike the Romantic sonata, the Romantic concerto abounds in examples. One of the earliest such examples is the image that the German composer Carl Maria von Weber identified with his *Konzertstück* (*Concert Piece*) for piano and orchestra (1821). Its four interconnected movements are said to describe a medieval lady's longing for her absent knight, her agonized fears for his safety, the excitement of his impending return, and the joys of reunion and love.

Sixth and last, there are numerous efforts to contract or consolidate the concerto cycle still more drastically, by fusion of movements. Four different solutions may be cited as representative. Tchaikovsky's *Piano Concerto No. 1 in B Flat Minor* (1875) follows a number of symphonies and sonatas of the period by integrating the slow movement with the scherzo (a lively movement that had become a rather frequent additional item in the cycle). Liszt's *Piano Concerto No. 2 in A Major* (published 1863) is a pioneer among the several concerti that reduce the separate movements to sharply contrasting sections within a single movement. Franck's *Variations symphoniques* for piano and orchestra (first performed 1885) substitute for the cycle a single movement based on a single principle of musical structure (in contrast to the distinct structures of distinct movements). And the Russian Nikolay Medtner's *Piano Concerto in G Minor* is a single, experimental variation of "sonata form." It consists, as he himself explains,

> of an exposition, [a short, transitional cadenza,] a series of [nine] variations on the two chief themes, constituting the development [section], and then the recapitulation.

Still other changes from the Classical to the Romantic concerto are concerned less with overall plans than with language and idiom: the characteristic harmonies, melodic styles, and manner of musical development. But such changes were not limited to the concerto. They touched all of Romantic music. Among them are fuller, more varied textures, greater use of the high and low extremes of instruments' ranges, and more sonorous, widespread spacing of sounds. Indicative of the third development was the significant change in piano writing from the Alberti bass in close position to the "um-pah-pah" bass and free arpeggiations in open position.

Romantic harmonies and nationalistic colour

In addition there was a marked new preference for minor keys as being almost indispensable to the intensity of Romantic feeling. There was also an increased use of chromatic harmonies (chords whose notes do not all belong to the key of the composition and that frequently seem to have a more expressive character). Similarly characteristic of the era were brief, temporary modulations whose functions were more colouristic than structural (*i.e.,* they were introduced more for the harmonic colour they embody rather than strictly as a means of changing keys). Another new development was the late-Romantic turn to nationalistic colours, introducing folk melodies or allowing folk music to influence melodies, harmonies, and rhythms. An example is the *Symphonie espagnole* for violin and orchestra (1875), by the French composer Édouard Lalo.

From beginning to end in the Romantic era, Germany reigned supreme in the concerto, both as leader and producer, as with all the major instrumental forms. The majority of the non-Germans whose concerti were more or less successful in their day were at least trained in Germany. Here, in one loose chronology, may be mentioned the most important of the Romantics from both in and out of Germany, along with their most important concerti, which generally are those with the best chance still of being heard today. The once successful piano concerti of the Czech Jan Ladislav Dussek and the Germans Johann Nepomuk Hummel and Ignaz Moscheles—all renowned virtuoso pianists—have given way to other early Romantic works. These include the *Konzertstücke* of Weber, two concerti by Mendelssohn, and, especially, two by Chopin and the one by Schumann. Mendelssohn's two piano concerti are rapidly slipping into the status of "student concerti" today, but his *Violin Concerto in E Minor* continues to hold top position in its class, along with the violin concerti of Beethoven, Brahms, and Tchaikovsky. These works followed and eclipsed the successes of Viotti, Paganini, the German Ludwig Spohr, and other violinist composers. Schumann left one of the era's few most played cello concerti, two others being the later ones by Saint-Saëns and the Czech Antonín Dvořák. As noted, Liszt was a pathbreaker with his two piano concerti. His other, more programmatic works for piano and orchestra are less played today, but they also exercised a variety of influences on such different late-Romantics as Grieg, Franck, the American Edward MacDowell, Rachmaninoff, Richard Strauss, and the Hungarian Ernő Dohnányi. Brahms's concerti, every one a highly popular masterpiece today, mark a peak for the era on the conservative side. They include besides the two piano concerti in D minor and B-flat major, the *Violin Concerto in D Major* and the *Double Concerto in A Minor* (with violin and cello as the solo instruments). Among later romantic concerti, though those onetime favourites for violin by Henri Vieuxtemps, Henryk Wieniawski, Max Bruch, Karl Goldmark, Aleksandr Glazunov, and Sir Edward Elgar have recently lost much ground in the concert hall, those of Dvořák, Saint-Saëns, the Finnish composer Jean Sibelius, and, especially, Tchaikovsky still hold strong. Similarly, while the piano concerti of the famed piano virtuoso Anton Rubinstein are all but forgotten, two (in G minor and C minor) out of the five by Saint-Saëns and the *Concerto No. 2 in D Minor* by MacDowell get occasional hearings, and those already mentioned by Tchaikovsky and Rachmaninoff remain among the most successful. Certain concerti are less likely to be heard at least partly because they are written for less usual solo instruments. These include works for bassoon by Weber; for clarinet by Spohr, Weber, and Ferruccio Busoni; and for horn by Weber and Richard Strauss.

The modern era (from about 1915). By and large, and up to about 1950, the concerto of the modern era has kept pace with the language and idiom of modern music. There has been little introduction of new principles, or new trends, or even further extensions of the structural changes that have been noted here in the Romantic era. If anything, it has turned back on itself. It has sloughed off the advances, if such they be, of the Romantic era and has reverted to styles and forms of the Baroque and Classical concerto. In so doing it has provided some of the most telling examples of the neo-Baroque and Neoclassical trends in modern music.

More explicitly, the modern concerto has kept pace with the breakdown in traditional tonality and various efforts to revitalize, bypass, or replace that comfortably secure system. It has shared in the modern erosion of the contrast between chords traditionally considered consonant (*i.e.,* bearing musical repose) and dissonant (*i.e.,* bearing musical tension), thus contributing to the release of endless new chord forms and progressions. And it has joined in perhaps the most basic trend; *i.e.,* the return from the

Changes in the soloist's role

Romantic and Classical tendency of groups of melodic phrases in predominantly homophonic textures to the Baroque ideal of interplay of melodic motives in predominantly polyphonic textures. But at the same time, the modern concerto has abandoned the gigantic orchestra, the massive technical requirements and extreme opposition of the solo part, and the decided preference for the piano as the ideal solo instrument. Similarly, it has abandoned the intensive effort to interconnect, consolidate, and contract the musical forms and has turned away from the frequent concern with extramusical programmatic content. The downgrading of virtuosity for its own sake has caused the soloist to become more a part of the orchestra again. Some modern works, such as *Piano Concerto No. 3 in C Major*, Opus 26 (1921), by Prokofiev, do continue to offer some of the formidable difficulties, glittering passagework, and soaring lyricism of the late Romantic concerto in the solo part. But even in these, the nature of the modern musical language permits the soloist generally to blend with the orchestra rather than to "do battle" with it, as has been said regarding Tchaikovsky's *Piano Concerto No. 1* and similar concert favourites of the Romantic era.

From the present limited perspective, no one country appears yet to have dominated the cultivation of the modern concerto. The total output has continued to be high, with nearly every composer of renown having contributed to it. Among representative German works that have won widest public endorsement—which, in the very nature of the solo concerto, must continue to be a main criterion—may be cited numerous concerti (mostly called "Chamber Music") that Paul Hindemith seems systematically to have written for almost every standard instrument as a solo, and for a variety of combinations. Both the Austrians Arnold Schoenberg and his disciple Alban Berg left 12-tone concerti for violin and Schoenberg left one for piano. (Twelve-tone music is based on a series or "row" of the 12 notes of the chromatic scale, chosen by the composer to serve as the melodic and harmonic basis for the composition.)

From France may be cited works by Claude Debussy for piano (*Fantaisie*) and for saxophone (*Rapsodie*); by Maurice Ravel for piano (two, of which one is for left hand alone) and for violin; and by Darius Milhaud for various instruments, even mouth organ, and various instrumental combinations, including percussion. From England there is a double concerto for violin and cello by Frederick Delius and there are various works by Sir Arnold Bax, Sir Arthur Bliss, Ralph Vaughan Williams, Sir William Walton, and Benjamin Britten. Among examples from the United States are successful concerti by George Gershwin, including *Rhapsody in Blue* for piano and jazz orchestra, and by Aaron Copland, whose *Piano Concerto* (1926) also exploits jazz. Of major importance have been solo or duo concerti by Prokofiev (five for piano, two for violin, and one for cello), the Russian-born Igor Stravinsky (two for horn, one for violin, one for oboe, and one for clarinet and bassoon), and the Hungarian Béla Bartók (four for piano and three for violin). Attention also should be called to the neo-Baroque *Harpsichord Concerto* (1926), by the Spaniard Manuel de Falla.

A special indication of neo-Baroque interest may be seen in the return on the part of a number of composers to the tutti–soli grouping, the motoric pulse, and the interplay of motives of the concerto grosso. Notable examples have been left by Bartók, Stravinsky, the German Max Reger, the Swiss-born Ernest Bloch, and the Austrian-born Ernst Krenek.

The present discussion of the modern era has concerned developments largely ending by about 1950, although occasional returns to what might already be called the "traditional (solo) concerto" have occurred since, as by John Cage, Leon Kirchner, and Elliott Carter in the United States; by the Argentine Alberto Ginastera; the French composer Olivier Messiaen; the Greek Yannis Xenakis; and the Russian Dmitry Shostakovich. In the main, from 1950 on, the pronounced swing of the avant-garde to electronic, computerized, and aleatoric, or chance music, has tended to do away with everything traditionally identified with "concerto," including the title itself. The only identifiable characteristic to remain is the basic idea of the group–solo relationship, as in several works by Karlheinz Stockhausen and Lukas Foss. That basic idea is essential not only to the concerto but to much other music. Whether it alone will survive in a way that still can be related to the venerable career of the concerto remains to be seen. (W.S.N.)

ELECTRONIC MUSIC

Definition and nature of electronic music

Although any music produced or modified by electrical, electromechanical, or electronic means can be called electronic music, it is more precise to say that for a piece of music to be electronic its composer must anticipate the electronic processing subsequently applied to his musical concept, so that the final product reflects in some way his interaction with the medium. This is no different from saying that a composer should have in mind an orchestra when he composes a symphony and a piano when he composes a piano sonata. A conventional piece of popular music does not become electronic music by being played on an electronically amplified guitar, nor does a Bach fugue become electronic music if played on an electronic organ instead of a pipe organ. Some experimental compositions, often containing chance elements and perhaps of indeterminate scoring, permit but do not necessarily demand electronic realization, but this is a specialized situation.

Electronic music is produced from a wide variety of sound resources—from sounds picked up by microphones to those produced by electronic oscillators (generating basic acoustical wave forms such as sine waves, square waves, and sawtooth waves), complex computer installations, and microprocessors—that are recorded on tape and then edited into a permanent form. Generally, except for one type of performed music that has come to be called "live electronic music" (see below), electronic music is played back through loudspeakers either alone or in combination with ordinary musical instruments.

This section covers both early experimentation with electronic sound-producing devices and composers' subsequent exploitation of electronic equipment as a technique of composition. Throughout the discussion it should be clear that electronic music is not a style but rather a technique yielding diverse results in the hands of different composers.

Historically, electronic music is one aspect of the larger development of 20th-century music strongly characterized by a search for new technical resources and modes of expression. Before 1945 composers sought to liberate themselves from the main Classical–Romantic tradition of tonal thinking and to reconstruct their thinking along new lines, for the most part either Neoclassical or atonal and 12-tone, in which a composition is built up entirely from a tone row consisting of all 12 notes of the ordinary chromatic scale.

This pre-World War II period was accompanied by substantial experimentation with electrical and electronic devices. The most important outcome for the composer was the development of a number of electronic musical instruments (such as the Hammond organ and the theremin) that provided new timbres and that laid the technical foundations for the future development of electronic music proper from about 1948 onward. The rapid development of computer technology has had its effect in music, too, so much so that the term computer music is replacing electronic music as the more accurate description of the most significant interaction between the composer and the electronic medium.

Electronic music is represented not only by a wide variety of 20th-century works, and not only by serious concert pieces, but also by a substantial literature of theatre, film, and television scores and by multimedia works that use all types of audiovisual techniques. Electronic music for theatre and films seems an especially appropriate replacement for a disembodied, nonexistent orchestra heard from a tape or a sound track. Electronic popular music has also won adherents. This mostly has consisted of arrangements of standard popular music for electronic synthesizers, the tentative use of electronic alterations by some of the more ambitious and experimental rock groups, and the preparation of recordings by innovative studio techniques.

History and stylistic development. *Beginnings.* During the 19th century attempts were made to produce and record sounds mechanically or electromechanically. For example, the German scientist Hermann von Helmholtz traced wave forms of regular sounds to check results of his acoustical researches. An important event was the invention of the phonograph by Thomas Edison and Emile Berliner, independently, in the 1870s and 1880s. This invention not only marked the beginning of the recording industry but also showed that all the acoustical content of musical sounds could be captured (in principle, if not in actuality at that time) and be faithfully retained for future use.

Cahill's pioneer work

The first major effort to generate musical sounds electrically was carried out over many years by an American, Thaddeus Cahill, who built a formidable assembly of rotary generators and telephone receivers to convert electrical signals into sound. Cahill called his remarkable invention the telharmonium, which he started to build about 1895 and continued to improve for years thereafter. The instrument failed because it was complex, impractical, and could not produce sounds of any magnitude since amplifiers and loudspeakers had not yet been invented. Nevertheless, Cahill's concepts were basically sound. He was a visionary who lived ahead of his time, and his instrument was the ancestor of present-day electronic music synthesizers.

The Italian Futurist painter Luigi Russolo was another early exponent of synthesized music. As early as 1913 Russolo proposed that all music be destroyed and that new instruments reflecting current technology be built to perform a music expressive of industrialized society. Russolo subsequently did build a number of mechanically activated *intonarumori* (noise instruments) that grated, hissed, scratched, rumbled, and shrieked. Russolo's instruments and most of his music apparently vanished during World War II.

Between World War I and World War II developments occurred that led more directly to modern electronic music, although most of them were technically, rather than musically, important. First was the development of audio-frequency technology. By the early 1920s basic circuits for sine-, square-, and sawtooth-wave generators had been invented, as had amplifiers, filter circuits, and, most importantly, loudspeakers. (Sine waves are signals consisting of "pure tones"—*i.e.*, without overtones; sawtooth waves comprise fundamental tones and all related overtones; square waves consist only of the odd-numbered partials, or component tones, of the natural harmonic series.) Also, mechanical acoustical recording was replaced by electrical recording in the late 1920s.

Invention of the electronic organ

Second was the development of electromechanical and electronic musical instruments designed to replace existing musical instruments—specifically, the invention of electronic organs. This was a remarkable achievement and one that absorbed the attention of many ingenious inventors and circuit designers. It should be stressed, however, that it was the objective of these organ builders to simulate and replace pipe organs and harmoniums, not to provide novel instruments that would stimulate the imaginations of avant-garde composers.

Most electromechanical and electronic organs employ subtractive synthesis, as do pipe organs. Signals rich in harmonic partials (such as sawtooth waves) are selected by the performer at the keyboard and combined and shaped acoustically by filter circuits that simulate the formant, or resonant-frequency, spectra—*i.e.*, the acoustical components—of conventional organ stops. The formant depends on the filter circuit and does not relate to the frequency of a tone being produced. A low tone shaped by a given formant (a given stop) is normally rich in harmonics, while a high tone normally is poor in them. Psychologically, one expects this from all musical instruments, not only organs but also orchestral instruments.

Some electronic organs operate on the opposing principle of additive synthesis, whereby individually generated sine waves are added together in varying proportions to yield a complex wave form. The most successful of these is the Hammond organ, patented by Laurens Hammond in 1934. The Hammond organ has odd qualities because the richness of its harmonic content does not diminish as the player goes up the keyboard. The German composer Karlheinz Stockhausen (in *Momente*, 1961–62), the Norwegian composer Arne Nordheim (in *Colorazione*, 1968), and a few others have scored specifically for this instrument.

New instruments in the 1920s

Third was the development of novel electronic musical instruments designed to supply timbres not provided by ordinary musical instruments. During the 1920s there was a burst of interest in building an extraordinary variety of such instruments, ranging from practical to absurd. The most successful of these were relatively few in number, were monophonic (*i.e.*, could play only one melodic line at a time), and survive chiefly because some important music has been scored for them. These are the theremin, invented in 1920 by a Russian scientist, Leon Theremin; the Ondes Martenot, first built in 1928 by a French musician and scientist, Maurice Martenot; and the trautonium, designed by a German, Friedrich Trautwein, in 1930.

The theremin is a beat-frequency audio oscillator (sine-wave generator) that has two condensers placed not inside the circuit chassis but, rather, outside, as antennas. Because these antennas respond to the presence of nearby objects, the pitch and amplitude of the output signal of the theremin can be controlled by the manner in which a performer moves his hands in its vicinity. A skilled performer can produce all sorts of effects, including scales, glissandi, and flutters. A number of compositions have been written for this instrument since the 1920s.

The Ondes Martenot consists of a touch-sensitive keyboard and a slide-wire glissando generator that are both controlled by the performer's right hand, as well as some stops controlled by the left hand. These, in turn, activate a sawtooth-wave generator that delivers a signal to one or more output transducers. The instrument has been used extensively by several French composers, including Olivier Messiaen and Pierre Boulez, and by the French-American composer Edgard Varèse.

The trautonium, like the Ondes Martenot, uses a sawtooth-wave generator as its signal source and a keyboard of novel design that permits not just ordinary tuning but unusual scales as well. Most of the music composed for this instrument is of German origin, an example being the *Concertino for Trautonium and Strings* (1931) by Paul Hindemith. In about 1950 a polyphonic version (capable of playing several voices, or parts, simultaneously) of this instrument was built by Oskar Sala, a former student of Trautwein and Hindemith, for preparing sound tracks in a Berlin film studio. These instruments have become virtually obsolete, however, because all the sounds they produce can easily be duplicated by electronic music synthesizers.

Tape music. With tape music the history of electronic music in the narrower sense begins. This history seems split into three main periods: an early (by now classical) period lasting from the commercial introduction of the tape recorder immediately following World War II until about 1960; a second period that featured the introduction of electronic music synthesizers and the acceptance of the electronic medium as a legitimate compositional activity; and the third period, in which computer technology is rapidly becoming both the dominant resource and the dominant concern.

Invention of the tape recorder

The invention of the tape recorder gave composers of the 1950s an exciting new musical instrument to use for new musical experiences. Fascination with the thing itself was the dominant motivation for composing electronic tape music. Musically, the 1950s, in contrast to the 1960s, were relatively introverted years: in all kinds of music, the focus of interest was technique and style, especially with the avant-garde. In time, the medium became fairly well understood, the techniques for handling it became increasingly standardized, and a repertory of characteristic and historically important compositions came into being. The burning issues were whether tape would replace live musicians; whether the composer was at last freed from the humiliations so often endured to get his music into the concert hall; and whether a new medium of expression had been created, quite different from and independent of instrumental music, analogous, say, to photography as opposed to traditional painting.

It became increasingly evident, however, that there was no reason to think that the electronic tape medium would eliminate instrumental performance by live musicians. Tape was increasingly regarded as something that could be—but did not need to be—treated as a unique medium. Thus the notion that the tape recorder could function as one instrument in an ensemble grew more and more popular. This conception obviated the visual monotony of an evening in an auditorium with nothing to look at but a loudspeaker. To this has been added a further stage of evolution, namely, live electronic music, in which the tape recorder and its tape is eliminated or greatly restricted in function, and transformations of the sounds of musical instruments are effected at the concert with electronic equipment. Not infrequently, this kind of performance environment also involves scores in which aleatory (chance, or random), improvisatory, or quasi-improvisatory musical guidelines for the manipulation of such equipment are supplied by a composer who prefers to let what happens just happen. Actually, it is open to question whether live electronic music is really an advance or a reversion to a more primitive state of the art, in the sense that it is the enhancement of the timbres of familiar instruments, rather than music conceived totally in terms of electronic media per se.

The first period of development was certainly one into which Europeans put the most consistent work. Tape music quickly gained recognition and financial support, and, before long, a number of well-equipped electronic music studios were established, primarily in government-supported broadcast facilities. Some important work was also done in the United States, but this was much more fragmentary, and not until after 1958 did Americans begin to catch up, either technically or artistically.

Establishment of electronic studios

In 1948 two French composers, Pierre Schaeffer and Pierre Henry, and their associates at Radiodiffusion et Télévision Française in Paris began to produce tape collages (analogous to collages in the visual arts), which they called *musique concrète.* All the materials they processed on tape were recorded sounds—sound effects, musical fragments, vocalizings, and other sounds and noises produced by man, his environment, and his artifacts. Such sounds were considered "concrete," hence the term *musique concrète.* To this Paris group certainly belongs the credit both for originating the concept of tape music as such and for demonstrating how effective certain types of tape manipulation can be in transforming sounds. These transformations included speed alteration, variable speed control, playing tapes backward, and signal feedback loops. Schaeffer however, opposed the use of electronic oscillators as sound sources, claiming that these were not "concrete" sound sources, not "real," and hence artificial and anti-humanistic.

Two of the most successful and best known *musique concrète* compositions of this early period are Schaeffer and Henry's *Symphonie pour un homme seul* (1950; *Symphony for One Man Only*) and Henry's *Orphée* (1953), a ballet score written for the Belgian dancer Maurice Béjart. These and similar works created a sensation when first presented to the public. *Symphonie pour un homme seul,* a descriptive suite about man and his activities, is an extended composition in 11 movements. *Orphée* is concerned with the descent of Orpheus into Hades.

The second event of significance was the formation of an electronic music studio in Cologne by Herbert Eimert, a composer working for Nordwestdeutscher Rundfunk (now Westdeutscher Rundfunk), who was advised in turn by Werner Meyer-Eppler, an acoustician from the University of Bonn. Eimert was soon joined by Karlheinz Stockhausen, who composed the first really important tape composition from this studio, the now-famous *Gesang der Jünglinge* (1956; *Song of Youth*). The Cologne studio soon became a focal point of the reemergence of Germany as a dominant force in new music.

At Cologne emphasis was immediately placed on electronically generated sounds rather than concrete sounds and on electronic sound modifications such as filtering and modulating rather than tape manipulation. Eimert and Stockhausen also published a journal, *Die Reihe* ("The Row"), in which appeared articles emphasizing the "purity" of electronic sounds and the necessity of coupling electronic music to serial composing (using ordered groups of pitches, rhythms, and other musical elements as compositional bases), which made no more sense than the Paris group's insistence on using only nonelectronic, nonserial material. This activity was part of the campaign of the 1950s that brought about the collapse of Neoclassicism (a style that drew equally on 20th-century musical idioms and earlier, formal types); the emergence of the Austrian composer Anton von Webern as the father figure of the new music; the development of total serialism, pointillism (a style making use of individual tones placed in a very sparse texture), and intellectualism; and an emphasis on technique. The examples set by these two studios were soon widely imitated in Europe. This trend continued in the 1960s, with many more studios, from modest to elaborate, being set up in almost every major urban centre in Europe. As time passed, the techniques and equipment in the newer studios became more standardized and reliable, and the rather peculiar issue of concrete versus electronic sounds ceased to concern anyone.

Stockhausen's first tape composition

In the United States the production of electronic music, until 1958, was much more sporadic. The only continuing effort of this sort was the project undertaken by two composers at Columbia University, Otto Luening and Vladimir Ussachevsky, to create a professional tape studio and to compose music illustrating the musical possibilities of the tape medium. Luening and Ussachevsky often collaborated on joint compositions. They gained particular attention for the composition of several concerto-like works for tape recorder and orchestra. In 1959 Luening and Ussachevsky joined with another U.S. composer, Milton Babbitt, to organize, on a much larger scale, the Columbia–Princeton Electronic Music Center, in which an impressive number of composers of professional repute have worked.

Other tape compositions in the early 1950s in the United States were largely those of individual composers working as best they could under improvised circumstances. One major composer who did so was Varèse, who completed *Déserts,* for tape and instrumental ensemble, in 1954, and *Poème électronique,* for the Philips Pavilion at the 1958 Brussels World's Fair. Another was John Cage, who completed *Williams Mix* in 1952 and *Fontana Mix* in 1958. Both Varèse and Cage had anticipated the electronic medium; Cage's *Imaginary Landscape No. 1* (1939) for RCA test records and percussion can well be regarded as a forerunner of current live electronic music.

Varèse's *Déserts*

With the establishment of the Experimental Music Studio at the University of Illinois in 1958 by Lejaren Hiller and the University of Toronto studio in 1959 by Myron Schaeffer, the formation of facilities for both production and teaching began to move forward. The number of studios in university music departments grew rapidly, and they soon became established as essential in teaching as well as composing.

The individual components may vary in a well-designed "classic" studio, but basically the equipment may be divided into five categories: sound sources (sine-wave, square-wave, sawtooth-wave, and white-noise generators; and microphones for picking up concrete sounds); routing and control circuitry (patch panels, switching boards, and mixers for coupling components together; amplifiers; and output connections); signal modifiers (modulators, frequency shifters, artificial reverberators, filters, variable-speed tape recorders, and time compression–expansion devices); monitors and quality-control equipment (frequency counter, spectrum analyzer, VU metres that monitor recording levels, oscilloscope, power amplifiers with loudspeakers and headsets, and workshop facilities); and recording and playback equipment, including high-quality tape recorders.

With this equipment the composer records sounds, both electronic and microphoned; modifies them singly or in montages by operations such as modulation, reverberation, and filtering; and finally re-records them in increasingly complex patterns. Inevitably, a major part of the composer's effort is tape editing, unless he is satisfied

with the crudest string of effects merely linked together in sequence. As in any other kind of music, the aesthetic merit of an electronic music composition seems to depend not only on musical ideas as such but also on the way in which they relate to one another and how they are used to build up a musical structure.

Integration of live instruments and recorder with performance ensembles

The integration of the tape has become a rather popular form of chamber music, if not of symphonic music. Varèse's *Déserts* is an early example of this. It is scored for a group of 15 musicians and a two-channel tape and consists of four instrumental episodes interrupted by three tape interludes. In other works the tape recorder is "performed" together with the remaining instruments rather than merely in contrast to them. The problems of coordination, however, can become overriding, for it is difficult for a group of performers to follow a tape exactly. Obviously, the tape dominates the situation, remorselessly moving along no matter what happens in the rest of the group.

Thousands of electronic tape compositions were in existence by the early 1970s, many of ephemeral interest. It is relatively rare for a composer to have established a reputation solely as a composer of tape music. Pierre Henry perhaps is an example, but in general the important names in instrumental music of the 1950s and 1960s are the significant contributors in electronic music, too.

Stockhausen remained in the forefront of electronic music composers with several important pieces following *Gesang der Jünglinge.* These included *Kontakte* (1959–60; *Contacts*), for tape, piano, and percussion, and *Telemusik* (1966), for tape alone. Luciano Berio and Bruno Maderna, both Italians, worked for a while at the Radio Audizioni Italia (now Radiotelevisione Italiana) studio in Milan. Besides *Différences* (1958–60), a composition for tape and chamber group, Berio's tape pieces include *Thema-Omaggio a Joyce* (1958; *Homage to Joyce*) and *Visage* (1961), which exploited the unusual voice of the American singer Cathy Berberian.

In the United States the Columbia–Princeton Electronic Music Center has had the greatest output, a long list of composers besides Luening and Ussachevsky having used its facilities. Tape music from the University of Illinois studio includes Salvatore Martirano's *L's GA* (1967), a savage political satire for tape, films, helium bomb, and gas-masked politico. The University of Toronto studio, in spite of its technical excellence, has not been well represented on discs. One Canadian piece that is very amusing, however, is Hugh LeCaine's *Dripsody* (1955), all the sounds of which are derived from the splash of a single drop of water.

Music synthesizers. Composing tape music by the classic method was neither easy nor free of technical pitfalls. A complex piece had to be assembled from hundreds or even thousands of fragments of tape. Splicing these sounds together consumed a vast amount of time and could also lead to an accumulation of errors and deterioration of the sound. Consequently, substantial efforts were expended to reduce this work load and at the same time improve quality. Music synthesizers were the first product of these efforts. They cannot, however, be regarded as more than an intermediate technological development because of later computer technology (see below).

In contrast to Cahill's period, by the 1950s the means finally existed to construct full-scale music synthesizers, starting with the RCA Electronic Music Synthesizers, designed by Harry Olson and Herbert Belar, research scientists working at the RCA Laboratories at Princeton, New Jersey. The first machine was introduced in 1955; a second, improved model was turned over to the Columbia–Princeton Electronic Music Center in 1959.

The basic advance of the RCA synthesizer was an information input mechanism, a device for punching sets of instructions into a wide roll of punched paper tape. The composer could at any time during the programming process interrupt this activity to listen to what had been punched, to make corrections, and to edit the material before making a final paper tape that then constituted the "master score" of the composition.

The composer whose name became particularly associated with the RCA synthesizer was Milton Babbitt. He had developed a precisely defined compositional technique involving total serialization (*i.e.,* of every musical element). When he became aware of the synthesizer, he was anxious to use it, because it gave him the opportunity to realize his music more precisely than had hitherto been the case. Among Babbitt's compositions created with this machine were *Composition for Synthesizer* (1961), *Vision and Prayer* (1961), *Ensembles for Synthesizer* (1963), *Philomel* (1964), and *Phonemena* (1974).

In about 1960 a new circuit, the voltage-controlled oscillator (VCO), attracted the attention of engineers interested in electronic music because the frequency of its output signal is proportional to an independently generated input voltage rather than being internally set. The response is immediate because no mechanical couplings or controls are required. Robert Moog was the first to design several types of compact synthesizers of moderate price that supplied an extended range of possibilities for sound manipulation. In addition to VCO's, which produce sine, square, sawtooth, and triangular waves, the Moog synthesizer contained white-noise generators, attack and decay generators (controlling a sound's onset and fading), voltage-controlled amplifiers, and band-pass filters and sequencers.

One major advance in sound manipulation provided by VCO's is frequency modulation; if the input is a periodic function, the output frequency will vary periodically to provide tremolos, trills, and warble tones. Moog's synthesizer soon had to compete with several other synthesizers of essentially the same design, the Buchla Electronic Music Box, the ARP, and the later, more sophisticated Prophet 10.

Design of the Moog synthesizer

These popular synthesizers eliminate much of the drudgery of tape splicing, but at a price. The range of timbres and processes is more limited because they operate by subtractive synthesis and impose transients that affect all partials (component vibrations) of a complex wave identically. An advantage of a harmonic tone generator built in 1962 by James Beauchamp at the University of Illinois, also from VCO's, was that it used additive synthesis—*i.e.,* it created sound by combining signals for pure tones (sine waves)—instead of removing partials from a complex signal. It was designed so that each partial of a sound could have its own entry point, its own rise time, and its own decay time. The improvement in tone quality was enormous, because the ear normally expects nuances such as higher partials that decay faster than lower ones. Salvatore Martirano's *Underworld* (1965) is a good example of music in which the tape was made largely by additive synthesis.

A composer closely associated with synthesizers is Morton Subotnik, who has produced a series of extended electronic music compositions, starting with *Silver Apples of the Moon* (1967). These pieces were created on the Buchla synthesizer, and any one of them demonstrates in relatively unmodified form the types of sounds one may obtain with these instruments.

The success of *Switched-on Bach*

A word should be said about realizations of instrumental music through synthesizers, notably an early, commercially successful album called *Switched-on Bach* (1968), arrangements made by Walter (later Wendy) Carlos on a Moog synthesizer. The record displayed technical excellence in the sounds created and made the electronic synthesis of music more intelligible to the general listening public. This is useful so long as it is realized that the materials on the record are arrangements of familiar music, not original compositions. (Carlos later created an original electronic score for the science fiction film *Tron.*)

Computer music. Perhaps the most important development in electronic music is the use of digital computers. The kinds of computers employed range from large mainframe, general-purpose machines to special-purpose digital circuits expressly designed for musical uses. Musical applications of digital computers can be grouped into five basic categories: data processing and information retrieval, including library applications and abstracting; processing of music notation and music printing; acoustical, theoretical, and musicological research; music composition; and sound synthesis. In all these fields considerable research and ex-

perimentation is being carried out, with sound synthesis perhaps being the most widespread and advanced activity. Dramatic illustrations of the growth of this work include the appearance of the periodical *Computer Music Journal,* the formation of the Computer Music Association, made up of hundreds of members, and the holding each year of the International Computer Music Conference. The 1982 conference dominated the Venice Biennale—one of the major festivals of contemporary music.

Computer composition. Composition and sound synthesis are complementary processes because the first may lead to the second. A composer may elect to use a set of compositional programs to produce a composition. He may then stop using a computer and print his results for transcription to instrumental performance. Alternatively, he may transfer his results directly into electronic sounds by means of a second set of programs for sound synthesis. Finally, he may desire only to convert an already composed score into sound. When he does this, he translates his score into a form that can be entered into a computer and uses the computer essentially as a data translator.

The first point to understand about computer composition is that, like electronic music, it is not a style but a technique. In principle, any kind of music, from traditional to completely novel, can be written by these machines. For a composer, however, the main appeal consists not in duplicating known styles of music, but, rather, in seeking new modes of musical expression that are uniquely the result of interaction between man and this new type of instrument.

At present, composers above all need a compiling language comprised of musical or quasi-musical statements and a comprehensive library of basic compositional operations written as closed subroutines—in effect, a user's system analogous to computer languages (such as Fortran) used by mathematicians. Two major obstacles stand in the way of building up an effective musical computer language. The first is the obvious one of allocation of sufficient time, money, and other resources. The second is defining what goes into the subroutine library; *i.e.,* of stating with precision the smallest units of activity or decision making that enter into the process of musical composition. Unlike mathematics, in which traditional modes of thinking prepared the way for such a definition of subroutines, in music the defining of "modules" of composition leaves even sophisticated thinkers much more at sea.

Earliest example of computer-composed music

The earliest example of computer-composed music is the *Illiac Suite for String Quartet* (1957) by two Americans, the composer Lejaren Hiller and the mathematician Leonard Isaacson. It was a set of four experiments in which the computer was programmed to generate random integers representing various musical elements, such as pitches, rhythms, and dynamics, which were subsequently screened through programmed rules of composition.

Two very different compositions, *ST/10-1,080262* (1962), by Yannis Xenakis, and *HPSCHD* (1968), by John Cage and Hiller, are illustrative of two later approaches to computer composition. *ST/10-1,080262* is one of a number of works realized by Xenakis from a Fortran program he wrote in 1961 for an IBM 7090 computer. Several years earlier, Xenakis had composed a work called *Achorripsis* by employing statistical calculations and a Poisson distribution to assign pitches, durations, and playing instructions to the various instruments in his score. He redid the work with the computer, retitled it, and at the same time produced a number of other, similar compositions. *HPSCHD,* by contrast, is a multimedia work of indeterminate length scored for one to seven harpsichords and one to 51 tape recorders. For *HPSCHD* the composers wrote three sets of computer programs. The first, for the harpsichord solos, solved Mozart's *Musical Dice Game* (K. 294d), an early chance composition in which successive bars of the music are selected by rolling dice, and modified it with other compositions chosen with a program based on the Chinese oracle *I Ching* (*Book of Changes*). The second set of programs generated the 51 sound tracks on tape. These contained monophonic lines in microtone tunings based upon speculations by the composers regarding Mozart's melodic writing. The third program generated sheets of instructions to the purchasers of a record of the composition.

Hiller has continued to develop compositional programming techniques in order to complete a two-hour cycle of works entitled *Algorithms I, Algorithms II, and Algorithms III.* Otherwise, interest in computer composition gradually has continued to grow. For example, Gottfried Michael Koenig, director of the Instituut voor Sonologie of the University of Utrecht in The Netherlands, has after a lapse of several years written new computer music such as *Segmente 99-105* (1982) for violin and piano. Related to Koenig's work is an extensive literature on theoretical models for music composition developed by the American composer Otto Laske. Charles Ames, another American, has written several works for piano or small ensemble that are less statistical and more deterministic in approach than most of the above. Clarence Barlow has written a prize-winning composition, *Çoğluatobüsîşletmesî* (1978), that exists in two versions—for piano or for solo tape. A different, but nevertheless important, example of computer music composition is Larry Austin's *Phantasmagoria: Fantasies on Ives' Universe Symphony* (1977). This is a realization, heavily dependent on computer processing, of Charles Ives's last and most ambitious major composition, which he left in a diverse assortment of some 45 sketch pages and fragments.

The borderline between composition and sound synthesis is becoming increasingly blurred as sound synthesis becomes more sophisticated and as composers begin to experiment with compositional structures that are less related to traditional musical syntax. An example of this is *Androgeny,* written for tape in 1978 by the Canadian composer Barry Truax.

Computer sound synthesis. The production of electronic sounds by digital techniques is rapidly replacing the use of oscillators, synthesizers, and other audio components (now commonly called analogue hardware) that have been the standard resources of the composer of electronic music. Not only is digital circuitry and digital programming much more versatile and accurate, but it is also much cheaper. The advantages of digital processing are manifest even to the commercial recording industry, where digital recording is replacing long-established audio technology.

Basic techniques for producing sounds with a computer

The three basic techniques for producing sounds with a computer are sign-bit extraction, digital-to-analogue conversion, and the use of hybrid digital–analogue systems. Of these, however, only the second process is of more than historical interest. Sign-bit extraction was occasionally used for compositions of serious musical intent—for example, in *Computer Cantata* (1963), by Hiller and Robert Baker, and in *Sonoriferous Loops* (1965), by Herbert Brün. Some interest persists in building hybrid digital-analogue facilities, perhaps because some types of signal processing, such as reverberation and filtering, are time-consuming even in the fastest of computers.

Digital-to-analogue conversion has become the standard technique for computer sound synthesis. This process was originally developed in the United States by Max Mathews and his colleagues at Bell Telephone Laboratories in the early 1960s. The best known version of the programming that activated the process was called Music 5.

Digital-to-analogue conversion (and the reverse process, analogue-to-digital conversion, which is used to put sounds into a computer rather than getting them out) depends on the sampling theorem. This states that a wave form should be sampled at a rate twice the bandwidth of the system if the samples are to be free of quantizing noise (a high-pitched whine to the ear). Because the auditory bandwidth is 20–20,000 hertz (Hz), this specifies a sampling rate of 40,000 samples per second though, practically, 30,000 is sufficient, because tape recorders seldom record anything significant above 15,000 Hz. Also, instantaneous amplitudes must be specified to at least 12 bits so that the jumps from one amplitude to the next are low enough for the signal-to-noise ratio to exceed commercial standards (55 to 70 decibels).

Music 5 was more than simply a software system, because it embodied an "orchestration" program that simulated many of the processes employed in the classical electronic music studio. It specified unit generators for the standard

wave forms, adders, modulators, filters, reverberators, and so on. It was sufficiently generalized that a user could freely define his own generators. Music 5 became the software prototype for installations the world over.

One of the best of these was designed by Barry Vercoe at the Massachusetts Institute of Technology during the 1970s. This program, called Music 11, runs on a PDP-11 computer and is a tightly designed system that incorporates many new features, including graphic score input and output. Vercoe's instructional program has trained virtually a whole generation of young composers in computer sound manipulation. Another important advance, discovered by John Chowning of Stanford University in 1973, was the use of digital FM (frequency modulation) as a source of musical timbre. The use of graphical input and output, even of musical notation, has been considerably developed, notably by Mathews at Bell Telephone Laboratories, by Leland Smith at Stanford University, and by William Buxton at the University of Toronto.

There are also other approaches to digital sound manipulation. For example, there is a growing interest in analogue-to-digital conversion as a compositional tool. This technique allows concrete and recorded sounds to be subjected to digital processing, and this, of course, includes the human voice. Charles Dodge, a composer at Brooklyn College, has composed a number of scores that incorporate vocal sounds, including *Cascando* (1978), based on the radio play of Samuel Beckett, and *Any Resemblance Is Purely Coincidental* (1980), for computer-altered voice and tape. The classic *musique concrète* studio founded by Pierre Schaeffer has become a digital installation, under François Bayle. Its main emphasis is still on the manipulation of concrete sounds. Mention also should be made of an entirely different model for sound synthesis first investigated in 1971 by Hiller and Pierre Ruiz; they programmed differential equations that define vibrating objects such as strings, plates, membranes, and tubes. This technique, though forbidding mathematically and time-consuming in the computer, nevertheless is potentially attractive because it depends neither upon concepts reminiscent of analogue hardware nor upon acoustical research data.

Another important development is the production of specialized digital machines for use in live performance. All such instruments depend on newer types of microprocessors and often on some specialized circuitry. Because these instruments require real-time computation and conversion, however, they are restricted in versatility and variety of timbres. Without question, though, these instruments will be rapidly improved because there is a commercial market for them, including popular music and music education, that far exceeds the small world of avant-garde composers.

Some of these performance instruments are specialized in design to meet the needs of a particular composer—an example being Salvatore Martirano's *Sal-Mar Construction* (1970). Most of them, however, are intended to replace analogue synthesizers and therefore are equipped with conventional keyboards. One of the earliest of such instruments was the "Egg" synthesizer built by Michael Manthey at the University of Århus in Denmark. The Synclavier later was put on the market as a commercially produced instrument that uses digital hardware and logic. It represents for the 1980s the digital equivalent of the Moog synthesizer of the 1960s.

The most advanced digital sound synthesis, however, is still done in large institutional installations. Most of these are in U.S. universities, but European facilities are being built in increasing numbers. The Instituut voor Sonologie in Utrecht and LIMB (Laboratorio Permanente per l'Informatica Musicale) at the University of Padua in Italy resemble U.S. facilities because of their academic affiliation. Rather different, however, is IRCAM (Institut de Recherche et de Coordination Acoustique/Musique), part of the Centre Georges Pompidou in Paris. IRCAM, headed by Pierre Boulez, is an elaborate facility for research in and the performance of music. Increasingly, attention there has been given to all aspects of computer processing of music, including composition, sound analysis and synthesis, graphics, and the design of new electronic instruments for performance and pedagogy. It is a spectacular demonstration that electronic and computer music has come of age and has entered the mainstream of music history.

In conclusion, science has brought about a tremendous expansion of musical resources by making available to the composer a spectrum of sounds ranging from pure tones at one extreme to random noise at the other. It has made possible the rhythmic organization of music to a degree of subtlety and complexity hitherto unattainable. It has brought about the acceptance of the definition of music as "organized sound." It has permitted the composer, if he chooses, to have complete control over his own work. It permits him, if he desires, to eliminate the performer as an intermediary between himself and his audience. It has placed the critic in a problematic situation, because his analysis of what he hears must frequently be carried out solely by ear, unaided by any written score. (L.Hi.)

Vocal music

Music for voices encompasses a broad variety of genres for solo voice and voices in combination, with or without instrumental accompaniment. It includes monophonic music (having a single line of melody) and polyphonic music (consisting of more than one simultaneous melody). This section deals with Western art music preserved in staff notation, either for a single solo voice or for voices in unison, and briefly discusses the differences between Western and non-Western traditions. It excludes the complex forms of opera, oratorio, cantata, mass, and requiem, in which solo singing is frequently combined with choral music. The earliest written examples date from the 10th century, prior to which music was transmitted principally by oral tradition.

GENRES OF VOCAL MUSIC

Medieval and Renaissance periods. The chant most important for Western music is the so-called Gregorian repertory, earliest preserved in French manuscripts beginning from *c.* 900. Music for other major early medieval Latin repertories either has not survived (old Frankish, or Gallican, chant), is indecipherable (Mozarabic chant from Spain), or did not serve as the basis for later musical development (Ambrosian chant from Milan).

French development of Gregorian chant

From *c.* 750 to 850, music and musicians moved freely between the north and south with the intention of transferring Roman chant to France, but the methods and the extent of the process cannot be documented. The French greatly expanded their repertory until *c.* 1150 through the addition of both melodies and texts. Particularly important for future developments in vocal music were the new hymns, sequences, and other poetic settings, which were organized into regular stanzas with rhymes and metrical patterns. Gregorian chants not only served a liturgical function but also provided source material for much of the polyphonic music of the Middle Ages and Renaissance.

The degree of elaboration in a particular chant melody generally relates to its function within the liturgy. In chants that serve for recitations, such as psalms, lessons, or prayers, the music is secondary to a clear projection of the text; these settings are predominately syllabic (*i.e.*, only one note per syllable) and use relatively few pitches. Somewhat more ornate are melodies that accompany a liturgical action (such as processionals or communions in the mass), while chants completely independent of these functions, such as mass graduals and alleluias, tend to become the most elaborate. In these last two types, settings vary from neumatic (two to five notes per syllable) to highly melismatic (many notes per syllable).

Unlike the Gregorian repertory, the medieval chants of the major Eastern churches no longer continue as living traditions. The Byzantine liturgy, codified by the 11th century, has been subject to continual change since the fall of Constantinople in 1453. The early chants, preserved in manuscripts from the 11th to the 15th centuries, show fascinating parallels with the Gregorian repertory, suggesting close relationships or common origins between the two liturgies. Other Eastern churches developed independent chant repertories: Coptic (Egyptian), Abyssinian, and

Armenian; but written sources for these chants are either nonexistent or presently indecipherable. Russian (*znamenny*) chant evolved from the Byzantine liturgy imported in the 10th century and reached a classical stage in the 15th–17th centuries; but the only legible manuscripts date from the end of this period.

Latin songs by wandering scholars as early as the 7th century survive in a musical notation now unreadable. But the largest repertories of monophonic songs come from the troubadours in southern France (late 11th to early 13th centuries), the trouvères in northern France (mid-12th through 13th centuries), and the German minnesingers (mid-12th to late 15th centuries). These musicians and poets from all classes of society composed and performed for the nobility until well into the 13th century, after which patronage gradually shifted to the bourgeoisie and prosperous clergy. Their texts most frequently treat the ideals of chivalry and courtly love, using polished and often obscure language; at times similar poems offer praise to the Blessed Virgin. Service songs, called *sirventes* in southern France (*Spruch* in German), deal with didactic, political, or personal matters, perhaps in a satirical fashion. Other texts record events of the court, such as marriages, deaths, or participation in crusades. Among the more traditional songs from northern France are the *chansons de geste,* extended narratives glorifying earlier heroes or saints.

Poetic form and music

The poetic texts inherited strophic (stanzaic) design, rhyming, and metrical schemes from earlier medieval Latin. To these devices the trouvères added the idea of a refrain, varying in length from a single word to several poetic lines and placed at any position within the stanza. Eventually certain arrangements became fixed forms: the *ballade* or German *Bar* form (a a B), the *rondeau* (A B a A a b A B), and the *virelai* (A b b a A). In the diagrams, identical letters indicate same rhymes, and capitals show the refrain; as a rule, two sections of music are repeated according to the design of the poem. Shown here in their simplest structures, the forms were regularly expanded or varied in detail. Less standard designs were the *lai* in northern France (*Leich* in German), with irregular groupings of couplets, and the lengthy *chansons de geste,* probably repeating a simple melodic formula for each text line.

Many monophonic songs resemble Gregorian chant, although without lengthy melismas. Others present a more modern sound through the use of the major scale and organization in short symmetrical phrases. Most of the earlier songs (before 1200) have no written indications of metre. Recent scholarship suggests a free rendition for songs with irregular phrasing and embellishments but more regulated rhythms for the simple dancelike tunes. Improvised accompaniments are often appropriate, although not indicated in the original manuscripts.

Vernacular songs spread to the courts of England, Spain, and Italy, although the surviving examples from these regions are primarily religious. The monophonic art eventually declined during the 14th century for three principal reasons: the rise of interest in polyphonic composition, the loss of aristocratic patronage, and the substitution of theoretical rules for creative instinct. The last phenomenon is best illustrated in the works of the German middle class meistersingers from the 15th and 16th centuries.

Polyphonic settings of fixed-form songs

The most characteristic and persistent type of early polyphonic song is the French chanson, in the form of a *rondeau, ballade,* or *virelai.* Chanson composers included the most outstanding musicians of the 14th and 15th centuries, among them Guillaume de Machaut, Guillaume Dufay, Gilles Binchois, Antoine Busnois, and Jean d'Okeghem. Their activities centred in the courts of France and Burgundy, although many travelled to other areas, particularly Italy and northern Spain. Indigenous forms developed in the 14th century in Italy (*madrigal, ballata,* and *caccia*), and in the 15th century in Spain (*villancico* and *romance*), England (carol), and German (*Bar*); but these types shared many features of the Franco-Burgundian compositions. The chanson consists of two principal sections of music, with no text repetition except as required by the poetic structure. Three contrasting voices are standard: cantus, tenor, and contratenor. The cantus typically moves in a high tenor or alto range, in counterpoint with the lower tenor. To this two-part framework is added the contratenor, at times following the style and range of the cantus but at other times that of the tenor. Although most performances undoubtedly combined the voice(s) with instruments, it is by no means certain how the parts were distributed. Evidence suggests that performances were quite flexible, depending upon the singers or instruments available and upon the style of the individual song.

During the later 15th century new ideals for vocal composition arose that were incompatible with the earlier fixed-form songs. The different voice parts, now at least four in number, tended toward more equalization in style. All voices were underlain with a text, or were potentially singable; they either imitated the same melody or had similar rhythmic and melodic characteristics. Poetic structure was now obscured by a continuous overlapping of sections, and the words of the text were often blurred by the activity of the various voices. Native Italian partsongs (*frottole,* carnival songs, and *villanelle*) generally presented texts with clearer declamation, but, as the century advanced, even these simpler types gave way to the more complex Renaissance madrigal, with frequent use of melodic imitation. Musicians regularly arranged these polyphonic works for solo performance with instrumental accompaniment. But no significant part of this artistic repertory, with the possible exception of Spanish *vihuela* songs, was designed exclusively for the solo singer.

Transition to a new style

The advent of the modern art song depended upon a rejection of two prevailing attitudes found in mid-16th-century polyphony: the principle that a piece of vocal music was performable in any conceivable medium (for solo, for ensemble of voices, or even for instruments alone) and the idea that the text needed only be the servant of the music. An increasing concern for textual interpretation and declamation began to appear in late 16th-century polyphonic compositions. Texts were often delivered in a speechlike recitation; emotionally charged words were emphasized through special rhythms, unexpected harmonic progressions, chromaticism (use of notes foreign to the song's mode), and coloratura (florid ornamentation); and simultaneous rhythms in the different voices made possible a clearer projection of the words. Of more temporary influence were the French experiments with quantitative metre in poetry and music (*musique mesurée*). But the final step in the transfer of these various techniques from part music to genuine solo music came at the end of the century, notably in Italian monody (expressive melody with chordal accompaniment) and English lute songs.

The 17th–20th centuries. The art song of the 17th through 20th centuries always reflects the mutual influences of music and literature, and most enduring masterpieces show an extraordinary sensitivity of the composer to the individual words, to the prosody, or simply to the overall character of his text. The poet Goethe felt that the simpler the musical setting, the more likely it was to reflect the original nature of the poem; any extensive musical elaborations often reinterpreted the message or character of the poem and were therefore undesirable. But the more imaginative composers, particularly those of the 19th and 20th centuries, used the full resources of their art to embellish the text or even to realize potentials that were not explicit in the original.

Ages producing great poetry have often prompted a flourishing of important song writing, as Elizabethan England, 19th-century Germany and Austria, and late 19th- through early 20th-century France. Since the early 19th century, composers have frequently selected a group of poems by a particular author or on a single topic by different authors to produce a collection of related songs. Some of these cycles are undoubtedly designed to be performed as integrated compositions. As examples, Beethoven's *An die ferne Geliebte* (*To the Distant Beloved*) musically relates the opening with the closing of the cycle and joins each song to the next without interruption; individual songs in Schumann's *Frauenliebe und Leben* (*Woman's Love and Life*) and Brahms's *Magelone* present lyrical moments within a continuous narrative.

Song cycles

Three methods are possible for setting strophic poetry.

Methods for strophic setting

Simple-strophic setting consists of a single piece of music to be repeated for all stanzas. Modified-strophic setting retains the same musical framework for each stanza but with changing details in the voice and accompaniment to suit the progressing text. Through-composed setting proceeds to a different musical plan for each new stanza. The simple-strophic approach is effective if the entire poem suggests a central mood that can be captured in the music or if the composer creates a neutral setting that avoids detailed text illustration. Prosody and syntax must follow a regular pattern in each stanza if the result is to be satisfactory. Thus in Franz Schubert's "Das Wandern" ("Wandering) from the cycle *Die schöne Müllerin* (*The Miller's Beautiful Daughter*), the accompaniment suggests the continual flow of the millstream, while the energetic vocal melody reflects the enthusiasm of the young traveller. The singer's rhythm is easily adaptable to each stanza of text.

Either the modified-strophic or the through-composed method is more likely to be successful for poems that contain widely differing moods in each stanza, progress to a dramatic climax, or follow irregular prosodic patterns. In the modified-strophic setting of "Der Lindenbaum" ("The Linden Tree"), from the cycle *Winterreise* (*Winter Journey*), Schubert changes from major to minor for the stanza suggesting bitter recollections, gives a more dramatic interpretation to both the voice and piano for references to the chilling winter wind, and, finally, repeats the music for the opening stanza but with modifications in the piano when the thoughts return to pleasant memories. The through-composed approach does not necessarily require new musical ideas for all parts of the song; the crucial distinction is the lack of any structural correspondence between the stanzas of text and the sections of music. Although the vocal lines in each stanza of Claude Debussy's "C'est l'extase langoureuse" ("This Is Langorous Ecstasy") are entirely different, the piano unifies the setting by frequently returning to its opening motive. The art song since the late 19th century and simple strophic works from earlier periods normally provide a straightforward setting that avoids any word repetitions. The frequent text repetitions in many art songs from the 17th through mid-19th centuries generally indicate a predominance of musical over textual considerations, a feature also important in the operatic or concert aria.

Speech rhythms and prosody

In setting a text to a vocal melody, the composer may choose to present his interpretation of the natural speech patterns in the poem; in his solution, the rhythmic complexity, the melodic range of tones, and variations in volume will depend ultimately upon his own musical language. Also open to the composer's interpretation is the versification of the poem. The music may reflect whatever prosodic principles are present in the language: poetic feet, qualitative or quantitative accent, or mere count of syllables. Although some vocal settings show a complete preoccupation with speech inflections (strict recitatives of the 17th century) or with prosody (*musique mesurée* experiments in the late 16th and early 17th centuries), most successful songs incorporate either or both of these considerations into a melodic line that is satisfying because of musical qualities as well. Hugo Wolf's "Kennst du das Land" ("Do You Know the Land") faithfully reflects the iambic feet (⏑′) of Goethe's poem, but this prosodic awareness is combined with a sensitivity to the important words in the text. Furthermore, the melody progresses to a musical climax, as Wolf prepares for his setting of the high point of the poem. Even in works in which the text is obviously the servant of the music, a neutral treatment of rhythm and pitch usually avoids glaring distortions of the words. In the final portion of Arnold Schoenberg's "Sommermüd ("Weary of Summer") Opus 48, the pitches in the vocal melody are entirely determined by the 12-tone row (composer's ordering of the 12 notes of the chromatic scale) chosen for the whole song; yet the rhythm generally follows that of the poem.

Continuo accompaniment

The nature and role of the accompaniment has undergone many changes since the earliest art songs. In the repertory of the 17th and 18th centuries, the singer is the prime interpreter of the text. As a rule, the accompanying part of these songs consists only of a figured bass (the basso continuo), in which the notation for the bass melody also indicates the harmonies to be improvised on the harpsichord, lute, or some other chord instrument. Except for an occasional imitation or anticipation of the voice or for interludes between the stanzas, the continuo accompaniment provides little commentary on the poem. Even when these early songs call for additional instruments, such as a flute or violin, or when the harmony is fully written out, as in 17th-century lute songs, the accompaniment only supports or imitates the voice. Complete piano parts regularly appear first in the late 18th century, replacing the abbreviated continuo. Although some piano accompaniments continue a subservient relationship to the voice, the trend in the 19th and 20th centuries has been toward greater participation in the interpretation. The piano may reinforce the emotional states of the poem; *e.g.,* underlying anxiety in Wolf's "In der Frühe" ("In the Early Morning"); represent external details in the setting, as the spinning wheel in Schubert's "Gretchen am Spinnrade" ("Gretchen at the Spinning Wheel"); or assist in building dramatic climaxes, as in Wolf's "Kennst du das Land." It may provide extensive preludes, as in Richard Strauss's "Morgen" ("Morning"), interludes or postludes, as in Schumann's "Alten, bösen Lieder" ("Old, Evil Songs") from *Dichterliebe* (*Poet's Love*), or complete the phrasing in the voice; *e.g.,* Schumann's "Nussbaum" ("Nut Tree"). In the present century, the piano frequently follows its independent ideas, freeing the voice for more expressive declamation, as in Maurice Ravel's *Histoires naturelles,* in which the instrument effectively portrays the various animals in the texts. Many songs from the 19th and 20th centuries, particularly the period *c.* 1880–1920, have either alternative or original accompaniments for orchestra (*e.g.,* by Gustav Mahler, Strauss, Schoenberg, Alban Berg, Anton Webern, Ravel, and many others). Such settings enrich the texture and make possible a much greater range of colouristic effects. Other 20th-century songs require small chamber ensembles. The instruments may provide interpretative details, as in Ravel's *Chansons madécasses* (*Madagascan Songs*) or simply complement the musical ideas of the voice, as in Webern's chamber songs for various combinations.

Role of the piano

The concert aria, primarily an 18th-century composition with orchestral accompaniment, was originally intended either as an independent showpiece, as a substitute aria for an operatic production, or as a special number, called *licenza,* to follow a performance. Usually composed for a specific singer, the aria was generally more concerned with displaying vocal qualities than with interpreting the literary details of the text. Consequently, the poems are concise, with each verse typically repeated many times throughout a setting. The structure follows the same designs of the operatic aria. Most characteristic is the *da capo* plan, consisting of two contrasting sections of music: after the second section, the performers repeat the first, this time with more elaborate embellishments improvised by the singer. Another plan, popular in the later 18th century, is the composite design, consisting of several different sections with contrasting moods, usually with a brilliant conclusion. In both the *da capo* and composite forms, the composer represents a minimum of stereotyped emotional states, generally one for each section of music. A single tempo and metre are maintained for each section. If the aria is preceded by a recitative, the entire composition becomes a dramatic scene (*scena*).

The concert aria's influence

The concert aria was so influential a form that many continuo songs followed its structure and style. Henry Purcell's "Ye Gentle Spirits of the Air, Appear" (published posthumously in 1702) is in *da capo* structure, with textual repetitions and difficult coloratura, but it is also an objective musical portrayal of the words "repeat" and "trembling." Such text painting, characteristic of the earlier madrigal genre and sometimes found in arias, is exceptional in the general literature of the art song.

The solo voice has at times been used within works that are primarily instrumental, as an imposing climax to a symphonic composition (the finales of Beethoven, *Symphony No. 9;* Mahler, *Symphonies Nos. 2* and *3;* and Franz Liszt, *Faust Symphony*—each example using a chorus as

well); as an incidental commentary to introduce completely instrumental movements (Hector Berlioz, *Roméo et Juliette*); as the primary participant in a song movement with a symphonic or chamber work (Mahler, *Symphonies Nos. 2–4*; Schoenberg, *Quartet No. 2* and *Serenade*, Opus 24); and as an inconspicuous member of an otherwise instrumental ensemble, as in the finale of Pierre Boulez's *Marteau sans maître* (*The Hammer Without a Master*), where the voice generally has a humming part. Two other of Mahler's symphonic compositions have more extensive vocal participation: *Das Lied von der Erde* (*The Song of the Earth*), labelled "A Symphony for Tenor, Contralto (or Baritone), and Orchestra," where one or the other soloist is heard in each movement, and *Symphony No. 8*, employing voices (solo or choral) throughout; the finale of the latter work has the spirit of an oratorio.

Vocal compositions with no articulated text are called vocalises (*vocalizzi* in Italian). Although such works have been traditionally used as exercises, many 20th-century composers have written concert vocalises as well, among them Ravel, Sergey Rachmaninoff, and Igor Stravinsky. Vocalises are particularly suitable for chamber compositions, since the voice without text is easily adapted to the level of the other instruments.

THE REPERTORY SINCE 1600

Continuo Lieder and concert arias

Art songs in German, French, and English. The most important German songs (Lieder) of the 17th century were continuo Lieder used for informal entertainment, notable composers being Heinrich Albert and Adam Krieger. With the rising prestige of opera in the later 17th century, these simple Lieder declined in favour of extended virtuoso songs and concert arias, such as Handel's nine *Deutsche Arien* (*German Arias*) of *c.* 1729. The concert aria eventually reached a peak in the late 18th-century works of Mozart and Haydn. At the same time, three counterdevelopments pointed toward the future for the German Lied: a reaction against the superficialities of the operatic aria, the availability of a new repertory of lyric poetry, and an increasing use of the keyboard (eventually the piano) as an expressive accompaniment. First to reflect these directions were north German composers (Carl Philipp Emmanuel Bach, Johann Friedrich Reichardt, Karl Friedrich Zelter, and Johann Rudolf Zumsteeg), particularly in their settings of devotional poetry by Christian Gellert, Julius Sturm, and Friedrich Klopstock. The keyboard part was often fully written out, yet generally subordinate to the voice. Beethoven eventually expanded the role of the accompaniment in his finest songs, including settings of Goethe and Gellert, and the cycle *An die ferne Geliebte*.

At the head of distinguished 19th-century Lied composers stands Schubert, whose masterpieces combine a natural feeling for musical design with an extraordinary sensitivity to the essentials of the text. More than 600 in number, his Lieder encompass a wide range of poets, forms, and moods. Schumann's approximately 250 songs draw from outstanding German lyricists: Heinrich Heine, Goethe, Friedrich Rückert, Joseph Eichendorff, Justinus Kerner, and Adelbert von Chamisso. His accompaniments are closely linked with the voice through doubling, imitation, or completion of musical ideas. Brahms, more like Schubert than Schumann, assigned prime importance to the voice but at times sacrificed text declamation for balance in musical phrasing. Among his approximately 300 solo works are numerous harmonizations of folk tunes (many altered according to his musical taste), a cycle of 15 romances from Ludwig Tieck's *Magelone*, and the extensive *Vier ernste Gesänge* (*Four Serious Songs*) of his last years. Wolf, in sharp contrast to Brahms, gave scrupulous attention to literary details, frequently requiring changes of pace and vocal styles within a single song. The best songs of Richard Strauss, like Wolf's, combine an expressive vocal line with a rich accompaniment, often in alternative versions for piano or orchestra.

The 20th century

Early 20th-century Lieder either develop further the possibilities of the orchestral song (Mahler, Schoenberg, Berg, Webern), explore revolutionary techniques in works using chamber ensemble or piano (Schoenberg, Webern), or merely continue late 19th-century traditions (Max Reger, Joseph Marx). Mahler's songs—*e.g.*, *Lieder eines fahrenden Gesellen* (*Songs of a Wayfarer*), settings from *Des Knaben Wunderhorn* (*The Youth's Magic Horn*), *Kindertotenlieder* (*Songs on the Death of Children*), *Das Lied von der Erde*—deal with the sorrows and aspirations of man, the consoling powers of nature, and childlike visions of heaven; the vocal lines range from folklike simplicity to soaring lyricism. Of central importance in their composers' careers are Schoenberg's *Buch der hängenden Gärten* (*Book of the Hanging Gardens*) and his 12-tone *Drei Lieder*, Opus 48; Webern's aphoristic yet highly contrapuntal chamber songs (Opuses 13–19) and later settings of Hildegard Jone; and Berg's more lyrical *Altenberg Lieder* and concert aria *Der Wein* (*Wine*). Continuing later into the century, Paul Hindemith's skillful songs in German, French, and English incorporate various accompaniments and styles.

Airs de cour

French publishers issued numerous books of *airs de cour*, or "courtly airs," during the early 17th century. Some airs treat serious secular topics. Others, called *voix de ville*, have jovial texts, which are often set to dance rhythms. *Récits* concentrate on textual declamation, since they usually originated as commentaries within the *ballets de cour*, or "courtly ballets"; but they have little of the passion found in Italian recitatives of the same time. Still other airs are settings from the Huguenot psalter. France was nevertheless slow in developing compositions designed only for the solo singer. Aside from the *récits* and psalm settings, the airs were either arrangements of polyphonic chansons or were easily singable as part-songs. In the late 17th and 18th centuries, most vocal writing was for the large forms of opera, cantata, and motet. But a demand for songs returned with the "back to nature" movement in the mid-18th century and with the French Revolution, giving rise to *romances*, or simple, rustic tunes with folkish texts, and to patriotic songs, including "La Marseillaise."

Many 19th-century composers continued writing *romances*, some of more extended scope. But the most important type of song was the new *mélodie*, which concentrated on subtle nuances of the text and provided a substantial accompaniment, as in Hector Berlioz' cycle *Les Nuits d'été* (*Summer Nights*; to poems by Théophile Gautier), with accompaniment for orchestra or piano. The *mélodie* flourished with the rich developments in French poetry during the later 19th century. Gabriel Fauré, in his cycle *La Bonne Chanson* (*The Good Song*), set nine love poems of Paul Verlaine; the lyrical voice soars above continuous figurations in the piano. Henri Duparc's *mélodies*, only 14 in number, have long been considered masterful settings of Charles Baudelaire, Charles Leconte de Lisle, Armand Silvestre, and others. Debussy's 57 published songs use poems of his contemporaries (especially Verlaine) but also three by the 15th-century François Villon. His vocal lines freely mix a declamatory style with more lyricism at points of climax. The piano emphasizes contours of the poem and imparts unity through recurring motives. Among the most colourful song composers of the early 20th century is Ravel. His *Shéhérazade* has orchestral accompaniment, while *Trois Poèmes de Stéphane Mallarmé* and the *Chansons Madécasses* use chamber ensembles. Originally for voice and piano (although some are also orchestrated) are his folk-tune harmonizations; *Don Quichotte à Dulcinée*, dance-inspired songs intended as movie music; and the *Histories naturelles*.

Darius Milhaud treated both humorous and serious poems from all periods, while Francis Poulenc's most characteristic texts are by the Surrealists. Among the more recent French composers, Olivier Messiaen, André Jolivet, and Boulez employed advanced vocal techniques with various instrumental combinations.

Lute ayres

England's first art songs are the lute ayres published in large numbers from 1597 to 1622; the principal composers are John Dowland, John Daniel, and Thomas Campion. Of high literary quality, the strophic texts are generally anonymous, except those by the composers themselves. Many ayres resemble dance music, using standard rhythms and symmetrical phrasing. The finest songs place the voice and lute in full partnership. The ayres of the early 17th century gradually gave way to declamatory songs, usually

through-composed, many of which were originally written for masques or the theatre. In the simplified accompaniment, the complete lute part was eventually replaced by a single basso-continuo line. Late 17th-century continuo songs reached a high point in the works of Purcell. His earliest songs emphasize textual prosody, but his more representative works become brilliant concert pieces.

In the 18th and 19th centuries, many songs continued to reflect the influence of opera and operetta. But more characteristic of the two centuries are less pretentious strophic works, many originating in popular concerts in the London Gardens. In the late 18th century, the turn toward simplicity resulted in collections of Scottish, Irish, and Welsh folk music; the Scottish publisher George Thomson commissioned folk-song arrangements from Haydn, Beethoven, and others.

Since the late 19th century, England has revived interest in the art song. Texts are often from the best contemporary poets, as well as from earlier classics. Musical styles have drawn on folk-music tradition as well as on advanced 20th-century musical idioms. Although the piano remains the principal accompanying instrument, orchestral or chamber-ensemble accompaniments are also prominent. Among the more significant song composers have been Sir Hubert Parry and Sir Charles Villiers Stanford; Frederick Delius, largely influenced by continental and Scandinavian music; Gustav Holst and Ralph Vaughan Williams, both with a strong interest in folk music; Peter Warlock (real name, Philip Heseltine); John Ireland; Benjamin Britten; and Sir Michael Tippett.

In the United States, songs composed before the mid-19th century were primarily by amateur musicians, and intended for singing instruction, devotion, or entertainment. Minstrel shows of the early 19th century provided the source for the stage songs of Daniel Decatur Emmett, Stephen Foster, and others. Songs of late 19th-century composers such as George Chadwick, George Foote, Horatio Parker, and Edward MacDowell were influenced by conservative trends in European Romanticism. Early 20th-century songs show the effects of French Impressionism (John Alden Carpenter, Charles Loeffler, Charles Griffes) or follow more individual directions. Sidney Homer's songs focus on a smooth vocal melody, while those of Charles Ives often vigorously represent textual details. After a lull during the 1930s and early 1940s, composers returned to the art song, often setting contemporary American literature. Some of the better known are Theodore Ward Chanler, Virgil Thomson, Samuel Barber, David Diamond, Aaron Copland, Ben Weber, Miriam Gideon, and Milton Babbitt.

Art songs in other countries. The Russian art song dates primarily from the 19th and 20th centuries, although the period of Catherine the Great (reigned 1762–96) supplies a substantial background in its imitations of French *romances* (either in French or Russian), editions of Russian folk tunes (or pseudo-folk tunes), ballads, and pseudo-Oriental songs. The chief pioneers of the 19th-century song were Mikhail Glinka and Aleksandr Dargomyzhsky, the latter brilliant for his depiction of realistic peasant scenes. The "Russian Five" (César Cui, Mily Balakirev, Aleksandr Borodin, Modest Mussorgsky, and Nikolay Rimsky-Korsakov) contributed the most significant repertory in the second half of the 19th century. Their songs present a remarkable variety of moods and styles, perhaps best illustrated in the works of Borodin and Mussorgsky. In contrast to "The Five," the conservatory musicians (chiefly Anton Rubinstein and Peter Ilich Tchaikovsky) were governed more by Western influences than by native styles. Among other pre-Revolutionary song composers, Aleksandr Grechaninov, Sergey Rachmaninoff, and Nikolay Medtner provided polished masterpieces, but no significant technical advances; more forward-looking are the early songs of Stravinsky and Sergey Prokofiev. Soviet composers have avoided the radical musical developments elsewhere. As a rule, songs since the Revolution are objective settings of Soviet poetry or traditional Russian literature (especially works by the poet Pushkin).

The art songs of Italy begin with the numerous books of monodies (continuo songs) from the first third of the 17th century by such composers as Giulio Caccini, Jacopo Peri, and Sigismondo d'India (a more significant composer). Although originally labelled with various titles, the songs fall into two general types: madrigals and strophic arias. Some madrigals are strict recitatives, although the vocal style is more frequently a smooth-flowing arioso (*i.e.*, freely expressive and lyrical). Arias tend toward symmetrical phrasing and standard rhythmical patterns, sometimes dancelike, but at times approach madrigalesque style. Many arias repeat the same music for each stanza, but others have a through-composed vocal line over the same bass (strophic-bass arias). As a rule, the accompaniments are entirely subordinated to the voice, which in the more expressive songs introduces ornaments for emphasizing important words or punctuating poetic lines. The early monodies eventually expanded into longer, more musically oriented compositions called cantatas.

Early Baroque monody

Opera was so dominant in the 18th and 19th centuries that song composition became a lost art. A return to song writing in the early 20th century, for composers such as Ottorino Respighi, Alfredo Casella, and Gian Francsco Malipiero, was inspired by the ideals and accomplishments of Italy's past, especially the Middle Ages and Renaissance. Other outstanding recent song composers are Mario Castelnuovo-Tedesco (settings of all Shakespeare's songs), Luigi Dallapiccola (using 12-tone techniques), Ildebrando Pizzetti, and Goffredo Petrassi.

Spanish songs from the 17th through 19th centuries are primarily related to theatrical productions: either the older and more enduring *zarzuelas* or the lighter *tonadillas* (*c.* 1750–1810). The vocal style is simple, often with rhythmic and ornamental clichés; the accompaniment frequently consists only of the composer's sketches to be filled out in performance. In the repertory of serious modern art songs the way was led by Felipe Pedrell, who composed folk-inspired melodies and published works of older Spanish masters. Among his better known successors are Enrique Granados, Manuel de Falla, Joaquín Turina, and Federico Mompou.

Spanish and Latin American songs

Latin America has produced a rich and varied repertory of art songs, but mostly during the present century. A great number of these compositions depict regional colour through their texts, melodies, and rhythms. Other works eschew native influences in favour of an international style. Among 20th-century Latin-American composers, the Brazilian Heitor Villa-Lobos and the Argentine Alberto Ginastera achieved worldwide fame.

The most outstanding Norwegian song composer was Edvard Grieg, whose song style blends folklike simplicity with imaginative musical ideas. As is usual with Scandinavian composers, the texts are drawn from several languages (German, Danish, Norwegian), but his finest works are in his native Norwegian. The Finn Jean Sibelius concentrated primarily on Swedish literature, interpreting a wide range of moods in a highly distinctive musical language.

Hungary's principal contributions come from Béla Bartók and Zoltán Kodály, whose songs reflect their lifelong interest in collecting native peasant tunes. For both composers folk-song arrangement became a refined art. Many songs faithfully set a traditional tune to a simple accompaniment, while more elaborate works blend native elements with advanced contemporary idioms.

In Czechoslovakia, strong ties with German culture long prevented the development of native art songs. Nineteenth-century nationalism inspired some composers to turn to Czech texts, although part of their output continued in German: Jaroslav Tomášek, Bedřich Smetana, Anton Dvořák, and the younger Leos Janáček. Poland shows a similar pattern: during the 19th century many composers turned to their native literature (especially the poetry of Adam Mickiewicz), the most important being Joseph Elsner, Frédéric Chopin, Stanislaw Moniuszko, and Karol Szymanowski. Belgium, the Netherlands, and Switzerland have also produced sizable repertories of art songs, particularly in the 19th and 20th centuries.

WESTERN AND NON-WESTERN CONCEPTIONS

In the relationship between poet, composer, and performer—and especially in the importance assigned to the

composer—Western vocal music has arrived at a stage during the past few centuries that is basically unlike that of any other world culture. By the 19th century composers were recording in musical notation virtually all the essentials in their interpretations of the text: pitch, rhythm, and tempo, as well as indications for dynamics and articulation. Although the performers must bring the composer's notation to life, particularly through subtle nuances and appropriate vocal sounds, this process is primarily one of reinterpreting a previously established work of art. Comparative research in the present century has revealed certain general parallels in the vocal art of other civilizations, but no culture other than Western has placed such a premium on individual compositions from the past, and consequently nowhere else is there preserved such an extensive history of vocal literature. Aside from certain types of ritualistic music, where the slightest change in tradition is viewed as a desecration, the non-Westerner has relied primarily upon the creative role of the performer. Although the singer at times begins with a preexistent "work" notated with some pitches, rhythms, or even other indications for performance, this notation merely functions as a suggested framework. The performer contributes new details for the voice and the accompaniment, so that the composition is actually re-created rather than reinterpreted. Because of this process of creative performance, most non-Western vocal art before the advent of 20th-century recordings has been irretrievably lost.

Performer's role

During the present century, Western concepts of art song have strongly influenced the vocal music in non-Western cultures, unfortunately threatening the continued existence of many indigenous practices. The influence has at times gone in the other direction: recent examples of Western avant-gardism give the singer many improvisatory options within broader limits prescribed by the composer. It can be expected that future vocal music will continue to show intercultural exchanges of ideas and techniques without requiring the complete sacrifice of any heritage.

(W.V.P.)

CHORAL MUSIC

Music sung by a choir, known as choral music, ranks as one of several musical genres subject to misunderstanding because of false historical perspectives or misinterpretation caused by the confusion engendered by unsolved semantic problems. Choral, chorale, choir, and chorus stand in obvious relationship to one another and are in some respects used interchangeably when a body of singers, for example, is referred to as a choir, a chorus (Latin noun derived from the Greek word *choros*), or a chorale, which properly is a Lutheran hymn tune. The adjective choral may therefore be applied in a general way (choral music, choral technique) or in a specific way (such as Beethoven's *Choral Symphony* and *Choral Fantasia*). The nouns chorale, choir, and chorus are frequently used as adjectives in such expressions as chorale prelude ("choral prelude" is incorrect), choir organ, or chorus part.

The definition of choral music has by circumstance and usage been forced to comprise a far wider area than a comparable definition of an instrumental genre. It is unusual, to say the least, to perform a symphony with only a single instrument to each part, even though the opposite has occasionally happened when a string quartet movement is played by the massed strings of an orchestra. Much music now performed by choirs, however, was originally intended for soloists; and, while the lack of historical authenticity may here be deplored, it is evident that a choral performance of a madrigal (equivalent to an orchestral performance of a string quartet movement) permits many amateur musicians to enjoy, as members of a team, music that might otherwise escape their knowledge.

If a choral performance of genres for several solo voices, such as the madrigal, ballett, villanella, and part-song, results in a more neutral sound and a less personal intensity of expression, it is nevertheless true that the reverse sometimes offers unsuspected advantages, as when a work written for choir alone is performed by a group of soloists. In certain cases the work may take on a new and enhanced aspect because each strand of melody within the texture carries a personal rather than a group expression.

In defining choral music, some attention should also be paid to the enormous variation in the size of choirs. A chamber choir need contain only a dozen voices, certainly not more than 20; whereas a choir assembled for the Handel Festivals in the 19th century or for the Berlioz *concerts monstres* in Paris during the same epoch, might have numbered thousands. Modern traces of such massive choral effects may be found in the *Symphony No. 8 in E Flat Major* (sometimes called *Symphony of a Thousand*) of the Austrian composer Gustav Mahler. This work calls for a large double choir and a separate boys' choir, in addition to a large orchestra and eight soloists. On the other hand, numerous modern choral works, because of their difficulty and complexity, seem to have been composed with a chamber choir in mind, as in the case of *Cinq rechants* (1949) by the French composer Olivier Messiaen.

Variation in size of choirs

If there is more than one voice to each part—*i.e.*, to each line of polyphony (music of several voice parts) or strand of melody—the performance is choral, even though the actual sonority may not seem choral in the accepted sense until there are more than five or six voices to a part. Both types of singing may also coexist, since a choir may contain several capable soloists who may at certain points sing as a group without the choir or with the choir as a background. This feature is the choral equivalent of the orchestral concerto grosso, in which a small group of solo instruments alternate or combine with the main body of players. Examples of this may be found in choral music of all types and ages. The medieval rondeau was usually performed by a soloist who sang the verses, with a small choir for the refrain. When the mass became a vehicle for choral performance in the 15th century, the Christe Eleison, certain parts of the Gloria and the Credo, the Benedictus, and the Agnus Dei were frequently assigned to a group of soloists within the choir. *The Eton Choirbook* motets demand similar treatment since red and black text is used to differentiate between those sections intended for soloists and those for full choir. Comparable effects may be found in music written for special occasions, oratorios, verse anthems, and settings of the Passion.

Although choirs existed throughout Europe in the Middle Ages, their role was restricted to unison singing of plainchant. Polyphony was the exclusive preserve of soloists. This state of affairs was gradually modified for several reasons. Early forms of musical notation were not precise enough to allow choral performance of even the simplest two-part polyphony. As time went on, improved accuracy in notating pitch and time values permitted some degree of experiment in choral performance.

Emergence of the choral tradition

Knowledge of the subtleties of mensural (precisely measured) music was at first the prerogative of a small number of initiates. The ordinary member of the plainchant choir, or schola, was not expected to understand the notation or to perform music using it. But the teaching of musical theory spread rapidly in the 14th century, and singers became better equipped and educated than they had been at any previous time. The ever-growing wealth of the church also acted to encourage choral performance, since abbeys, cathedrals, parish and collegiate churches, and court chapels vied with each other in the opulence and perfection of their choral establishments. Laws were passed enabling royal chapels to impress (that is, to seek out and enroll) eligible provincial choirboys for the great central establishments, and in consequence every boy was a soloist in his own right, just as were the countertenors, tenors, and basses. Finally, the rapidity with which composers took advantage of this situation, evolving new techniques and adapting old ones, created a tremendous surge of choral activity and composition, which the new art of music printing was to aid even further in the early years of the 16th century. From that time until the present, there has been no abatement of interest in choral music, which is performed at amateur and professional levels throughout the entire world.

Sacred music. *The mass.* The ordinary of the mass (consisting of the Kyrie, Gloria, Credo, Sanctus and Benedictus, Agnus Dei, and in some medieval masses also the

"Ite, missa est") has been a focal point of choral music for more than 600 years. The earliest masses, such as the four-part setting by the 14th-century French composer Guillaume de Machaut, were intended for soloists; remarkable both in musical texture and structure, they are often performed chorally today. In the 15th century this tradition, in which architectonic considerations still held sway, was carried on in the masses of the English composer John Dunstable and his Burgundian contemporary, Guillaume Dufay. The use of a plainchant cantus firmus, or dominating tenor theme, knit together the movements even though they were separated during the liturgy. Modern concert performances and recordings obscure this feature, sometimes to the disadvantage of even the greatest masterpieces, which, with all movements in immediate sequence may sound too concentrated. The Renaissance saw the highest development of the cantus firmus mass, using as the central melodic support not only plainchant but even secular songs, as Josquin's *L'Homme armé* (printed in 1502) or folk songs, as John Taverner's mass, *The Western Wynde* (*c.* 1520).

Hundreds of composers wrote settings of the ordinary of the mass at this time; some, like the Italian composer Giovanni da Palestrina, wrote more than 100 masses. The Spaniards Cristóbal de Morales and Tomás Luis de Victoria and the Englishmen William Byrd and Thomas Tallis all avoided secular melodies, even though these would have been largely obscured by the texture of the voices. On the other hand, the Netherlanders Orlando di Lasso and Philippe de Monte did not hesitate to draw upon themes of diverse origins. Byrd and his Flemish contemporary Heinrich Isaac also set a considerable amount of the proper of the mass (that part of the liturgy liable to change according to the feast), but such settings remained comparatively rare.

The parody mass found many advocates, since it was possible by this means to base a long work on all voice parts of a shorter one, such as a motet or a hymn, and by beginning with familiar and recognizable material, to progress gradually into inventive independence. This particular technique may have owed as much to convenience as to a desire to pay homage to another composer.

Addition of instruments

The 16th- and 17th-century Venetian school, especially Giovanni Gabrieli and Claudio Monteverdi, added an instrumental element to the basically choral foundation of the mass. They also occasionally employed two or more choirs to create massive antiphonal effects. Further development of the orchestral mass occurred in the 17th century in the works of the Italian composers Francesco Cavalli and Alessandro Scarlatti and the French composer Marc-Antoine Charpentier, while the polychoral element was brought to a colossal and almost unmanageable pitch by Orazio Benevoli in his mass for the dedication of the Salzburg cathedral (1628) in 53 parts.

In the 18th century, Haydn's early masses, notably the *Missa Sanctae Caeciliae,* lean toward Italian models. His choral writing is robust and sonorous, even though four-part writing is the norm. His later masses emphasize soloists and orchestra but without diminishing the interest of the choral writing. Mozart's early masses tend to be brief (because of the taste and dictates of his archbishop patron), yet the fugal choruses sometimes dispel this impression by their very excellence, as in the *Mass in C Major,* K. 317 (1779; *Coronation Mass*). The unfinished *Mass in C Minor,* K. 427, abounds in magnificent choral music.

Remote in style and function from the Classical Viennese works, J.S. Bach's *Mass in B Minor* (1733–38) was a monument of the preceding Baroque era. It was never intended to be performed as a whole within the liturgy, and its various movements date from different periods of Bach's life. Five-part choral writing is most in evidence, the two soprano lines adding brilliance and edge to a richly contrapuntal (interwoven melody) texture. In the "Sanctus," Bach branches into six-part polyphony, and in the "Osanna" he calls for an eight-voice double choir apt for antiphonal writing.

Beethoven's *Mass in C Major,* Opus 86 (1807), and *Missa Solemnis,* Opus 123 (1823), written in the maturity of the Classical era, are not liturgical, yet they stem from an inner need to carry on a great tradition and to set to music a text of central importance. The role of the choir is central to the work. The composer uses it to produce effects ranging from breathtaking mystery to the utterly grandiose. The masses of the 19th-century Austrian composers Franz Schubert and Anton Bruckner worthily continue the same tradition in their individual ways. The *Petite Messe solennelle* (*Little Solemn Mass;* 1864) of Italian composer Gioacchino Rossini was originally written for soloists, chorus, and an accompaniment of two pianos and harmonium, but it was later scored for full orchestra.

Outstanding among 20th-century masses are those of the English composer Ralph Vaughan Williams, the Czech composer Leoš Janáček (*Glagolitic Mass,* setting an Orthodox text in Old Slavonic), and the Russo-American composer Igor Stravinsky, who is said to have derived his inspiration from Mozart, although some of the effects created by the mixed chorus and wind instruments are more reminiscent of medieval music.

The Missa pro Defunctis ("Mass for the Dead"), or Requiem Mass (often simply called Requiem) also stimulated numerous choral masterpieces, beginning with Jean d'Ockeghem in the late 15th century and continuing through Victoria, Felice Anerio, Scarlatti, Mozart, Luigi Cherubini, Hector Berlioz, Giuseppe Verdi, and Gabriel Fauré to the present century. Johannes Brahms' *Ein deutsches Requiem* (*German Requiem,* 1857–68) is based on the composer's own selection of Biblical texts. The *Requiem* (1914–16) of the early 20th-century British composer Frederick Delius derives its libretto from the 19th-century German philosopher and poet Friedrich Nietzsche. The *War Requiem,* Opus 66 (first performed, 1962), of the British composer Benjamin Britten makes skillful and impressive use of liturgical texts but also contains secular poetry by Wilfred Owen, killed in World War I. The work as a whole is thus linked with the senseless suffering of war and the idea of sacrifice induced by false patriotism. The choral effects are rich in novelty, originality, and forcefulness. One of the most successful of 20th-century masses for unaccompanied chorus is the *Mass in G Major* (1937) by Francis Poulenc.

Vespers and Anglican services

In the Middle Ages, the service of greatest musical importance, after the mass, was Vespers. Its component antiphons, psalms, hymn, and Magnificat have given rise to much noble choral music, from the time of the Flemish composer Adriaan Willaert in the 16th century, through Monteverdi, Scarlatti, and Mozart. In the Anglican Church, service settings embrace Holy Communion and Morning and Evening Prayer and have been continuously written since the time of Byrd and Tallis. These early services for choir and organ were followed by "verse services," in which solo voices played an important part, combining or alternating with the choir. By the time of the 17th-century British composer Henry Purcell, instruments were accepted as a means to fuller accompaniment, notably in the Chapel Royal, London. But modern composers, except in works for ceremonial use, tend to return to scoring their services for choir and organ.

Motets. Choral music has been enriched for centuries by the composition of motets, which were originally settings of liturgical or biblical texts. Responsories (liturgical texts originally performed responsively) were of major importance until the great monastic institutions lost their influence in the early years of the 16th century. Subsequently, the choral motet was mainly cultivated in royal and collegiate chapels. Settings of votive antiphons (verses preceding psalms and canticles), frequently, though not exclusively, texts in honour of the Virgin Mary, were popular in the late 15th and early 16th centuries. Many of these compositions demanded a high degree of skill and virtuosity from the choir and its soloists; a noble example is the British composer John Browne's *Stabat Mater,* from *The Eton Choirbook.* An Italian contemporary, Giovanni Spataro, displays a more simple and restrained style in his four-part *Virgo prudentissima,* which nevertheless belongs to the same category of motet.

During the 16th and 17th centuries, the term motet was used in looser connotation, sometimes linked with a few

verses of a psalm, sometimes a complete psalm including Gloria Patri (lesser doxology). Many of these longer settings, by 16th-century composers such as Josquin, Willaert, and Lasso, attain the level of symphonic choral writing through their high degree of formal organization and their imaginative vocal scoring. The concertato motet (using contrasting groups of singers and instruments), as developed and perfected in the 17th century by Gabrieli, Monteverdi, Heinrich Schütz, and Scarlatti, added the vivid colours of the orchestral palette to the already highly malleable vocal textures. Pergolesi's *Stabat Mater,* although sometimes performed as a choral work, was originally written with solo voices in mind. Bach's motets, of which *Jesu meine Freude (Jesus My Joy, c.* 1723) is a typical and splendid example, return to the a cappella manner of performance. Contrary to one popular conception, this often included instrumental doubling of the voice parts and the use of an organ continuo, an improvised part. Subsequently little used in the Protestant Church, the motet continued to be cultivated by the Catholic composers of Europe and the Americas. Especially worthy of note are the motets and psalm settings of Anton Bruckner, whose *Te Deum* (composed 1881, revised 1883–84) is one of his choral masterpieces. Conservative tastes in much religious music somewhat discouraged the greatest talents from contributing fully to this genre. Stravinsky's *Threni* (on the Lamentations of Jeremiah), for instance, is more frequently heard in the concert hall than in church, as are also Poulenc's *Stabat Mater* (1951) and other liturgical motets of his.

Anthems. The use of the vernacular after the Reformation in England made it necessary for composers to forge a new style of choral music. The elaborate melodic tracery of Robert Fayrfax and John Taverner gave way to a completely unelaborate kind of choral counterpoint designed to allow the English words to be clearly heard. Both Thomas Tallis and William Byrd made outstanding contributions to the development of the anthem. Tallis perfected a style of contrapuntally animated homophony that ensured clarity of declamation, while Byrd experimented with more elaborate textures both in full anthems (for choir alone) and in verse anthems, in which the choir was supported by the organ and sometimes other instruments, allowing solo voices to detach themselves from the main body of singers. Among Byrd's finest verse anthems are *Christ rising again* (for Easter) and *O God that guides the cheerful sun.* Orlando Gibbons carried to a further stage the use of a consort of viols, which accompanies with a rich but discreet body of sound the countertenor and bass soloists in *Glorious and powerful god.* One of the most effective of his full anthems is the seven-part *Hosanna to the Son of David* for Palm Sunday. Thomas Tomkins displays a mastery of 12-part polyphony in his full anthem *O praise the Lord, all ye heathen,* but for quiet expressive intimacy of thought there is little to surpass *When David heard that Absalom was slain.* Among a considerable number of verse anthems by Tomkins, two of the most inspiring are *My Shepherd is the living Lord* and *Thou art my King, O God,* both of which can be accompanied by organ alone or by organ and string ensemble.

When the monarchy was restored in 1660, Matthew Locke contributed a number of fine anthems to the repertory of the revived Chapel Royal, among them the double-choir setting of *Not unto us, O Lord* and the grandiose, almost Venetian *The king shall rejoice,* scored for three four-part choirs and orchestra. Another eminent musician of the time was Pelham Humfrey, whose verse anthem *By the waters of Babylon* is one of the best examples of its kind. For chromatically expressive music Michael Wise provides an admirable pattern in his *The ways of Sion do mourn,* as does Daniel Roseingrave in his *Lord, thou art become gracious.*

The verse anthem with instruments reached its zenith in the late 17th century in the music of Henry Purcell and John Blow. Much of their music was performed in the Chapel Royal, the choir and consorts of which had improved markedly. Among the most memorable of Purcell's full anthems are the eight-part *Hear my prayer, O Lord* and the five-part *Remember not, Lord, our offences.* His most successful verse anthems frequently make use of short, impressive passages for choir alone, as in the evocation of the turtle's voice in *My beloved spake* and the moving harmonies of "O worship the Lord" toward the end of *O sing unto the Lord.* Blow excels in the antiphony of verse soloists and full choir in *I beheld, and lo, a great multitude.* In his full anthems, such as *God is our hope and strength* and *O Lord God of my salvation,* he sometimes almost equals Purcell in the richness and resource of his eight-part writing.

Of the succeeding generation of composers, William Croft seems most at ease in his full anthems, notably *Put me not to rebuke* and *O Lord, rebuke me not,* two distinct and different works in spite of the similarity of text. Maurice Greene excelled in this style in works such as *God is our hope and strength* and *Acquaint thyself with God.* William Boyce carried on the tradition of sensitive word setting in such works as *I have surely built thee an house* and *O where shall wisdom be found?*

Although the late 18th and early 19th centuries did not exactly overflow with masterpieces, a trio of composers proved themselves competent craftsmen. *O Lord, look down from heaven* will assure Jonathan Battishill a place in the history of the genre, while the Epiphany anthem *O God, who by the leading of a star* speaks eloquently for Thomas Attwood. Although Samuel Wesley, converted to Catholicism, chose Latin for the greater number of his church compositions, one of these is sometimes sung to its English text, *Sing aloud with gladness.*

Samuel Sebastian Wesley attempted, often with considerable success, to raise up the anthem to a new level of artistry and accomplishment, extending it so as to form a kind of cantata giving freer rein to soloists than was customary in the older type of verse anthem. His finest contributions are perhaps *The Wilderness; Ascribe unto The Lord;* and *O Lord, Thou art my God.* Also noteworthy from this epoch are Sir John Goss's setting of *The Wilderness,* Thomas Attwood Walmisley's *O give thanks,* and the double-choir anthem *O Saviour of the world* by Sir Frederick Gore Ouseley.

Sir Joseph Barnby, Sir John Stainer, and Sir Arthur Sullivan wrote anthems of fair quality, but not until Sir Hubert Parry demonstrated the need for a return to conscientious word setting did new spirit begin to pervade English church music in works such as Parry's double-choir anthem *Lord let me know mine end.* Sir Charles Stanford's similarly scored *Jesus Christ is risen today,* and Charles Wood's *O thou the central orb.* In the 20th century, T.T. Noble's *The souls of the righteous* and John Ireland's *Greater love hath no man* are typical of the earlier period, while *O pray for the peace of Jerusalem* by Herbert Howells and Benjamin Britten's *Hymn to St. Peter* successfully continue a long tradition.

Cantata and oratorio. The cantata, as developed in northern Germany in the 17th century, often relied only upon soloists and a small group of instruments, although the role of the chorus gradually became more important. In more than 200 church cantatas written by J.S. Bach, the chorus often occupies a prominent place and is given music of challenging complexity—frequently on a par with the music of the accompanying instrumental forces. The cantatas use the chorus again in the closing chorale, which is usually a special setting of a hymn tune with orchestral doubling or accompaniment.

Bach's 200 church cantatas

In Italy, the oratorio achieved what was beyond the motet's capabilities by projecting through verse and music a story of Biblical origin that the public could enjoy while learning. Giacomo Carissimi, whose *Jephtha* is still an established classic, led the way to the oratorios of Antonio Vivaldi (*Juditha triumphans,* first performed 1716), Handel (a long series of oratorios written for London, all dramatic in form except for *Israel in Egypt* of 1739 and the *Messiah* of 1741), and Haydn, whose greatest oratorio is *Die Schöpfung* (1798; *The Creation*). The choral contribution to 19th-century oratorios remained at a remarkably high level, enhancing such works as Beethoven's *Christus Am Ölberg* (1803; *Christ on the Mount of Olives*), the perennially popular *Elijah* (1846) of Mendelssohn, Franz Liszt's *Die Legende von der heiligen Elisabeth* (*The Leg-*

end of St. Elizabeth), Berlioz's *L'Enfance du Christ,* Opus 25 (1854), and a series of compositions by the British composer Edward Elgar, culminating in *The Dream of Gerontius* (1900). The oratorio tradition, because of its links with choral bodies, has shown constant renewal and growth in the 20th century. Among outstanding 20th-century oratorios are Frank Martin's *Golgotha* (1949), Arthur Honegger's *Le Roi David* (*King David;* 1921), Sir William Walton's *Belshazzar's Feast* (1931), and Bernard Rogers' *The Passion* (1944). A work in oratorio style, though in a class of its own, is Ernest Bloch's *Avodath Hakodesh* (*Sacred Service*) composed 1930–33 and scored for baritone solo, chorus, and orchestra.

Occasional music. In addition to sacred and secular works, a very considerable number of compositions, many of them choral, were written for great occasions of state. These include motets and cantatas based on special texts, suitable for performance in a palace, outdoors on a platform or rampart, in a private chapel, or wherever the occasion demanded. The signing of a peace treaty, a royal marriage, ducal obsequies, consecration, election of a doge—all these and many similar events called for music written to order; since composers have always been happy to receive a commission, the number of occasional works is virtually incalculable.

Soon after St. Mark's, Venice, inaugurated in 1403 a choir of boys from the city, their master Antonio Romano was invited to compose a festive work in honour of the doge. When Francesco Foscari was elected doge in 1423, Christoforo de Monte introduced the choral parts of his motet with brass fanfares. Dufay, asked to produce a stirring work for the consecration of a new cathedral at Patras (now Pátrai) in Greece, scored his *Apostolo glorioso-Cum tua doctrina-Andreas* (1426) for wind ensemble and mixed chorus; but, although the work was undoubtedly performed in the cathedral, the use of an Italian rather than a Latin text places it firmly in the category of occasional music. An equally impressive work by the same composer, *Supremum est mortalibus bonum pax* (*The Supreme Gift for Mortals Is Peace*), was written expressly for the signing of the Treaty of Viterbo in 1433, when Pope Eugenius IV and King Sigismund of Bohemia were both present at the ceremony. Toward the end of the motet, the choir sings, in successive block chords, the names of Pope and King, syllable by syllable. Another peace treaty celebrated in music is that of Bagnolo, Italy, when the Franco-Flemish composer Loyset Compère was commissioned to write the motet *Quis numerare queat* (1484). Imaginative use is made of the chorus throughout this work, even to the extent of the composer's choice of tessitura (high or low part of the voice range): when the chorus sings of the lamentations of the people over the terrors of war, the words are sung by the dark-hued combination of tenors, baritones, and basses in their middle or lower register. A further example of choral writing so disposed as to represent a state of mind is the "Amen" of Isaac's *Optime pastor* (written in 1513 in honour of the newly elected Pope Leo X), where the opulent six-part polyphony suggests the wealth and substance of the Emperor Maximilian I and his desire to impress listeners with a show of temporal power at least the equivalent of the Pope's spiritual power.

Occasional music is sometimes considered of less value than sacred or secular music, even when it stems from a composer of high reputation. Since the work could by definition receive only one formal performance and since it might have been written in a hurry, the theory is that the music must be inferior. There are, however, examples of such works whose music was used for more than one occasion, thanks to the simple but effective process of stripping away the original text and substituting another, or even substituting one name for another. A study of the text of Taverner's motet *Christe Jesu pastor bone* (*Jesus Christ, Good Shepherd*) shows that it must have been intended first as a votive antiphon for St. William of York, then as a paraliturgical prayer for Cardinal Wolsey (Taverner being at one time organist and master of the choristers at Cardinal's College, now Christ Church, at Oxford), and finally as a prayer for Henry VIII. Similarly, the anthem *O Lord, make thy servant Elizabeth our Queen,* written by William Byrd for Queen Elizabeth I, remained in the repertoire of the Chapel Royal for several decades, the name being changed first to James and then to Charles.

Repetition of occasional works

Most events of importance were planned months in advance, and the composer could usually count on being given adequate warning of a new commission. The meeting of Louis XII of France and Ferdinand V the Catholic of Castile at Savona in 1507, for which the French composer Antoine de Févin wrote a superb choral work, *Gaude Francorum regia corona,* was certainly not decided upon at short notice. Nor was the visit of Cardinal Ippolito de' Medici to Venice the result of a sudden decision, for Willaert had ample time to pen his solemn and sonorous motet *Adriacos numero* just as he did in the case of *Haud aliter pugnans,* in honour of King Ferdinand.

A later Ferdinand, who became Holy Roman Emperor Ferdinand III in 1637, commissioned two outstanding choral works by Monteverdi, both of which were published in his *Madrigali guerrieri et amorosi* (*Madrigals of War and Love,* 1638). *Altri canti d'amor* (*Let Others Sing of Love*) is a choral cantata for six voices, bass solo, and instrumental ensemble. The Emperor's military prowess is recounted in considerable detail, with choral imitations of swords clashing and guns firing. His qualities as a leader are also referred to in the ballet *Movete al mio bel suon* (*Move to my Beautiful Sound*), which extols him also as a just and equitable monarch in time of peace—although the Thirty Years' War did not in fact come to an end for several years. The text used by Monteverdi was a reworking of a poem which his friend the Italian poet Ottavio Rinuccini had originally written for Henry IV of France.

Purcell's odes

Purcell, a composer of occasional music who was also a brilliant choral writer, enriched the history of music with a series of odes and welcome songs beginning in 1680 (*Welcome, vicegerent of the mighty King*) and extending until the year of his death, 1695, which saw the production of the ode for the Duke of Gloucester's birthday, *Who can from joy refrain?* Among the finest of the series, and especially notable for the noble vigour of the choruses, are the odes for Queen Mary's birthday and for the St. Cecilia's Day celebration, 1692.

In France scores of comparable proportions were being written for such occasions as the baptism of the Dauphin (1688), for which Jean-Baptiste Lully set Pierre Perrin's *Plaude laetare* for double chorus and orchestra. Numerous court ceremonies or rejoicings called for large-scale performances of the Te Deum, Marc-Antoine Charpentier and Michel-Richard de Lalande, as well as Lully, providing music of the requisite pomp and proportions. Handel wrote two festive settings of the Te Deum for the Treaty of Utrecht (1713) and the British victory at Dettingen (1743). His royal odes worthily continue the Purcellian tradition, especially in the *Ode for the Queen's Birthday* (1713) for Queen Anne and in two wedding anthems, *This is the Day* (1734) for Princess Anne and *Sing unto God* (1736) for the Prince of Wales.

Although J.S. Bach did not disdain to write occasional music, he followed Handel's practice in the *Occasional Oratorio* (a patriotic piece given in 1746) without ever knowing Handel, by reworking this kind of music to a new text. One of the cantatas Bach supplied for the election of the Leipzig town councillors was deftly changed into a cantata for the 12th Sunday after Trinity; another, destined for the same annual event, *Preise, Jerusalem, den Herrn* (*Praise the Lord, O Jerusalem*), BWV 119 (1723), has been reedited in modern times with a new text, in imitation of the composer's own practice.

Haydn, in spite of his considerable duties as court conductor and composer, found time to write occasional works of considerable proportions, such as the two-hour birthday cantata, *Applausus* (1768), intended for the Abbot of Zwettl Stadt, Austria. His masses, even though they are liturgical, sometimes border also on the occasional because of their close ties with contemporary events, such as the *Missa St. Bernardi de Offida* (1796) written to celebrate the recent canonization of a Capuchin monk from Offida in Italy. An occasional choral composition of Beethoven's is his *Kantate auf den Tod Kaiser Josephs*

II (1790; *Cantata on the Death of the Emperor Joseph II*).

Berlioz, who had toyed with the idea of a large-scale choral and orchestral work to honour Napoleon, eventually had to abandon it but salvaged certain movements and incorporated them into his *Te Deum* (1849). His contemporary, Liszt, was more deliberately productive in this area, enjoying consistently enthusiastic receptions for his choral works of an occasional nature, such as the St. Cecilia antiphon *Cantantibus organis* (for a Palestrina festival in Rome in 1880), the *Missa solennis zur Einweihung der Basilika in Gran* (1855; *Mass for the Dedication of the Basilica at Gran*); the *Hungarian Coronation Mass* for Emperor Francis Joseph I (1867), and a unique composition for male chorus and organ accompaniment, *Slavimo Slavno Slaveni!*, written in 1863 for the millenary of SS. Cyril and Methodius. Also noteworthy are his two cantatas in honour of Beethoven.

The Czech composer Josef Förster achieved widespread recognition in his own country as a master of choral style, and a telling example of this may be heard in the cantata *Mortuis fratribus*, written as a kind of requiem after the end of World War I. In Hungary, Zoltán Kodály went to texts of a 16th-century Hungarian poet, Michael Veg, for his *Psalmus Hungaricus* (first performed, 1923) celebrating the 50th anniversary of the union of the cities Buda and Pest. For the Paris Exhibition of 1937, the French composer Florent Schmitt composed one of his finest choral works, the *Fête de la lumière* (*Festival of Light*).

Modern English occasional music

In 20th-century England the royal odes appeared less frequently than in the time of Purcell and Handel, yet there are a few choral works worthy of mention—Charles Stanford's *Welcome Song* for the opening of the Franco-British Exhibition (1908), and Sir Arthur Bliss's *Song of Welcome* (1954) for the homecoming of Queen Elizabeth II. Britten's cantata *St. Nicolas*, for tenor solo, mixed chorus, strings, piano, organ, and percussion, was written for the centenary of Lancing College in 1948, and 12 years later he supplied a *Cantata Academica* for the quincentenary of the University of Basel. The score of this work has parts where alternative words may be used for celebrations at other institutions of learning.

Secular music. Since the vast majority of secular vocal works of the Middle Ages and the Renaissance were written with soloists in mind rather than a chorus, this repertory will be dealt with in a later section of this article. A truly secular choral tradition does not really emerge until the 17th century, apart from dramatic works, which are mainly dealt with in the section on opera. Choruses were, however, supplied by way of incidental music to plays in the late 16th century; outstanding examples include the music written in 1585 by Andrea Gabrieli for the *Oedipus Tyrannus* of Sophocles and that of Giovanni Giacomo Gastoldi for Battista Guarini's play *Il pastor fido* (1590; *The Faithful Shepherd*). Choruses appear in 17th-century drama from time to time, as well as in masques and comparable extravaganzas. In the age of Lully, Marc-Antoine Charpentier, Purcell, and Matthew Locke, their position is clearly established. Secular cantatas tended for the most part to rely on solo voices, and when the chorus does make its appearance it sometimes consists only of three-part writing, as in Purcell's setting of Abraham Cowley's poem "If ever I more riches did desire."

The majority of Bach's secular cantatas call for solo voices only, in addition to the orchestra. Among those that do make full use of the chorus are *Phoebus und Pan* (*Geschwinde, geschwinde, ihr wirbelnden Winde*, BWV 201; 1731), the *Birthday Cantata* (*Schleicht, spielende Wellen*, BWV 206; 1733), and the *Hunt Cantata* (*Was mir behagt, ist nur die muntre Jagd*, BWV 208; 1716). The choral writing in Handel's secular cantatas and odes tends to be as massive and dignified as in the best of his oratorios, yet they are on the whole less frequently performed in the 20th century; as a group they do not fit easily into any single category. *Athalia* (1733) draws its inspiration and plot from the drama by the 17th-century French playwright Jean Racine; *Il trionfo del tempo e del disinganno* (1708; *The Triumph of Time and Truth*) is an allegory deriving from two of the composer's youthful Italianate compositions; *Alexander's Feast* (1736) and the *Ode for St. Cecilia's Day* (1739) both have texts by the 17th-century English poet Dryden; and the trilogy *L'allegro, Il penseroso, ed il moderato* (1740) is based on the poetry of another Englishman, John Milton.

Those powerful and opposite poles, church and opera, monopolized choral writing for many years, and apart from isolated works of an occasional nature there is little in the truly secular field until Beethoven's *Choral Fantasia* (1808), an unusual work in nine movements, the first seven of which are a set of variations for piano and orchestra. Voices are introduced only in the eighth movement—solo voices at first, singing verses in praise of music by a minor German poet of the early 19th century named Christoph Kuffner, then the choir, so that the previously dominant instrumental texture is gradually and effectively modified to include richly deployed vocal sonorities that assist the work to a climax in the same way as in the later *Choral Symphony*.

Beethoven's "Choral" symphony

This gigantic work, the ninth and last symphony by Beethoven, is planned in such a way that the choral finale is the only proper and logical way for it to end, although performances have been given where the finale has been omitted (using the scherzo as ending). The choral finale of the *Ninth Symphony* grows from the fertile soil of its predecessors and becomes a structural, thematic, and aesthetic necessity. It is notoriously difficult to perform, as Beethoven often seems to treat the singers like instruments.

The influence of his *Ninth Symphony* on later symphonic literature was considerable. Beethoven's bravura choral writing sent its echoes to the outer limits of the Romantic era, and there were many subsequent essays in the integration of choral and orchestral forces. In *La Damnation de Faust*, Opus 24 (1846), Berlioz uses the weight of massed voices in an imaginative and dramatic way; in contrast, in his *Roméo et Juliette* symphony the voices tend to serve as an extra dash of colour to the orchestral palette. Brahms made skillful use of the chorus in his *Rhapsodie* (1869) and *Schicksalslied* (*Song of Destiny*; 1871), and Schumann relied upon it throughout his *Das Paradies und die Peri* (*Paradise and the Peri*; 1843), a kind of secular oratorio based on the long poem *Lalla Rookh* (1817) by the Irish poet Thomas Moore. The best of both composers, chorally speaking, is to be found in their many settings of contemporaneous poems for mixed voices, male voice choir, or female choir. Much of this remains little known outside Germany, to the detriment of choral programs that would gain interest from one of Schumann's finely constructed double-choir compositions or from one of Brahm's sensitive settings of the poetry of Ludwig Uhland or Goethe.

The technical demands of the choral sections in Antonín Dvořák's *Svatební košile* (*The Spectre's Bride*), a cantata written for the Birmingham Festival of 1885, are within the capabilities of the amateur choral societies for which it was intended, and in general his treatment of voices shows consideration as well as ingenuity. The macabre plot of this work is a narrative poem by a learned countryman of the composer's, the Czech poet Karel Erben, who achieved fame as a collector of folklore. Czech folk songs and tales exercised a powerful attraction for Dvořák throughout his life, and some of his best choral music consists of settings such as *V přírodě* (*Amid Nature*, 1882) and *Tři sbory* (*Three Slovak Folksongs*, 1877). Czech poetry gave rise to many remarkable compositions among the choral works of Janáček, perhaps the most memorable being the three male-voice choruses written between 1906 and 1909 that were based on poems by Petr Bezruč: *Kantor Halfar* (*Teacher Halfar*), *Maryčka Magdanova*, and *Sedmdesát tisíc* (*The Seventy Thousand*).

In modern Germany and Austria, the most far-reaching attempt to bring together choral and orchestral forces in symphonic literature was that of Gustav Mahler. Unable for three years to find the solution to the problem of a finale for his second symphony, Mahler heard at the funeral of the eminent conductor-pianist Hans von Bülow the *Resurrection* Ode by the 18th-century German poet Friedrich Gottlieb Klopstock. He decided to use this poem as a basis for a choral finale in the *Symphony No. 2 in C*

Minor (1894). The use of massed voices for unaccompanied passages, such as the beginning of the ode, and later on with orchestral accompaniment and the collaboration of soprano and contralto soloists, affords ample evidence of Mahler's deep understanding of choral effects and techniques. The role of the choir is considerably less in his *Symphony No. 3 in D Minor* (1896), but it is nonetheless highly artistic and imaginative in the setting of the old popular verses *Es sungen drei Engel* ("Three angels were singing"). The *Eighth Symphony* (1906–07) marks the high point of symphonic choral music not only in Mahler's own output but in the entire history of the symphony as an art form. Instead of saving the chorus for climactic effects in the finale, as in his *Second Symphony* (and as in Beethoven's *Ninth*), Mahler integrates it from the very beginning into the complex and many-hued vocal and instrumental colours—eight soloists, a boys' choir, two large choirs of mixed voices able to project powerful antiphonal effects with orchestra and organ. This *Symphony of a Thousand,* as it is generally called, presents two texts of a complementary and opposing nature: the hymn *Veni creator spiritus* and the closing scene of Goethe's *Faust.* Mahler's inspired use of his colossal forces to enhance, explain, and endow with added meaning the divine and human aspects of the two texts is without parallel. His achievement has not since been matched for sheer virtuosity and impact.

The importance of Mahler

It is true that Arnold Schoenberg's *Gurrelieder* (1900–11) calls for even larger orchestral forces than Mahler's *Eighth Symphony,* although it has never enjoyed as much success. Choirs have preferred other early works of Schoenberg or those of Anton von Webern.

At the opposite end of the scale are the robust, tonal, and extrovert compositions of Paul Hindemith and also of Carl Orff, whose particular genius for setting classical and medieval texts may be seen in his *Catulli Carmina* (1943) and *Carmina Burana* (1937). Modern American choral music has been much enlivened by the contributions of Charles Ives (*An Election* composed in 1920), Randall Thompson, Roger Sessions, and many other eminent composers. Igor Stravinsky, who spent the latter part of his life in the United States, retained his interest in choral writing and constantly sought new ways of presenting the sonorities of a massed group of voices. To his earlier *Les Noces* (1923; *The Wedding*), and *Symphony of Psalms* (1930) for chorus and orchestra, he added the *Cantata on Old English Texts* (1952) on anonymous English poems of the 15th and 16th centuries and *A Sermon, A Narrative, and a Prayer* (1961) which is not a liturgical work, though its text is taken from the New Testament.

Twentieth-century English choral music for secular use finds one of its best advocates in Ralph Vaughan Williams, whose early setting of *Toward the Unknown Region* (first performed 1907) by the 19th-century American poet Walt Whitman was followed by *A Sea Symphony* (1910) based on material by the same poet. Frederick Delius also drew upon Whitman for his *Sea Drift* (1903) and upon the poems of the contemporary British poet Arthur Symons for his *Songs of Sunset* (1907). Britten's genius for word setting is evident in his *Hymn to St. Cecilia* (1942) and *A Ceremony of Carols* (1942) and in the handling of the boys' choir and mixed chorus in his *Spring Symphony* (1949), which ends with a choral waltz combining syllabic effects and the Old English lyric *Sumer is icumen in.* Outstanding among contemporary Polish choral works are three compositions by Krzysztof Penderecki: *Dimensions of Time and Silence* for chorus and chamber orchestra (published 1961); *Stabat Mater* for three choirs (1962); and *Psalms of David* for choir and percussion (1958).

Madrigals and related forms. A considerable amount of music sung by choirs in the 20th century is not really choral music at all, since it was conceived for performance by small groups of soloists and attains its fullest expression only through the individually projected personality of the solo voice. Assignment of these solo lines to a body of singers tends to neutralize this effect of personality, producing instead a weight of tone and an impression of superimposed dynamics and expression which, however carefully cultivated and disciplined, cannot surpass the kind of performance originally envisaged by the composer; yet a reasonable multiplication of voices does no harm to the texture as such, since the harmonies, the interweaving of parts, and the vocal spacing all remain constant. It is also true that a madrigal sung by 50 instead of by only five musicians will be more readily and rapidly understood by those directly involved because a massed performance of a five-part madrigal with 10 singers on each line is a more practical proposition than forming 10 separate consorts of five soloists. Individual voices, especially in amateur groups, may not possess the technique, the stamina, or the confidence to sustain a part on their own, but if they sing as a member of a group the likelihood is that they will achieve good results.

Choral performance of madrigals

Madrigals were originally published for professional singers and for amateur singers of high standard. They were issued not in score, as is the 20th-century custom, but in the form of part books, each one of which contained only the music necessary for one line—soprano, alto, tenor, bass, or any intermediate voice. The quantity printed of each edition was generally modest, with the result that prices were high, and choral performance was ruled out for economic reasons as well as artistic ones. The development of modern methods of engraving and printing music, allied to the creation of a worldwide market for choral works, has brought about a situation directly opposed to that of the Middle Ages and the Renaissance, whereby each singer now has a full score (or vocal score) that is less expensive than the part books printed in earlier times. In consequence, the choral performance of madrigals and related forms has become an economic possibility.

One of the most important predecessors of the madrigal proper was the frottola, which flourished in Italy between 1490 and 1520. In its early stages, the frottola was a song with instrumental accompaniment, with the main melody and text in the uppermost part (usually in the soprano or alto range) and supporting harmonies below. These harmonies were so simple and functional that an entire line could be dispensed with when intabulations for voice and lute were made. Four-part harmony was thus reduced to three, though without any serious loss since the polyphonic element tended to be of minimal importance. In later collections of frottolas, however, a different technique appears: instead of the upper line alone being supplied with text, all four parts join in. These completely texted frottolas were certainly intended to be sung by four singers, possibly, though not necessarily, doubled by instruments; and they could even have been sung by a small chorus.

Contemporary with the frottola were cognate forms such as the German lied, the French chanson, the Spanish villancico, and the English songs for voice and viols. All these began as accompanied songs, and all eventually followed the Italian fashion by dropping the instruments and substituting voices. This process was at first an obvious makeshift and can be detected as such because of the characteristically instrumental nature of the lower three parts, with numerous unvocal skips and contours. Words can be added to lines such as these, but they are often uncomfortable to sing because of the lack of conjunct movement and the paucity of breathing spaces. Occasionally, the added words appear only in one source, often a manuscript copy rather than a printed edition, the earlier sources on the other hand retaining the instrumental nature and function of the alto, tenor, and bass. The songs of Isaac provide clear examples of this gradual change, by which *Tenorlieder* (songs with the tune in the tenor) were transformed into part-songs by the addition of text to the instrumental lines. Some German composers, however, favoured the purely vocal or choral type of performance and made certain that all parts were texted.

Similar tendencies can be seen in France, in Spain, and in England, where many of the court songs written during Henry VIII's reign have text in all voice parts. One of the best known of these, *Passetyme with good cumpanye,* is a part-song for three male voices, written in all probability by the monarch himself. As the century progressed, amateurs began to take an interest in the part-song, which was generally for four voices, and several composers helped

Henry VIII's part-song

to lay the foundation for the English madrigal school. It is worthy of note that Byrd, in his *Psalmes, Sonets, & songs of Sadnes and pietie* (published, 1588), underlaid text to every part but mentioned in his preface that the songs were "originally made for Instruments to expresse the harmonie, and one voyce to pronounce the dittie."

The early development of the Italian madrigal was fostered as much by foreigners as by natives, and the considerable contributions made by the 16th-century Flemish composers Jacques Arcadelt, Philippe Verdelot, and Adriaan Willaert should not be underestimated. Although Willaert's settings of the works of the 14th-century Italian poet Petrarch and other serious Renaissance poets maintain an invariably high contrapuntal interest and are frequently suitable for choral performance, his compositions in the lighter, more homophonic vein, are well worth acquaintance.

Cipriano de Rore, another Netherlander adopted by Italy, felt Willaert's influence strongly yet contrived to set new standards in the interpretation of poetry through music and also to encourage an artistic fusion of the contrapuntal and homophonic styles, using them alternately in one and the same composition according to the dictates of the poem. Even his early madrigals show a deep concern for intensity of expression, as in the Petrarch setting for five voices *Hor che'l ciel e la terra.* One of his finest four-part madrigals, *Ancor che col partire,* sets off pairs of voices one against the other. New heights of expression are reached in his descriptive madrigal *Quando lieta sperai* (text by the woman poet Emilia Anguissola), in which a sudden and disappointing change in the weather is perfectly mirrored in the music. The four-part *Datemi pace,* based on a Petrarch sonnet, favours homophony and looks eagerly forward to the bold chromaticism of Pomponio Nenna and Don Carlo Gesualdo. In his maturity, Rore produced a number of remarkably intense madrigals for the court of Parma. One of the finest is his setting of *Dalle belle contrade,* full of powerful contrasts of mood and colour underlining the interplay of direct and indirect speech.

Further experiments in chromaticism were carried out by Nicola Vicentino, whose dramatic setting of *O messaggi del cor,* by the Renaissance poet Ludovico Ariosto, makes highly effective use of a mounting modulatory scheme (changes of key) to enhance the insistent repetition of the opening exclamations. His early madrigals exploit a more classical vein, without ignoring illustrative possibilities. His most typical and fascinating work is nevertheless to be found in such madrigals as *Poichè il mio largo pianto* or *L'aura che il verde lauro* in which Petrarch's verbal puns are suitably matched by Vicentino's harmonic ambiguities. Even more extreme is the Neapolitan composer Pomponio Nenna, whose striking and original harmonies must have made an indelible impression on his pupil Gesualdo. But whereas Gesualdo's chromaticism is often wayward and illogical, that of Nenna tends toward reason and reality. Several of the master's madrigals can be usefully compared with those of his noble pupil that were set to identical texts. *Mercè, grido piangendo,* for example, is treated by Nenna with an enviable intensity of expression heightened by tremendous contrasts of timbre and dynamic; and, although this pattern is followed in Gesualdo's setting (*Book V,* 1611), perhaps with even greater violence, the most favourable musical impression comes from Nenna. His four-part madrigal *La mia doglia s'avvanza* is startling by any standards, for the opening four bars move rapidly from G minor to F-sharp major, D minor, and C-sharp major.

Gesualdo's extraordinary range

Gesualdo's preoccupation with poems containing diametrically opposed ideas and concepts finds its outlet in his last two books of madrigals (V and VI, both 1611). *Itene, O miei sospiri* not only looks forward in its manneristic treatment of vocal texture and harmony; it looks backward to classical procedures such as the interpolation of rests at the word *sospiri* (sighs), invented much earlier when the quarter-note rest was called *suspirium.* It would be wrong, however, to classify Gesualdo as an extremist on every occasion, for he could often write melting phrases of unforgettable beauty. He can even be witty at times, as in the madrigal about a venturesome mosquito (*Ardita zanzaretta*), which is somewhat in the vein of a vocal scherzo.

Luca Marenzio, one of the most prolific among late 16th-century Italian madrigalists, achieved his high reputation not through experiment but rather through his remarkable sensitivity to words, both as single entities and as the basic elements of a poetic phrase. His balance between the two opposing claims of general mood and particular effect is always perfect, and the mastery of his vocal spacing is probably unrivalled, no matter whether four, five, or six parts are involved.

At the court of Mantua (now Mantova, Italy), two important composers were active toward the very end of the 16th century—Giaches de Wert and Giovanni Giacomo Gastoldi. Each of them, in his own particular way, helped to renew and transform madrigal techniques even though the countless admirers of Marenzio felt that the pinnacles of perfection had already been reached. De Wert's contribution to the new madrigal was in some ways unusual and unexpected, for he approached the dramatic madrigal-poetry in a way that combined realism with clarity. He returned, in fact, to homophonic writing when it was necessary to emphasize a point, allowing the highest voice part to project the melody in what was essentially a kind of "choral recitative." His pupil Monteverdi published nine books of madrigals. From the sixth book onward continuo support becomes obligatory, and in consequence solo voices emerge from a choral background with tremendous dramatic effect, especially in the later works. The ballet *Tirsi e Clori* is rich in five-part choral writing of considerable elegance and resource, and the same is true (though in six-part texture) of *Altri canti di Marte. Vago augelletto* contrasts solo and choral writing until the last tutti, when all singers combine in a sonorous statement. Perhaps the greatest Monteverdi work of all is *Hor che'l ciel e la terra,* a six-part madrigal in two sections, with many solos and choral sections accompanied by violins and continuo. Monteverdi rarely surpassed the heights of emotional expressiveness found in this product of his maturity.

Monteverdi's mastery of the madrigal

At the time of the Italian madrigal's fullest flowering, German composers derived much inspiration from the south while still contriving to retain something of their earlier heritage. The result was often a kind of international style, greatly influenced by Orlando di Lasso, who was as much at home writing Italian madrigals as he was with French chanson and German lieder. His pupils, the Austrian Leonhard Lechner and the German Johann Eccard, developed this style still further, as may be seen in the former's setting of *Wohl kommt der Mai* (*Welcome May*), a lively and optimistic May song full of expressive harmonic colour. The setting by Lasso of the same text is calmer, more homophonic; yet its apparent simplicity and unostentatiousness hides a subtle and skillful mastery of vocal art.

In his five-part lieder, Lasso makes the most of contrasting duets and trios very frequently, as in *Es jagt ein Jäger* a hunting song which serves as an excuse for lightly concealed amatory dalliance. Hans Leo Hassler was obviously fired by Lasso's lead in the sheer variety and latent possibilities of secular vocal style, and much of his best work was done in the dialogue form. A peak of brilliance and energy is reached in his eight-part dialogue for two opposing choral bodies, *Mein Lieb will mit mir kriegen* (*My Love Wants to Wage a War*), which might be described as a musically stylized battle of the sexes, with blows given and taken freely until the two groups combine to sing of final reconciliation and contentment.

Dialogues in this vein were also cultivated successfully by Christoph Demantius, whose anthology of 1609 contains examples of memorable beauty and charm. In his *Jungfrew, ich het ein' Bitt' an euch* (*Maiden, I have a Request for You*), Demantius allows one four-part choir to represent the girl and the other the boy in a conversation full of innocent affection and honest courtship, the two groups joining at the end to sing goodnight. In his five-part lieder, Demantius sometimes displays a learned touch in his imitative counterpoint, although the general impression is one of Italianate elegance rather than of studious endeavour. It is worthy of note that many of his lieder are

strophically conceived, and in consequence he printed the verses complete in each voice part, a feature which has been unfortunately obscured in the modern edition of his works. One of the finest of his lieder is *Lieblich ich hörte singen*, which tells of the Sirens' song and reproduces its allegedly hypnotic effect by means of flowing melismata in the upper voices.

The dialogue, considered as an art form of the Renaissance and Baroque eras, contains many choral elements. In its earliest form, as exemplified by the dialogues of Willaert, seven voices is the norm, and the texture is not yet clearly separated into two groups. Instead there is a kaleidoscopic impression caused by the skillful deployment of varied groupings. By the time of Andrea Gabrieli, a dialogue such as the popular and erotic *Tirsi morir volea* calls for a trio of high voices representing the girl and a quartet of deeper voices for the man. The amorous interchanges are carefully allocated to the individual groups, and there is no attempt to join them together until the very end. But in a typical dialogue by the younger Gabrieli, *Dormiva dolcemente*, there is no relationship between direct and indirect speech as far as the music is concerned. The setting is in this sense abstract, and the beauty of the dialogue lies in its purely musical architecture and expression.

The dialogues of Lasso

One of the greatest masters of the French dialogue was Orlando di Lasso, who set two poems of the 16th-century French poet Pierre de Ronsard in eight-part, double-choir compositions of exceptional quality. *Que dis-tu, que fais-tu?* (1576; *What Are You Saying, What Are You Doing?*) plays off one group against another in a series of sympathetic exchanges culminating in a final chorus praising the constancy of the lovebirds. Another masterpiece of this kind is *O doux parler* (1571), in which the interlocutors are human and the approach of both poet and composer more intensely passionate.

The French chanson, one of the most popular secular vocal genres in the 16th century, is essentially in miniature form. Unlike the Italian madrigals, which were sometimes composed in sequences of three, four, or more sections, French chansons tend to remain individual in the sense that they are self-contained, epigrammatic, and brief. It is partly for this reason that they have been less explored by 20th-century choral groups, although the language factor must also be taken into consideration.

English madrigals, because of their relatively innocuous texts and their moderate degree of difficulty, have always been a staple diet of choral societies and to an even greater extent of chamber choruses. The 16th- and 17th-century madrigals of William Byrd, Thomas Weelkes, John Wilbye, Thomas Morley, and their contemporaries and successors are too well-known to need elaborate description and too numerous to permit individual discussion. It is nevertheless true that although this repertory may today be considered as generally choral, certain madrigals are better reserved for performance by soloists. The criterion for making such a choice lies often with the text rather than with the music, for a certain degree of personal intensity in the words demands a corresponding projection of individual lines and their message. On the other hand, others are eminently suitable for choral performance.

After the vogue of the madrigal had disappeared, that of the glee eventually took its place, flourishing from the early 18th century to the middle of the 19th. Like the madrigal, the glee was originally intended for solo voices, but choral performances were by no means infrequent. The word glee, derived from the Anglo-Saxon word for music (*gligge*) does not necessarily imply a composition of a cheerful nature, and many of the best glees in fact express solemn or poetic themes. Samuel Webbe's *Glorious Apollo* and R.J.S. Stevens's *Ye spotted snakes* provide very different, though typical, examples of this vocal genre. Tonality is for the most part simple and unaffected, harmony is robust, and the span of musical thought necessarily brief. (D.W.S.)

Theatre music

Music as an art of the theatre has its roots in primitive ritual and ceremony and its branches in every modern means of theatrical presentation. Its functions are as varied as the forms require and range from being the primary reason for performance, as in opera, to mere noise, filling a vacuum in imagination for some screen and stage presentations. The more significant and universal aspects of theatrical music are considered in this section; opera is the subject of a separate section.

Theatre music is all music composed to govern, enhance, or support a theatrical conception. Music composed for theatrical purposes obeys different laws than does the music for concert performance or conventional opera. Whereas in opera the music dictates the form in which the dramatic visual imagery is presented and governs its development, in other kinds of theatre the music is, at best, an equal partner among its principal elements. In concert, of course, the music is the sole factor that determines the experience.

In the West, the concept of music as an intellectual experience for its own sake emerged only in the second half of the 18th century. Theatrical music is variously related to something other than itself, whether as an enrichment of words (as in operetta), a factor in structure and mood (ballet), or an intensification of situation and feeling (as in incidental music for plays and films).

In some instances music is dominant, in some it is subservient, and in operetta or stage musical the emphasis alternates between speech, song, and dance. In opera and spoken drama, in which words are wholly sung or spoken, a convention once set is consistently sustained and thereby creates its own kind of reality. The constant change of focus in operetta and musical, from music to speech and back again, emphasizes the artificiality of the illusion they seek to create.

The classical mainstream of theatre music in the West extends from the mid-17th century to the 1930s, and the instances of drama and music meeting on an equal level of imagination are relatively few. More frequently great music was lavished on weak or corrupt theatre, or great drama was embellished with indifferent music. From the early 20th century new dramatic developments were seldom directly matched in music. A German-Italian composer, Ferruccio Busoni, wrote in 1906:

> The greater part of modern theatre music suffers from the mistake of seeking to repeat the scenes passing on the stage, instead of fulfilling its own proper mission of interpreting the attitudes of the persons represented.

The German composer Kurt Weill's score for *Der Silbersee* (1933; *The Silver Sea*) was the last major musical contribution to a serious play requiring a full orchestra and chorus. Thereafter, for economic reasons, the dramatic theatre had to equip itself with small-group music or prerecorded tapes. The orchestra and chorus became the prerogative of stage musicals and films. The more these were commercially debased the more they came to rely heavily on the clichés of 19th-century music, to the exclusion of newer musical developments.

Producers of stage musicals, the choreographers of dance, and the directors of drama need to be wary of the properties of music. It is more demanding of attention than is often thought, and its use should ideally be confined to circumstances where it can provide something that none of the other theatrical elements can offer. The more its qualities are understood and respected, the better it can be guided to an effective theatrical purpose.

MUSIC FOR BALLET

The partnership of choreography and music

During the 20th century the element of music in all forms of ballet has changed and developed its significance to an unprecedented extent. It has acquired the status of an equal partner with the choreography, where once it was entirely the servant of the ballet master. In the 19th century he asked little more than that the music should decorate his ballets prettily and give rhythmic support to the movements of the dancers. His modern successors have been made aware that the highest level of balletic achievement now requires the music and choreography to become extensions of each other, to be heard and seen on equal levels of perception.

The finest modern choreographers are not content simply

to ride the surface of their chosen music, whether it is specially written, borrowed, or adapted. They seek to exploit the relationship of eye and ear, recognizing that the effect of any danced step can be changed by the stress of the musical rhythm, the degree of loud or soft in its dynamics, the nature of its harmonic character, and the expressive quality of its instrumental timbre. All these factors can make a positive contribution to the balletic image, and they give coherence to the sequence of movement as they merge into its continuous momentum.

Until the end of the 19th century, each new ballet customarily had music specially composed for it, but it was rare for any composer of distinction to write ballet music, unless it was part of an opera. There were exceptions—such as Beethoven's score for *Die Geschöpfe des Prometheus* (1801; *The Creatures of Prometheus*), originally a ballet by an Italian choreographer, Salvatore Viganò—but the great era of Romantic ballet from about 1830 was seldom enhanced by music of intrinsic worth. When ballet gained a musical interest, the difference was soon apparent; it has been well said that Léo Delibes gave ballet music a heart, Peter Tchaikovsky gave it a soul, and Igor Stravinsky made an honest woman of it.

Stravinsky's influence on music for ballet

Stravinsky was the dominating figure for nearly half a century (beginning in 1910) in composing music for ballet. He gained international acclaim with the first products of his collaboration with the Ballets Russes of the Russian impresario Sergey Diaghilev: *The Firebird* (1910), *Petrushka* (1911), and *The Rite of Spring* (1913). The first two continue to be performed in their original choreography by Michel Fokine, also a Russian, each with a narrative basis illustrated in music notable for its expressive colour and harmonic innovations. *The Rite of Spring* provoked one of the most notorious scandals in theatre history when Vaslav Nijinsky's original ballet reduced its first Paris audience to verbal insult and physical assault; its rhythmic audacity has since remained a recurring challenge to other choreographers.

Largely as a result of the standard set by Diaghilev's flair and artistic success, most leading composers in the 20th century have contributed something to the art of dance. Diaghilev directly commissioned two outstanding examples in the French composer Maurice Ravel's *Daphnis et Chloé* (1912), which the composer defined as a "poème chorégraphique," and *The Three-cornered Hat* (1919) by the Spanish composer Manuel de Falla. Distinctive original scores for ballet continued usually to be the outcome of specific commissions. Composers do not yet normally think in terms of dance (as they do in terms of song), although in Great Britain the composer Peter Maxwell Davies incorporated an integral role for solo dancer in his otherwise instrumental work, *Vesalii icones* (1969).

Contrary to what is still sometimes thought by musicians and a section of the public, music for ballet is not necessarily written to be "interpreted" in dance. Stravinsky has emphasized:

> Choreography must realise its own form, one independent of the musical form though measured to the musical unit. Its construction will be based on whatever correspondences the choreographer may invent, but it must not seek merely to duplicate the line and beat of the music.

Stravinsky's collaboration with Balanchine

The composer was writing from the experience of a long collaboration with a Russian-born choreographer, George Balanchine, mainly for what is now the New York City Ballet. Their partnership began in 1928 with *Apollo*, reached a peak in 1957 with *Agon*, and was to the 20th century what the collaboration of Tchaikovsky with choreographers Marius Petipa from France and Lev Ivanov from Russia was to the 19th.

In the former Soviet Union and present-day Russia, a post-Revolutionary equivalent to the classical three-act narrative ballet has continued to be in demand. This form has been furnished by many composers of ballets that have not been performed outside of Russian cultural circles, but it has been chiefly distinguished by the work of Sergey Prokofiev. His full-length scores for *Romeo and Juliet* (1940), *Cinderella* (1948), and *The Stone Flower* (posthumously staged in 1954) have variously succeeded in reconciling an older classical form to new expressive demands. Its offshoots in western Europe have included, in Great Britain, Benjamin Britten's music for *The Prince of the Pagodas* (staged by the Royal Ballet, 1957) and Hans Werner Henze's music for *Ondine* (Royal Ballet, 1958).

The stronger emphasis in western Europe and the United States in the late 20th century was on one-act ballets, varying from about 15 minutes' to more than one hour's duration. Composers continue to show some reluctance to write music specifically for dancing, partly because they are seldom closely involved with the art and also because they have relatively less control over the finished performance than in opera and in most other forms of musical theatre. Apart from works already mentioned, however, the ballet repertory has been enriched by such scores as the French composer Erik Satie's *Parade* for Diaghilev in 1917; the British composer Vaughan Williams' *Job* (1931) and the English composer Sir Arthur Bliss's *Checkmate* (1937) for the British choreographer Ninette de Valois, in Britain; and the American composer Aaron Copland's *Appalachian Spring* (1944) and the American composer Samuel Barber's *The Serpent Heart* (1946; later revised as *Cave of the Heart*, 1947) for the choreographer Martha Graham, in the United States.

Creation of modern ballets to existing scores

Nevertheless, the greater proportion of new ballets in the West during the last half-century have been created to preexisting music, and it is evident that choreographers have felt a greater freedom to experiment visually in the use of such music. The practice dates principally from the first orchestration (by the Russian composer Aleksandr Glazunov, 1894) of an arbitrary suite of piano music by Frédéric Chopin to which Fokine created *Chopiniana* (1908)—a title retained by Soviet ballet companies for what Diaghilev renamed *Les Sylphides* (1909). More than 60 years later, another arbitrary suite by Chopin, although retained in its piano form, proved to be no less fruitful for the American choreographer Jerome Robbins in *Dances at a Gathering* (1969).

Almost every category of music—from medieval music to advanced electronics and from symphonic compositions to the simplest pop tunes—has now been used for choreographic purposes. The function of music in a dance context has varied almost as much—staining the ballet's surroundings as a kind of aural decor at one extreme, as with the soundscapes of John Cage for Merce Cunningham's dance works in the United States, to the mutual absorption of music and choreography phrase by phrase in such works as the British choreographer Sir Frederick Ashton's *Symphonic Variations* to the music of César Franck (Royal Ballet, 1946), as well as the Balanchine-Stravinsky *Agon* (1957) and *Movements* (New York City Ballet, 1963).

Sometimes the same music has been used for several different ballets within a short time by various choreographers. An outstanding example is the *Sinfonia* by an Italian composer, Luciano Berio, written originally in 1968 as a concert work. By the end of 1971 it had been taken over for at least eight separate ballets in almost as many countries in western Europe alone.

Ballet concerned with musical associations

Another trend in ballet in the second half of the 20th century has been to make ballets apparently more concerned with musical associations than with human personality. Instances include Balanchine's *Agon* and *Movements*, already mentioned, and the British choreographer Kenneth (later Sir Kenneth) MacMillan's *The Song of the Earth* (1965) to the song-symphony by the Austrian composer Gustav Mahler. The dancers seem required to assume the "personality," or expressive character, of the musical instruments they parallel, as if the choreographers were moving toward a form of "ideal" dance once postulated by a French poet, Stéphane Mallarmé, who envisaged music and dance not only as equals but also equally devoid of human personality.

In the view of most ballet critics, the antidote lies in the continuing appeal of narrative dance-dramas with their illustrative music, although the success or otherwise of any ballets that engage preexisting music is basically governed by a single crucial principle: the level of choreographic imagination should never be less than that of the music. A ballet can be better than its music, but it can never

afford to be worse. There will always be ballets dependent on music for no more than expressive colour and supporting rhythm, but the "perfect analogous concord between what we see and what we hear," recommended as the ideal nearly 150 years ago by Carlo Blasis, a great Italian teacher, still remains the most desirable aspiration for every kind of ballet music.

STAGE MUSICALS

When, in the 1930s and '40s, dancing became an integral element in a genre governed chiefly by song—instead of being merely a diversion—the "musical" established itself as the legitimate theatrical heir to "musical comedy" and a form of popular theatre art that dominated the latter half of the 20th century. It has been challenged by the newer "rock musical," using a variation of the common musical vernacular and techniques related more to the recording studio than to the theatre, the effect of which is not yet determined. Meanwhile, what originally started as a democratic counterpart to aristocratic opera reached its fruition as the theatrical association of sentiment with illusion.

The sentiment is usually dispensed by the narrative; the illusion is created by the music. The most potent narratives in stage musicals have often been adaptations of classical drama and literature—for example, *Romeo and Juliet* transformed into *West Side Story: The Taming of the Shrew* into *Kiss Me, Kate; Don Quixote* into *Man of La Mancha;* and *Oliver Twist* into *Oliver*—or the many variations on the *Cinderella-Pygmalion* legend by which rags are transformed into riches (from *The Shop Girl* in 1894 to *My Fair Lady* in 1956). A distinction was at one time drawn between the frivolous musical comedy and the "musical play," denoting a dramatically serious or even tragic narrative, but both are now equally defined as musicals.

Their specifically musical character is born from a marriage of convenience between first- and second-generation descendants of European operetta and music-hall variety, on the one hand, and American jazz and American music hall, on the other—plus the romantic balladry of both continents. An English musicologist, Wilfred Mellers, asserts that, although most successful stage songs contain subtleties unappreciated by the nonmusical listener, they all reflect "an illusion that we can live on the surface of our emotions" and that "the world of musical comedy never gets beyond, or wants to get beyond, this illusion."

First musical comedy

The first musical comedy to be called so was *A Gaiety Girl,* staged in 1893 by George Edwardes at the Gaiety Theatre, London. A romantic farce adorned by the songs of Sidney Jones, it was successfully exported to New York in the same year. John Hollingshead (Edwardes' predecessor at the Gaiety Theatre) wrote in 1903:

> The invention or discovery of musical comedy was a happy inspiration of Mr. George Edwardes's. It provided a new form of entertainment for playgoers who go to a theatre for amusement and recreation, which was more elastic in plot or story than the old burlesque . . . [It] exhibited a little of the old burletta and vaudeville, most of the best elements of farce, a dash of the French revue . . . and much that would not have been out of place in Parisian *opéra-bouffe.*

Some 50 years of development in musical theatre are reflected in the contrast between the foregoing remarks and the following comment in 1952 by Jack Burton, American theatre historian, on *Oklahoma!* (1943), an epoch-making musical by Richard Rodgers and Oscar Hammerstein:

> This phenomenal production set a new pattern in which every line, every song, every dance routine is an indispensable part of a closely-knit whole. It was a show that had dramatic substance and never ran off the plot track, and so real, so simple, so engrossing was its story that its narrative could be safely entrusted to other than big-name stars.

The years embraced by these comments set up a dominant axis of theatrical exchange between New York and London. Success in this field is governed more by economic than artistic considerations, with longer and longer runs of each production becoming necessary to recover increasingly heavy expenditures before profits can be made. The primary requirements for the composer are, therefore, quick assimilation combined with durability. His music should also be easily adaptable to other media such as motion pictures and phonograph or tape reproduction, whereby it becomes a commonplace of experience to a mass audience far beyond the reach of the original theatrical context.

Although musical theatre of this kind has developed toward a closer integration of music and story, its primary feature has remained the individual song. Lehman Engel, a leading conductor of stage musicals in the United States, has defined five types of song basic to the stage musical: ballad—usually but not exclusively romantic in feeling; rhythm song—varied in emotional character but primarily propelled by a prominent musical beat; comedy song—enhancing verbal humour and divided into "short joke" and "long joke"; charm song—generally delicate, optimistic, and lightly rhythmic; and musical scene—in which a song may form part of a continuous dramatic episode. Engel further asserts that the successful impact of any song in the first instance is generally governed by the following considerations: the tempo, the mood of the scene, the song's position in relation to the whole production, the inherent value of the song itself, and the relative importance of the character who delivers it. It will be noted that integral musical quality is subordinate on this scale, although it is specifically the musical appeal that establishes success in the first place, disseminates that success through other media, and may later lead to revival in the country of origin and to reproduction in other countries.

Success of *My Fair Lady*

One of the most successful specimens is *My Fair Lady,* with music by Frederick Loewe, a Viennese-born American composer. This musical had first runs of 2,717 performances in New York (from 1956) and 2,281 in London (from 1958), and it has since been staged in translation in most European countries. It is rare for the English-language dominance of the musical-comedy genre to be breached by other countries, as France did with *Irma la Douce* (1956) or pre-Nazi Germany did with *Die Dreigroschenoper* (*Threepenny Opera,* 1928) and *Im weissen Rossl* (1930; *White Horse Inn*); but in most European countries except Britain the line between musical and operetta (see below) is less distinctly marked.

In Italy such lighter forms of musical theatre are submerged in an already popular taste for the broadest range of opera, while in Spain they manifest themselves in the category of zarzuela (discussed below in conjunction with operetta). Differences of idiom are often more the outcome of theatrical or other conditions in their respective countries than of theatrical or musical distinctions in the work itself. In the erstwhile Soviet Union, the musicologist Andrey Olkhovsky once noted that

> the numerous attempts which have been made to create a Soviet repertory have led to no results. At best the plots of comedies are based on episodes from Soviet life, but musically they are still imitations of the pre-Revolution operettas.

Stage musical comedies in the Western sense have produced their own original talents among composers—notably Jerome Kern, Irving Berlin, George Gershwin, Cole Porter, and Richard Rodgers in the United States and Noel Coward, Vivian Ellis, Ivor Novello, Lionel Bart, and Sandy Wilson in Great Britain. They have also had occasional recourse to adaptations from classical composers, including Franz Schubert and Edvard Grieg, who are dramatically characterized respectively in *Lilac Time* (originally *Das Dreimäderlhaus;* 1916) and *The Song of Norway* (1944); Georges Bizet, whose music became the basis of *Carmen Jones* (1943); and Aleksandr Borodin, for *Kismet* (1953).

Musicals ought to be adaptable to varied instrumentation, because theatre orchestras can vary considerably in size and composition from place to place. Paradoxically, the looser form of the rock musical is propelled by a much more rigid instrumentation derived from the ensemble used in pop-music recording, itself determined by studio techniques. In *Jesus Christ Superstar* (1971) the covering of the orchestra pit, the permanent amplification of instruments, and the use of voices entirely dependent on microphones amounts to a replacement of the illusion of theatre in any traditional sense

The rock musical

with the actuality of a modern recording studio made visible.

MUSIC FOR MOTION PICTURES

Many successful stage musicals have become additionally popular through the medium of motion pictures, but music as a basic element in filmmaking has gained recognition only since midcentury as something more than a means to heighten local colour or intensify emotional expression. In the early silent films, all kinds of music were recorded, classified, and adapted to fit different moods (Beethoven overtures for cowboy-Indian chases, for instance). Several talented hacks also wrote short descriptive pieces. A few bigger films, such as *The Birth of a Nation,* had special scores fitted to them. Since the 1960s it has turned a full circle of the wheel back to extensive musical quotation from classical resources for similar ends but in different ways.

Russian filmmakers first gave serious consideration to the contribution music could make. V.I. Pudovkin, a Russian musicologist, defined a theory and practice of film music in the early 1930s, advocating a close and contrapuntal relationship between sound and sight. The Russian film director Sergey Eisenstein described his careful collaboration with Prokofiev in making *Alexander Nevsky* (1938). His perceptive observations on the potential link between cinematic rhythm and musical rhythm suggested a technique that has influenced others, such as the British composer Sir William Walton in his score for *Hamlet.*

Hanns Eisler's theories of film music

Hanns Eisler, a German-born composer, formed his own theories of film music, based on empirical experience composing in this medium. His published findings recommended short musical forms in a film context, the composer's conscious awareness of the film's realistic sound element (the "where" and "when" of its location), and music that could suggest an objective, universal character for the film's emotions, rather than being introspective on its own account. Eisler also supported Pudovkin in maintaining that film music should create its own sense of line independently of, although related to, the film narrative.

Film music has travelled through five broad phases: an initial borrowing from existing conventional sources; the use of musical-cliché catalogs, which enabled any musician of modest ability to assemble an emotional or dramatic sequence and which served as the basis for most later background music in films; the active interest of major composers in writing original scores; a subsequent reaction of either near silence or advanced techniques of electronic sound generation and transformation; and the borrowing from classical sources for new purposes.

In France, in particular, the regular participation of leading composers in film music has been the rule rather than the exception. The opposite holds true in the United States and Great Britain, although most composers of distinction in both countries between the mid-1930s and the mid-1950s made some original contributions to the motion-picture medium. In the United States these included Aaron Copland, Marc Blitzstein, and Virgil Thomson, who received the first Pulitzer Prize awarded to film music—for *Louisiana Story* (1948); in Great Britain, Ralph Vaughan Williams, Benjamin Britten, Sir William Walton, Alan Rawsthorne, and Richard Rodney Bennett.

Isolated experiments to marry films to specific classical music have been made from time to time. These include the Austrian director Max Reinhardt's film of Shakespeare's *A Midsummer Night's Dream* (1935), which varied the cinematic structure to incorporate the complete suite of Mendelssohn's incidental music originally written for the play. The American filmmaker Walt Disney's celebrated *Fantasia* (1940) adapted the technique of the animated cartoon to illustrate a sequence of musical classics, outraging some people because the visual relationships were held to be irrelevant to the music but continuing to the present to entertain audiences, especially young ones, on an international scale.

When the making of motion pictures became an industry more than a craft, a situation developed in which music was recognized as desirable by the manufacturers, who nevertheless made no claim to "understand" music in the way they would be expected to understand motion-picture techniques. A parallel attitude among musicians unfortunately came to regard the skilled provision of a score tailored to the demands of script and camera as a spiritually impoverished relation of aspiring symphonic or operatic works.

Renewed use of concert music

In the late 1960s original film composition tended to decline in favour of renewed and often extensive borrowing from existing concert music. The slow movement from a Mozart piano concerto served to express the passage of time as well as for emotional mood in *Elvira Madigan.* The American film director Stanley Kubrick's *2001: A Space Odyssey* (1968) led an audience's imagination outward into space by a transition from the diatonic (using the natural scale of five tones and two semitones) C major of the introduction to Richard Strauss's tone-poem *Also sprach Zarathustra* to the polytonal Kyrie from the *Requiem* by the contemporary Hungarian-born composer György Ligeti. In the Italian film director Luchino Visconti's *Death in Venice,* four repetitions of a long passage from the Adagietto movement of Gustav Mahler's *Symphony No. 5* achieved a different expressive purpose in association with the visual scene each time it was heard.

Examples like these achieved an even greater impact than many original scores because they formed an organic part of the filmmaker's conception. Conversely, even scores distinguished by their own merits—such as Copland's for *Of Mice and Men* (1939) or Walton's for *Henry V* (1944)—were added only after the film itself was more or less finished. The major hope for the future of this medium lies in what Vaughan Williams urged: the composition of original scores but prepared in conjunction with the director from the film's inception. Film music might then be turned to more constructive instead of merely decorative purposes, without the dramatic license of the British film director Ken Russell's treatment of extensive passages from Tchaikovsky's music in his film *The Music Lovers* (1971).

MUSIC FOR TELEVISION

The screen medium's first law, that the visual element must come first, has been intensified by television. On the home screen, the experience of music performed for its own sake customarily operates under a double disadvantage. First, it runs the risk of being swamped by its visual presentation, which may range in character from the matching of nonmusical images in varying degrees of relevance to the technique of using close-ups of musicians in action. Secondly, it suffers the continuing handicap of inadequate reproduction by the average television receiver.

Limited repertory of television music

Apart from rare exceptions—such as an occasional "television opera," a dance-film, or Stravinsky's mixed media *The Flood* (1962)—original music to television is chiefly confined to the provision of theme passages or supporting music hopefully intended to enhance verbal or dramatic presentation. Like the cinema pianist who played for silent films, television music has a limited repertory of conventional gestures. Even when these are given a more contemporary harmonic or instrumental garb, they remain basically governed by the 19th-century mode of musical thought, to which it is assumed that mass audiences will most easily react.

Programs about, rather than of, music have obtained a modicum of television success. While the occasional theme quotation has perhaps introduced a famous musical classic to millions who would not otherwise havehead it, the "workshop" program, showing how music and musicians go about their business, has broken down barriers of technique and exposed the raw materials of music in a way that has probably helped to foster a wider interest in the finished product. Television cannot otherwise be accepted as a musical medium, until sets have a higher standard of musical reproduction.

INCIDENTAL MUSIC FOR THE THEATRE

Incidental music in the theatre, whatever its idiom or degree of stylistic emancipation, justifies itself through its exclusive concern with a specific play or theatrical presentation. Its three main uses involve songs, intensi-

fied dramatic effect, and interlude filling, and these have been clearly defined in Western theatre since Renaissance drama freed itself from the church in the 16th century.

A major modification of its character since the 1920s has been brought about largely by the wider use of mechanical techniques of amplification and recorded music. This has encouraged short musical fragments rather than fully composed pieces, except where the latter are specifically called for. Examples of this technique were heard in modern times in the musical productions of the National Theatre and the Royal Shakespeare Company in Great Britain. Such carefully planned but more informal use of incidental music has replaced the elaborate suites customary in the 19th and early 20th centuries, which presupposed the complete performance of each piece and required the stage drama to be produced so that the music could be accommodated in it (a characteristic example is Mendelssohn's music for *A Midsummer Night's Dream* at Potsdam, Germany, in 1843).

Informal incidental music

Economic conditions are now the principal factor governing the provision of incidental music. Theatres not concerned with opera or ballet can no longer afford to hire musicians for a pit band. Trade-union restrictions in the musical profession also limit the public use of recorded music in many countries. The trend is consequently for spoken drama either to dispense with music, to restrict it to one or two musicians with a singer, or to make increasingly fruitful use of electronic sounds on prerecorded tape.

Some famous 19th-century suites of incidental music were brought into being by conditions that favoured resident musicians at court theatres in Germany or lavish orchestral resources in Tsarist Russia. The music has since acquired independent status on its own merits and has become part of the classical concert repertory, such as the Mendelssohn just mentioned and Beethoven's music for Goethe's *Egmont* (1810); Schubert's for the German playwright Helmina von Chézy's *Rosamunde* (1823); Schumann's for Lord Byron's *Manfred* (1852); and Grieg's for Henrik Ibsen's *Peer Gynt* (1876).

Earlier theatre music was often, for long periods of time, governed by measures of censorship and legal restrictions that varied greatly from one country to another. In England, for instance, the monopoly of spoken drama was vested by King Charles II in the Theatres Royal in the 17th century, and this continued until 1843. Other theatres that opened during this time—including those catering to a new working class—were licensed only on condition that plays included five musical items in each act or a "musical accompaniment." The latter condition was sometimes held to be satisfied by no more than a chord struck at intervals on a piano during the performance. Such conditions inevitably brought about a profusion of inferior music, which in turn gave rise to the traditions of music hall and burlesque.

The renaissance of secular theatre, from the 17th century onward, led in Italy to the evolution of the predominantly musical forms of opera and oratorio, in France to the court ballet, and in England and Spain to the cultivation of spoken plays with incidental music. The unparalleled achievements of secular drama in the latter two countries are the roots of present-day musical theatre and help to explain why opera failed to flourish in competition. The drama in England expanded into the allied form of masque and involved the participation of such composers of distinction as Henry Purcell.

The masque in relation to its own period might well have been defined as "mixed media." This term has now come to stand for theatre presentations in a line of descent from Stravinsky's *Histoire du Soldat* (1918; *The Soldier's Tale*), which combines speech, song, mime, dance, and instrumental music with pictorial design. These elements have since been supplemented by the mechanical techniques of film or photographic projection, and of electronic sounds, in almost infinite permutations, together with a free form of expression no longer necessarily shaped by a narrative content.

The masque

Most of these manifestations incorporated two different kinds of musical contribution. One has been defined by a 20th-century German composer, Bernd Alois Zimmermann:

> All elements of the theatre of movement, including film, sound, speech, electronic music, must be mobilized into one great time-space structure, whose arrangement will be constituted by music as the most general form of temporal order.

Zimmermann's ideas were embodied in his opera, *Die Soldaten* (The Soldiers). The alternative is described by another composer, John Cage, as "Single sounds or groups of sounds which are not supported by harmonies but resound within a space of silence" and are added more or less at random to the other elements. It remains to be discovered whether the future of theatre music in drama or mixed media lies primarily with the highly organized patterns of interaction postulated by Zimmermann or with Cage's arbitrary combination of simple, disparate activities into a complex whole.

OPERETTA AND ALLIED FORMS

It seems unlikely that any future exists for operetta except as part of a "museum" repertory, because the contemporary musical has taken its place in musical theatre. Operetta in the usual sense of a work of lesser musical pretensions than opera, with spoken dialogue linking the musical episodes, was a direct descendant of comic opera, overlapping this category, on one hand, and early musical comedy, on the other. It was born as a democratic expression of popular wit and social satire, flourished for almost exactly a century (*c.* 1840–1940), and died from a surfeit of sentiment.

Offenbach. The satirical, romantic operetta emerged primarily in Paris in the mid-19th century with the French composer Jacques Offenbach; two of his works are still widely staged: *Orphée aux enfers* (1858; *Orpheus in the Underworld*) and *La Belle Hélène* (1864; *Beautiful Helen*). The character of Offenbach's operettas established several musical precedents, including the burlesque of Italian opera, the romantic ballad in $\frac{3}{8}$ or $\frac{6}{8}$ metre, and the drinking song and the *ensemble de perplexité* ("ensemble of confusion"). In England, Arthur Sullivan followed in Offenbach's wake with his fruitful partnership with the author W.S. Gilbert, bequeathing a commentary on aspects of Victorian society through music of popular and enduring, if somewhat relentless, charm.

Viennese operetta. Charm is the main ingredient of the more sentimental Viennese operetta, and it usually submerges the rarer shaft of social comment. The younger Johann Strauss made operetta an international entertainment by an expert blend of charm and craft, and his *Die Fledermaus* (1874; *The Bat*) remains a classic of its kind. A second generation in this tradition was chiefly distinguished by Franz Lehár, whose *Die lustige Witwe* (1905; *The Merry Widow*) represents the genre at its peak of romantic elegance, demonstrating a style and craftsmanship that seems in serious danger of being lost altogether.

Johann Strauss's contribution to operetta

Such operettas remain current in today's musical theatre mainly as an indulgence of musical and emotional nostalgia. Their popular style enabled them to take root and flourish far from their native territories, including transplantation to the United States. The indigenous tradition of the U.S. stage musical, already mentioned, first had to compete with European-style operetta. That the latter keeps a tenacious hold on popular affections is demonstrated by figures listing Rudolf Friml's *Rose Marie* (1924) and Sigmund Romberg's *The Desert Song* (1926) as the most frequently performed works in U.S. musical theatre, in terms of both amateur and professional performances.

Zarzuela. Spain was a prominent exception to the wide dissemination of operetta, preferring instead the flourishing native variety of zarzuela. This form customarily incorporates regional songs and dances, sometimes with traditional rather than original music. It continues to some extent as a staple fare in Spanish musical theatre, although the general contemporary trend toward a more universal style of musical expression has meant that the younger Spanish composer has shown much less interest in the zarzuela form as an outlet for his musical imagination.

The Romantic zarzuela has little resemblance to the aristocratic and courtly character of its 17th-century namesake and emerged with French and Viennese operetta during the 19th century. It divided into two forms—the *zarzuela*

grande in three acts, equivalent to romantic operetta, and the *género chico* in one act, invariably comic, usually satirical, employing the broadest musical vernacular, and verging on revue. In the former category, the names of Francisco Barbieri, Amadeo Vives, and Federico Moreno Torroba are probably the most significant representatives of their respective generations.

The Spanish character and language of the Romantic zarzuelas made them exportable to Central and South America, where they became a model for the limited indigenous musical theatre. The South American centres are otherwise dominated by imports or imitations of the Italian opera tradition or used as transit bases for the latest North American stage musical on its theatrical circumnavigation. Certain examples of the Spanish zarzuela, such as Moreno Torroba's *Luisa Fernanda* (1932), have achieved popular success in Latin American countries, where local contributions to the genre have notably been made by Juan Bautista Massa in Argentina, Andrés Martínez Montoya in Colombia, Luis Delgadillo in Nicaragua, and Teodoro Valcárcel in Peru.

ORIENTAL MUSICAL THEATRE

Theatre music generally serves different purposes in non-Western idioms—usually adding dimension and perspective to song and dance, indicating symbolic associations, suggesting mood, and even inducing a desired response in an audience. Most Oriental streams of music divide between popular music of a folk character and a more sophisticated style for a cultured elite. The distinction is often less clearly defined than in Western music and is now not so firmly maintained in the wake of recent political and social changes.

China. The classical Peking opera (*ching-hsi*) in China is a form of musical theatre in which music is one among several elements rather than a governing factor, as in Western opera. The vocal writing alternates between styles broadly equivalent to recitative and song, distinguished by a forced high falsetto tone required from the male singers. A less stylized variety is the all-female *yüeh ch'ü*, in which natural singing voices perform musical plays in realistic and decorative scenery, and the Manchurian *P'ing Hsi*, which has developed into an operetta-like equivalent, with traditions and subjects derived from strolling players and folk legends.

Since 1964 the performance of classical Peking opera in Communist China has been mainly restricted to festival occasions (although state-sponsored schools continue to train performers especially for it). More emphasis has been put on entertainments closer to Western musicals, involving contemporary dialogue, everyday dress, and less stylized music. As a popular form of musical theatre it has been turned to political and social advantage with a new and adapted repertory of dramatic ballets and musical plays, bearing such titles as *Taking Tiger Mountain by Strategy* and *The Red Detachment of Women.*

Political overtones of modern Chinese opera

Japan. Music is as much a regular part of theatre performance in Japan as it is in China. The highly formal tradition of Japanese Nō drama incorporates music as an integral feature, usually performed by flute, a variety of stringed instrument called the samisen, drums, and singers. The music varies in content and character with the subject of the play and obeys detailed melodic rules—especially in the central dance episode designed to reveal the spirit of the play's principal character. A less formal counterpart, the Kabuki theatre, has almost as impressive an ancestry as the Nō and continues to be widely performed, with music used to indicate period, place, time, or mood and often functioning by phrase association like the principle of leading motives in Richard Wagner.

India. Japanese theatre also incorporates music dramas of Indian origin, and the Indian theatre tradition is a full combination of poetry, music, dance, and symbolism. The music is often interpolated rather than specially composed and is likely to be drawn from the repertory of widely known songs without aiming at a high classical standard. The close association of music with drama in Indian culture has been carried over into Indian film, which cannot hope to enjoy wide success among its modern audiences unless it is liberally embellished with songs and other forms of music.

THE HISTORY OF THEATRICAL MUSIC

Formative period. What is thought to be the oldest document of musical history depicts a man wearing an animal mask, manipulating what is possibly a form of musical bow, and dancing in the wake of a herd of reindeer. This is a prehistoric cave painting dating from the Stone Age, discovered at Ariège in France. Masks are tangible signs of that transfer of personality on which every form of theatre is based and in which song and dance have participated since the dawn of communication and animated ritual. Music in dramatic entertainment reached early peaks of development in European and Oriental cultures in, respectively, the ancient Greece of Homer and, some centuries later, the Chinese classical drama.

Descriptive evidence of the earliest Greek theatre indicates that music, mostly sung by a chorus, was essential but not continuous. At drama festivals the poet wrote his own music (as well as being actor, producer, and choreographer), probably based on some kind of traditional repeated formula. Later Greek theatre, after the fall of Athens (404 BC), initiated both the repertory system and a category of musicians trained more highly than the populace. Amateur and professional became separated for the first time, and increasing sophistication brought about its counterpart in popular pantomime expressed in song and dance, often satirical or bawdy in character.

Early Greek and Roman theatrical music

The Roman musical theatre derived directly from the Greek, ousting a short-lived native form with Etruscan actors who also danced to pipe music. Latin versions of the Greek theatre with music were supplemented by a Roman variant of the pantomime as a dramatic solo dance with chorus and orchestra. It implied some prior knowledge on the audience's part of the subject and the dance vocabulary. Amphitheatre shows of gladiatorial contests were regularly accompanied by music, sometimes involving up to 100 horn blowers and 200 pipers, as well as such extra devices as water organs.

About the time the Roman theatre flourished, an Oriental equivalent emerged in China from ritual ceremonies that came to be repeated for their entertainment value. The puppet theatre was a significant intermediate stage in this process, and the forms evolved into different styles of entertainment for courtier and commoner. Strings, flute, and handbells accompanied the songs and dances in upper-class entertainments; a form of mouth organ replaced the bells in shows for the common people. By the time of the Sung dynasty (AD 960–1279), from which the earliest written music survives, a type of musical variety theatre, the *tzarjiuh,* was widely popular.

The Chinese classical opera tradition has already been mentioned as a modern form of musical theatre. It first developed during the Yüan dynasty (1206–1368) and reached its peak of style and classical form in the Ming period (1368–1644). Its evolution was accompanied by a less formal counterpart based on the dramatization of folk songs linked by a thin narrative plot (*Chueichang*). The full-scale opera and its regional variants remained the most significant form of Oriental musical theatre until the modern post-revolutionary times, but throughout the Far East the indigenous forms of music have always played a prominent part in theatrical presentations.

In Europe the vestiges of Greco-Roman culture were submerged by the early Christian Church. By the 6th century the church had suppressed drama and adapted pagan rituals to its own liturgical puposes. A small flame of musical theatre was left burning only in the form of religious ceremonial (for example, in the mass). Festive religious celebrations eventually expanded into the liturgical music drama that slowly developed from about the 10th century. This brought in its wake the equally religious "mysteries" and miracle plays of the Middle Ages in Europe, which were performed in the vernacular instead of in Latin, had a strong musical element, and, in due course, developed a secular counterpart.

Musical elements of the miracle plays

In a pattern that was to repeat itself after the birth of opera 200 years later, the secular theatre in the Middle

Ages established itself either as lighthearted interludes in serious moralities or as deliberate parody tolerated by the church as a safety valve to consistent piety. The annual Feast of Fools in 15th-century Paris, for instance, incorporated an obscene parody of the mass performed in song and dance within the church. By the year 1400 numerous comedies and farces had appeared, usually performed on festive occasions in aristocratic houses or on open stages in municipal squares.

These plays often employed musical forces comparable to those of the religious plays and used them for similar purposes. Choirboys from the church sometimes took part, but surviving texts suggest that there was little choral music as such. The individual actors incorporated parts of songs chanted monophonically to embellish or heighten the dramatic effect, and dancing to specific instrumental music also had a regular place in the entertainment. Professional musicians might be hired and might also be required to act; the constituent parts of the entertainment varied widely from place to place.

The fact that, except for songs, documents of the period contain almost no music directly linked with the theatre is thought to indicate that very little original instrumental music was written for theatrical purposes at this time. Whatever was suitable for weddings, banquets, and other feasts perhaps served a theatrical purpose just as well. Musicians probably had little or no acquaintance with musical notation and played pieces from their regular repertory. These seem to have included arrangements of vocal melodies as well as dance tunes, among which the play texts most frequently identify *basses-dances* and branles.

The Renaissance and Baroque periods. When Catherine de Médicis married King Henry II of France in 1533, she brought from Italy a taste for entertainments in which dancing was prominent. Her encouragement established the court ballet (*ballet de cour*) as the foundation of classical ballet, the source of a new theatrical identity for music and a precursor of French opera. As a unified blend of poetry, music, and movement, the court ballet dates from the performance of the *Ballet comique de la reine* at a court wedding in 1581. The form comprised an optional number of scenes in mime and dance, prefaced by explanatory verses that were either spoken or sung; the scenes were accompanied by solo and choral songs with lute, and instrumental ensemble pieces for strings.

The French court ballet

In about 1605 a more mannered style of singing had become customary, and by 1620 the court ballet was more a vehicle for display than drama. Unified dramatic plots were restored by the poet Isaac de Benserade in midcentury, and Jean-Baptiste Lully, who entered the service of King Louis XIV in 1652, endowed the music with fresh distinction. He favoured dramatic musical expression with the use of larger choral and orchestral forms and formulated such dances as the minuet, first danced by Louis as "Le Roi soleil" (the sun king), the gavotte, rigaudon, bourrée, passepied, and loure—each with its particular rhythmic metre.

Lully collaborated with the playwright Molière in a famous succession of comedy-ballets, of which *Le Bourgeois Gentilhomme* (1670) is probably the best known. Thereafter the character of Lully's work became essentially operatic, and music in the French theatre was left to function in a more subsidiary role. The dramatist Pierre Corneille, for instance, wrote "I have employed music only to satisfy the ear while the eyes are occupied with looking at the machines." In another category, the pastoral comedies derived from Italian models were liberally embellished with songs loosely strung together and alternating with spoken verses.

The French court ballet exerted an influence on the English masque, which took its name and some of its early character from the medieval Italian *mascherate* (masquerades) in carnival entertainment. At a time of distinctive English literary achievement, the masque reached a high artistic level, performed mainly as an aristocratic entertainment. It combined instrumental and vocal music, mixed with dancing and acting, in the representation of mythological and allegorical subjects. At the same time, the first public theatres in London came into being. They

The English masque

date from 1576 (61 years before the first public Venetian opera house); the earliest public plays are known to have incorporated some form of music.

Cues for music recur throughout Shakespeare's plays, usually for simple songs or dances. Music between the acts of public plays was customary by 1600, with the audience often calling for the tunes they wanted played. Instrumental music was employed for supernatural effects and to heighten dramatic tension; it was usually performed behind, at the side of, or even under the stage. After the suppression of playhouses during the Civil War, the restoration of the English monarchy with King Charles II brought an even richer flowering of theatre music, led by Henry Purcell.

Besides those works of Purcell that are nearer to masque than drama, such as the Shakespeare adaptations for *The Fairy Queen* (1692) and *The Tempest* (1695), he composed suites of incidental music for more than 40 plays. These generally comprised overtures, "act-tunes" (interludes), dances, and songs. Rather than growing out of the verbal drama, however, they are often so arbitrarily interpolated into it that only the quality of the music can justify most of them. After Purcell's death, English theatrical music ceased to contribute significantly to the theatre, but Thomas Arne, who wrote numerous masques and ballad operas such as *Love in a Village* (1762), was very popular in the mid-18th century, and his simplicity of expression has a certain direct appeal.

The flourishing tradition of Spanish Renaissance drama precluded much opera from taking root in Spain, but the music for plays had generally less distinction than the English equivalent. The early zarzuela (not to be confused with the later Romantic version already mentioned) originated in the 17th century as a court entertainment. It was the Spanish counterpart to the court ballet and acquired a strong Italian influence on its musical character. Spanish music and musicians travelled to the Western Hemisphere with the early explorers, and by the late 17th century the Peruvian capital of Lima had become musically important. The composer José Diaz worked there and wrote much incidental music to the plays of Calderón de la Barca.

Renaissance theatre in Italy bred the *intermedio*, which consisted of songs and instrumental music added before or after the acts of a play. The words of the songs were generally relevant to the action of the drama, and this development—together with more extended musical settings in pastoral plays—became the direct precursor of Italian opera. As a new form of "drama in music" which rapidly acquired serious artistic pretensions, the opera inevitably brought in its train a less aristocratic variety of musical theatre variously termed opera buffa (comic opera), vaudeville, ballad opera, singspiel (literally, song-play), or *tonadilla*, always performed in the vernacular of its audience and often in dialect.

The Italian *intermedio*

These depicted current events instead of historical or mythological subjects, involved elements of parody and social satire, and usually depended on modest musical resources for economic reasons. They began as interludes performed between the acts of serious opera and comprise an essential link in the history of musical theatre. By about 1700 the scenes (usually two) had acquired a linked plot, and by 1740 they were performed apart from the opera as a genuinely popular entertainment. Eventually they responded to the demands of the rising middle classes by raising their own standards into the category of comic opera.

Classical developments. The Italian commedia dell'arte entertainment of strolling players in mainly improvised comedy had left its mark on French fairground theatre, although the performers were expelled from France in 1697 for having ventured their satire too close to court topics. Ten years later French satirical comedies were also banned, whereupon the resourceful performers found a new way round by employing monologue, mime, and music. They thereby developed a new form of popular entertainment to contrast with the aristocratic *opéra-ballets*, which were soon to be dominated by the spectacular productions with Jean-Philippe Rameau as composer, and in 1713 two theatrical managements in

Paris were given license to perform "Le nouvel Opéra-comique."

Opéra-comique was a contraction of *opéra rendu comique* ("opera made comic"), signifying parody and satire at the expense primarily of serious opera. The entertainment soon came to veer either toward *comédie vaudeville,* mostly made up of bawdy satire or simply songs of disparaging social comment, or to the alternative *comédie à ariette,* involving a generally more decorous musical parody at the expense of Italian styles. The *Guerre des Bouffons* ("war of the comedians") between partisans of French and Italian theatrical styles was eventually resolved by the emergence of the opéra bouffe (literally, "comic opera")—the French variety of operetta. It is usually dated to the Paris production in 1753 of *Les Troqueurs* ("The Barterers"), based on a fable by Jean de La Fontaine and having original music by a court violinist, Antoine Dauvergne.

Ballet was declining about this time from courtly heroics to simple diversion unrelated to any dramatic point. Apart from the *opéra-ballets* of Rameau, little significant music was composed for the dance until the German composer Christoph Willibald Gluck, who initiated the major reform of serious opera during the century, first turned his attention to a move for balletic reform involving a more dramatic style. In 1761 Gluck composed the music for *Don Juan,* a ballet by Gasparo Angiolini, the Italian ballet master at Vienna, who maintained that dancing should be self-expressive without recourse to verbal explanations.

Gluck's contribution to ballet music

Gluck's vividly descriptive score contains 31 musical pieces, alternating between formal dance and narrative drama. It made the music a foreground element in the ballet instead of a background accompaniment and could have brought about—if its example had been followed up—a revitalization of ballet music almost as significant as the operatic reform Gluck launched in *Orfeo ed Euridice* a year later. In the ballet, the fight scene near the beginning and the dance of the Furies at the end (itself later incorporated into *Orfeo*) have a concentrated intensity of musical expression, and the graveyard scene has a degree of imaginative orchestration that is unsurpassed in any other music at that date.

For reasons that belong more properly to the history of ballet, Gluck's influence on its future course was less fruitful than in opera. Perhaps his example, nevertheless, encouraged the participation of such composers as Mozart with *Les Petits Riens* (1778; "Sweet Nothings") and Beethoven in *The Creatures of Prometheus* (1801). It was, otherwise, an era theatrically dominated by opera of various kinds, so that there was at first little call for music in relation to spoken drama. Haydn, however, composed some music (1796) for an early German translation of Alexander Bicknell's *The Patriot King, or Alfred and Elvida,* and Mozart contributed a suite of superior choral and orchestral music for *Thamos, König in Ägypten* (1773; *Thamos, King of Egypt*), which was never used for the play in his lifetime but which has survived where the play has long been forgotten.

Eighteenth-century opera nourished musical developments in the theatre chiefly through establishing regular orchestras of some quality. Outside of cities with more than one theatre, such as Vienna, Prague, Paris, and London, the numerous court theatres needed to keep a resident and costly orchestra reasonably occupied, with interest divided between opera and drama. It therefore became customary either to commission incidental music for existing plays whenever possible (especially the historical classics, as more and more of them were translated from one language to another) or to commission new plays that would incorporate ample provision for orchestral and sometimes choral music.

Romantic expansion. Examples of commissioned incidental music have previously been cited in Beethoven's music for *Egmont,* which belongs to the first category just mentioned, and Schubert's for *Rosamunde,* which is in the second. The practice spread as a matter of rivalry and prestige to cities without a court but which maintained a municipal theatre (for example, Hamburg and Leipzig) and to other countries with a thriving theatrical interest and ample funds. In Russia, for instance, Mikhail Glinka composed music to *Prince Kholmsky* (1840), an otherwise obscure drama by Count Kukolnik, and the Shakespeare repertory brought the collaboration of such composers as Mily Balakirev (*King Lear,* 1861) and Tchaikovsky (*Hamlet,* 1891).

France and England, having different systems of patronage, produced different results during the 19th century. English theatre music was confined for most of its course to a taste for crude melodrama and burlesque at a low level, apart from a sporadic interest in mostly imported opera and ballet. Arthur Sullivan, however, provided incidental music for Shakespeare plays as well as cultivating, in his collaboration with the author W.S. Gilbert, a native variety of operetta derived from the French model. France fared somewhat better with the popularity of opéra bouffe, and the birth of romantic ballet in Paris also kindled a new kind of theatre interest, even though its musical quality was usually secondary.

Gilbert and Sullivan operetta

Music for Romantic ballet developed in two directions. From the time of the French composer Adolphe Adam's score for *Giselle* (1841), ballet composers made rudimentary attempts to express mood and scene, to create dramatic tension, and to characterize personality in music. The general level was somewhat raised by the French composer Léo Delibes in his music for *Coppélia* (1870) and more especially for *Sylvia* (1876); the latter was a score that Tchaikovsky came to know and admire. The second feature in many ballet scores of the period was the attempt to compose suitably flavoured music to match the new growth of interest in national and regional dances, which were regularly incorporated into the ballets.

Music in 19th-century ballet reached its peak of achievement with Tchaikovsky, whose instinct for the theatre was probably stronger than his talent for the subtleties of symphonic argument. He treated the art of ballet as worthy of real musical imagination and told a colleague who adversely likened some of his *Symphony No. 4* to ballet music: "I cannot understand why the term should be associated with something reprehensible. There is such a thing as good ballet music." Tchaikovsky demonstrated its possibilities in three original scores for ballet that enjoy continuing universal popularity in the theatre: *Swan Lake* (first performed 1877); *The Sleeping Beauty* (1890); and *The Nutcracker* (1892).

Swan Lake achieved lasting success only after the composer's death—a fact which accounts for the recurring problems of the relationship of music to choreography, because some of the original musical sequence was changed for the 1895 production at St. Petersburg (now Leningrad), from which most current versions of the ballet are descended. The two later scores benefitted from detailed choreographic specifications. According to Stravinsky, *The Sleeping Beauty* is "the convincing example of Tchaikovsky's great creative power," and *The Nutcracker* in its theatre context has a narrative vividness much beyond the limited charm of the concert suite that Tchaikovsky arranged from it.

Adolphe Adam's contribution to the development of ballet music had its parallel in the sphere of romantic operetta. By incorporating a measure of frivolous vaudeville into the otherwise conventional comedy of *Le Châlet* (1834), Adam stimulated a popular taste for what became the mainstream of operetta. Its source was in Paris, and it flowed in turn principally to Vienna, to London and thence to North America, submerging the German singspiel and its Scandinavian offshoots but leaving the Spanish zarzuela to cultivate its own regional idiom.

Adam's enterprise in opening a theatre in 1847 to stage his own works and those of other young composers disdained by the operatic establishment in Paris was brought to a premature end by the political uprising a year later, but Offenbach was poised to take advantage of the subsequent situation. He opened his Bouffes-Parisiens theatre in 1855, whence travelled such immediate hits as *Orpheus in the Underworld, La Belle Hélène, La Grande-Duchesse de Gérolstein,* and *La Périchole* over almost all of Europe. The Parisian operetta was principally continued to the end of the century by Charles Lecocq and André Messager.

Offenbach's influence in Europe

Offenbach meanwhile had paid several visits to Vienna

from 1858, when Franz von Suppé was quick to turn the French model to local advantage, notably with *Die schöne Galatea* (1865; *The Beautiful Galatea*). The younger Johann Strauss was eventually persuaded to follow this trend by turning the Viennese craze for his waltzes, polkas, and other social dances to theatrical purpose. With the aid of an unusually good libretto, Strauss created the supreme example of Viennese operetta in *Die Fledermaus*. The Viennese tradition was continued in turn by Franz Lehár and Emmerich Kálmán.

Offenbach's influence extended southward to Bohemia, where the composer Bedřich Smetana compared his first song-and-dialogue version of *The Bartered Bride* (1866) to an Offenbach operetta, and Antonín Dvořák composed an outstanding but little-known example in *The Peasant a Rogue* (1878). Otherwise, no particularly distinguished composer of operetta emerged in southeastern Europe, nor in Poland or Russia, where there were only occasional contacts with forms of musical theatre other than full-scale opera and ballet for the moneyed classes.

The northward spread of the Offenbach model reached England, where it influenced the character of Sullivan's first operetta, *Cox and Box* (1867). It led in due course to the success of *H.M.S. Pinafore* (1878), in collaboration with Gilbert, and the subsequent line of "Savoy operettas" (their collective nickname derived from the London theatre where they were first performed by the D'Oyly Carte Opera Company, Ltd.). England made no other contributions of comparable musical interest to the operetta repertory until it was overtaken in due course by the trend to musical comedy in the 20th century.

English operetta represented by Gilbert and Sullivan nevertheless put down fresh roots in North America after the D'Oyly Carte company first travelled there in 1879, in the wake of a pirated version of *H.M.S. Pinafore*. The impact of Sullivan's music in New York and Boston was comparable to that of Offenbach in Vienna. Instead of stimulating an American equivalent, it first opened the way to 20 years or so of European imports to the American stage. The composers Reginald De Koven and Victor Herbert later established a short-lived local counterpart to European operetta, before it was overtaken by the indigenous idiom of American musical theatre noted earlier.

The language of ragtime and early jazz, with its rhythmic syncopation and varying degrees of harmonic innovation within a common musical vernacular, brought the first new element to the idiom of musical theatre (in musical comedy) since the emergence of national folk characteristics in 19th-century Europe. As the trends already described succeeded one another during the 20th century, in and out of fashion, and the musical theatre tried to reconcile the nostalgia for its past heritage with the need to experiment in search of a viable future, the immediate present can be seen to represent only one turn of a larger wheel across seven or eight centuries. The religious rock musical of the contemporary musical scene is but a variant of the mysteries and miracle plays that initiated all our modern forms of musical theatre when Western civilization first groped its way out of the Dark Ages.

(N.Go.)

Opera

The English word opera is an abbreviation of the Italian phrase *opera in musica* ("work in music"). It names a theatrical form consisting of a dramatic text (libretto, or "little book") combined with music, usually singing with instrumental accompaniment. Besides solo, ensemble, and choral singers and a group of instrumentalists, the forces performing opera since its inception have often included dancers. A complex, often costly variety of musicodramatic entertainment, opera has attracted audiences for nearly five centuries. Although its supporters have greatly outnumbered its detractors, it has been the target of intense adverse criticism.

Charles de Saint-Évremond, a French man of letters in the 17th century, called it "a bizarre thing consisting of poetry in music, in which the poet and the composer, equally standing in each other's way, go to endless trouble to produce a wretched result." The 18th-century English statesman and writer Lord Chesterfield wrote to his son: "As for operas, they are essentially too absurd and extravagant to mention. I look upon them as a magic scene contrived to please the eyes and the ears at the expense of the understanding." At the opposite extreme of reaction to opera, it has been said that the mere existence of such a masterpiece as Mozart's *Le nozze di Figaro* (*The Marriage of Figaro*) suffices to justify Western civilization.

The unique characteristics of opera

Although the characteristic of opera that most clearly separates it from other theatrical forms is that its principals sing rather than speak their lines, to approach it or criticize it as simply one variety of the musical art is to misjudge it. Its multiple creators almost always have intended an opera to be a lofty and eloquent form of theatrical performance. What commonly differentiates it from other varieties of musicodramatic theatre such as operetta (literally "small opera") and musical comedy is sobriety of workmanship, density of texture, and (even in operas with comic and farcical librettos) accompanying seriousness of musical tone. On the other hand, some lighter works—by Jacques Offenbach, Johann Strauss the Younger, Gilbert and Sullivan, Kurt Weill, George Gershwin, and a few others—make neat categorization impossible.

In the preparation of an opera performance, many individual artists and artisans, sometimes spread out across a century and more, necessarily are or have been involved. The first, unintentional recruit is likely to have been the writer of the original story. Then comes the librettist, who puts the story or play into a form suitable for musical setting and singing, and the composer, who sets that libretto to music. Architects and acousticians have built an opera house suited or adaptable to performances that demand a sizable stage, a pit to house an ensemble of instrumentalists, and a reasonably large audience. A producer-director has to specify the work of designers, scene painters, costumers, and lighting experts. The producer, conductor, and musical staff have to work for long periods with chorus, dancers, orchestra, and extras as well as the principal singers to prepare the performance—work that may last anywhere from a few days to many months. All this does not even take into account the part played by the administrative staff.

Once the complete operatic score—the final libretto and music—is available, what must rule all of those involved is dedication to fulfilling the wishes of the librettist and the composer. Overemphasis or underemphasis of any larger component of an operatic performance can be as damaging to it as off-pitch singing or false entries by instrumentalists. More than one desirable balance among the constituents of performance is often possible. What is certain is that one or another of them must be decided upon, worked toward, and achieved.

THE EARLY HISTORY

Italian origins. Works in antiquity had combined poetic drama and music. The plays of the ancient Greek dramatists Aeschylus, Sophocles, and Euripides employed choral music in a manner that certainly reflected related usages in earlier times. During the Middle Ages, biblical dramas were commonly accompanied by some music, being known under various labels, including mystery and miracle plays. These and other related musicodramatic forms may or may not have become collateral ancestors of opera: their descent seems most certain in some 17th-century operas on religious subjects performed in Rome and at several places in Germany. Musical historians and musicologists continue to debate opera's ancestry. The earliest universally accepted direct ancestors of opera appeared in 16th-century Italy. Purely nonreligious works of edifying drama with music, they included intermezzos and *intermedii* played between the acts of spoken dramas, with which their purported subject matter often claimed a tenuous connection, and staged ballet. The latter, Italian by birth, achieved a complex, quasi-operatic state in the court ballet (*ballet de cour*) danced in France late in the 16th century and throughout the 17th: it approached ever closer to opera in the *comédie-ballet* evolved by Molière and Jean-Baptiste Lully in the 1660s, beginning with *Le*

Mariage forcé (*The Enforced Marriage,* first performed 1664).

Musicians, singers, poets, playwrights, and enthusiasts of the literary, musical, and theatrical arts had long cherished a desire for some more formally constituted and more stable form of drama with music, especially in Italy. One response to that expressed desire was the 16th-century "madrigal comedy," the singing of dramatic or semidramatic lines (often farcical, and most often with story and characters borrowed from the traditional commedia dell'arte as it had become formalized during the 16th century) in a linked series of more or less discrete madrigals and other varieties of polyphonic song.

16th-century "madrigal comedy"

But polyphony—the musical texture created by simultaneous, largely unaccompanied singing of interwoven melodies—was by nature alien to theatrical drama: it made extremely difficult, when not impossible, the delineation of individual characters through clearly understandable text words. This is noticeable even in the most celebrated of the madrigal comedies, Orazio Vecchi's paean to the "double Parnassus" of poetry and music, *L'Amfiparnaso* (Modena, 1594).

The gestation of opera required the simultaneous availability of a dramatic literary style and a musical texture suitable for incorporation into a new theatrical unity. The essential literary materials had begun to appear in Italy in such chivalresque epics as Lodovico Ariosto's *Orlando furioso* (published complete in 1532) and Torquato Tasso's *Gerusalemme liberata* (1575), both of which were to be mined for subjects by innumerable opera librettists. More immediately decisive in setting the first direction of opera was one sort of poetic drama: the shorter pastoral writings of 16th-century Italian poets, notably Tasso's *Aminta* (1573) and Giovanni Battista Guarini's *Pastor fido* (*The Faithful Shepherd,* completed in 1590). Idylls or eclogues that had sprung up in the 15th century, like the *Orfeo* of the Italian poet Poliziano (Politian) with music by Germi (one of the earliest examples, which was staged at Mantua in 1472, with solo song, chorus, and spoken dialogue), were seized on, adapted, and imitated by the men who had begun to evolve the musical texture essential to the birth of opera and who found apt subjects in the loves, joys, and sorrows of Arcadian shepherds and shepherdesses, often with the intervention of gods, demigods, and heroes.

Until the 1950s it was generally accepted that opera originated with a *camerata* (a sort of humanistic discussion group) that met in the late 1570s and early 1580s in the Florentine palace of Giovanni Bardi, count of Vernio. In 1953, however, the Roman musicologist Nino Pirrotta showed that the Bardi Camerata, far from having furthered innovation or interested itself in musical drama, was predominantly conservative, often acted in defense of the polyphonic madrigal, and showed no sympathy with the new combinations that would shortly produce opera. In fact, that literary-musical texture was evolved at Florence, but largely among a group of intellectuals, artists, and dilettantes who met informally in the palace of the theatrical theoretician Jacopo Corsi during the 1590s. This latter group also included Emilio del Cavaliere, the composer, impresario, and choreographer who was to write what is often called the first oratorio, *La rappresentazione di anima e di corpo* (*The Representation of Soul and Body,* an acted form unlike later oratorios); the singer-composer Jacopo Peri; and—although they attended infrequently—both the poet Tasso and the composer Claudio Monteverdi. Still active at the time, though a little out of favour, was the singer-composer Giulio Caccini. Corsi and his friends were by no means the first creators of solo vocal lines with instrumental accompaniment, and they shaped their musicotheatrical creations partly in the mistaken belief that their performances were reviving ancient Greek procedures. What, in fact, they did was to take hints from the French court ballet and simultaneously discard polyphony in favour of monody (or homophony)—accompanied singing or recitation on musical tones (recitativo) of one melody at a time. Thus, they insured both the relative comprehensibility of the words (which to them seemed much more important than the accompanying music) and the use of at least some instrumental support.

Florentines who "created" opera

An important "manifesto" of the monodic innovators was a collection of short vocal pieces with thorough-bass accompaniment (instrumental chords in sequence as accompaniment to melody) by Caccini, published in 1602: *Le nuove musiche,* a title that often has been extended to cover the novel musical texture itself. The interaction of these and other Italians with the texture of monody was what finally led, after some false starts, to the emergence not only of opera more or less as it is known today but also of the cantata and the oratorio.

The honour of being deemed "the first opera" usually is given to a setting by Peri of *Dafne* by the Renaissance pastoral poet Ottavio Rinuccini. It was staged at the Palazzo Corsi in Florence during the pre-Lenten Carnival of 1597–98. The text, divided into a prologue and six scenes, was published in 1600 and therefore survives, but neither Peri's music (the prologue and one aria excepted) nor that of an almost contemporary setting of the same text by Caccini can now be recovered. The earliest surviving opera is also Peri's: a setting of Rinuccini's pastoral *Euridice,* likewise in a prologue and six scenes, which was performed at the Palazzo Pitti in Florence on October 6, 1600. More unusual, the musical score also was issued in 1601 and reprinted several times thereafter.

However significant historically, the pioneering operas of Peri and Caccini were tentative in both style and structure; further, neither of the founding fathers of opera seems to have possessed notable dramatic talent.

Within 10 years of the premiere of Peri's *Dafne* at Florence, Mantua heard an opera that is a masterpiece and still is staged frequently. This was *La favola d'Orfeo* (*The Fable of Orpheus*), a setting by Monteverdi of a poetic text by Alessandro Striggio the Younger. Presented during the Carnival of 1607 (the libretto was published then, the score in 1609), it soon was presented elsewhere in Italy. In *Orfeo,* the accompanying instruments come into their own as a dramatic element: the score contains more than two dozen pieces for increased (though not precisely determinable) numbers of instruments. It not only introduces, as a preluding toccata, the idea of the operatic overture but also achieves some sectional unity by repeating brief instrumental numbers (ritornellos). More important, Monteverdi uses recitative expressively and gives it an organizational function by repetitions and developments in predetermined patterns.

Monteverdi's *Orfeo*

Monteverdi continued to compose operas for more than 35 years; meanwhile, the new manner of musicodramatic entertainment spread to other Italian cities. Rome probably first heard an opera as early as 1606, Bologna before 1610. Continuing to employ librettos based on Italian interpretations of Greek and Roman myth, legend, and pseudo-history, literary men and composers rapidly swelled the number of operas heard. At Venice in 1642, the 75-year-old Monteverdi created his masterpiece *L'incoronazione di Poppea* (*The Coronation of Poppea*). Gian Francesco Busenello's superior libretto carried a new note of realism into opera, particularly in the development of human character; it was to have a prolonged, important line of descent, and Monteverdi translated it blazingly into music. Throughout that first period of operatic history, the importance given by composers to emotional drama, to instrumental music, and to structural stability increased along with the capabilities (and pretensions) of singers and the magnificence and complexity of stage settings, stage machinery, and costuming.

The first opera house

The inauguration early in 1637 of the first opera house open to the general public, the Tron family's Teatro di San Cassiano at Venice, was another decisive factor in establishing opera. That action removed opera from the exclusive hands of royalty and nobility and placed it within reach of all but the poorest sectors of the Italian urban population.

A pupil of Monteverdi, Pier Francesco Caletti-Bruni, known as Francesco Cavalli (1602–76), became the most popular opera composer of his era by furnishing the opera houses of Venice with some 40 operas between 1639 and 1669. A highly talented but not always fastidious composer, Cavalli reacted to the librettos he used with dramatic force and directness. The most renowned of his

operas was *Giasone* (*Jason,* 1649), whose libretto by Giacinto Andrea Cocignini included farcical episodes. His chief Venetian rival and successor was Pietro Antonio (often called Marc' Antonio) Cesti (1623–69), about a dozen of whose nearly 100 operas have survived. Some notion of the extravagance to which imitation of Louis XIV's spectacles at Versailles had driven the production of opera elsewhere can be gained from descriptions of the Cesti opera *Il pomo d'oro* (*The Golden Apple,* 1667), composed for the wedding of Emperor Leopold I and Margarita Teresa of Spain in Vienna. Constructed in a prologue and five acts (the third and fifth of which have been lost), with 48 characters, it contained 66 scenes requiring 24 stage settings making use of complex stage machinery. Ballets occurred in every act, and a grand triple ballet brought the opera to its conclusion. *Il pomo d'oro* provided numerous purely instrumental introductions and interludes, gave relatively little importance to the chorus, skipped rapidly over the essential storytelling recitative, and concentrated on arias and duets that often were most sensuous and almost feminine in allure.

Opera in Venice and Rome

Venetian opera continued to flourish in the works of such greatly talented theatrical composers as Cavalli, Cesti, and Giovanni Legrenzi (1626–90). In some details, these Venetian operas reflected the pressures exerted by the tastes and wishes of the paying audiences for which they were designed. Not so lavish with choral interpolations as their Roman contemporaries, the Venetians demanded and received complex, strong librettos calling for large casts and special lavishness in staging. They also began to develop the sensuous melodic profiles that have come to be thought of as particularly "Italian." Furthermore, they all but separated the solo aria from the surrounding recitative. They also frequently prefaced and followed solos with purely instrumental music, so continuing the orchestra's elevation from a purely accompanying role. After the middle of the 17th century, the Venetian operatic style began to decline. Among the later Venetian operatic composers of talent and fame were Antonio Lotti (*c.* 1667–1740), Carlo Francesco Pollaroli (1653–1722), Antonio Vivaldi (*c.* 1678–1741), and Baldassare Galuppi (1706–85), who is often referred to somewhat loosely as "the father of opera buffa."

Several Italian cities soon developed recognizably indigenous operatic styles. At Rome, for example, a group of composers tended toward unified structure, gave ensemble and choral song expanded roles, and increased the difference between the solo (aria) and the Florentine type of continuous recitative by allowing arias to interrupt dramatic progress in order to express or comment upon emotional moods. Less emphatic about stage magnificence than their Venetian counterparts, such Roman composers as Stefano Landi (*c.* 1590–*c.* 1655), Domenico Mazzocchi (1592–1655), Luigi Rossi (1597–1653), and Michelangelo Rossi (1600?–70) also permitted comic episodes to lighten prevailingly tragic stories. They concentrated attention productively on instrumental overtures and on overture-like pieces preceding acts or sections of acts. Two Roman composers—Domenico Mazzocchi's brother Virgilio (1597–1646) and Marco Marazzoli (1619–62)—often are cited as having created the first completely comic opera, *Chi soffe speri* (*He Who Suffers, Hopes,* 1639). Its libretto was written by Cardinal Giulio Rospigliosi, who was to be elevated to the papacy in 1667 as Clement IX. The invited guests at its first performance, in the Palazzo Barberini, included the English poet John Milton and Giulio Mazarini, the future Cardinal Mazarin, statesman to Louis XIV.

Contributions of Zeno and Metastasio

With the 18th century the centre of Italian opera shifted to Naples, where so great a variety of styles evolved that the term Neapolitan opera eventually covered operas that dominated most of Italy and many foreign centres of operatic activity. With some exceptions, the earliest unmistakably Neapolitan operas changed their focus back from the music to the words. Two of its instigators were dramatic poets: Apostolo Zeno (1668–1750), born a Venetian, and the Roman Pietro Trapassi, known as Metastasio (1698–1782)—perhaps the greatest of the 18th-century librettists. Continuing the custom of basing librettos on Greco-Roman legend and pseudo-history (but dispensing almost entirely with classical mythology), Zeno and Metastasio wrote texts of formal beauty and linguistic clarity, preferring solemn, usually tragic subjects (opera seria) in three acts to comic episodes and characters. The aria came to dominate, and the use of chorus declined.

The term Neapolitan opera also came to indicate harmonically naïve, melodious lighter operas in the gallant tone of the Rococo style; the rich development of the bel canto styles (where beautiful singing *per se* was predominant), signifying supreme vocal agility and smoothness that was supplied first by castratos, men who had been castrated before puberty in order to preserve the high ranges of their boyish voices; and the appearance of the *centone* or pasticcio, a libretto set to a score made up of music borrowed either from scores (then uncopyrighted or otherwise legally protected) of several composers or from several operas by a single composer. The use of the orchestra also became limited. But perhaps the most discussed, and often senselessly maligned, feature that particularly designated Neapolitan opera was the aria da capo, an aria in three sections, the third part repeating the first. It had appeared in northern Italy early in the 17th century but was employed with comparative infrequency there. Some Neapolitan operas, however, consisted of up to 20 da capo arias separated by a minimum of story-advancing recitativo secco (narrative passages in which voice is accompanied only by a thorough bass).

Domination of the aria da capo

A masterly operatic composer of the transitional style who bridged the era between the Baroque and the pre-Classical Neapolitan style was Alessandro Scarlatti (1660–1725). In his many operas Scarlatti triumphed, by the strength of musical imagination, over librettos intended to provide vehicles for phenomenally trained singers in the prevailing pattern and the consequent reduction of dramatic interest to a narrow minimum. Talented and influential among Scarlatti's contemporaries were such composers as Nicola Antonio Porpora (1686–1768), Leonardo Vinci (1690–1730), and Leonardo Leo (1694–1744).

In 1720 the Venetian composer-poet-statesman Benedetto Marcello (1686–1739) published a mordant satire on the increasingly rigid and undramatic conventions that had taken hold of opera seria: *Il teatro alla moda, o sia metodo sicuro e facile per ben comporre ed eseguire opere italiane in musica* ("The Theater à la Mode, or The Secure and Easy Method of Composing and Performing Italian Operas"). The distress that it and other criticisms brought resulted in an improved genre, still in effect opera seria but showing attempts at reform of its mannerisms. The principal operas against which that reform later evolved were the often melodically seductive works of Gaetano Latilla (1711–88), Giuseppe Sarti (1729–1802), Antonio Sacchini (1730–86), Johann Christian Bach (1735–82), Antonio Salieri (1750–1825), and Mozart's *Idomeneo, rè di Creta* (1781) and *La clemenza di Tito* (*The Clemency of Titus,* 1791). Representative composers within the short "reform" movement itself were Niccolò Jommelli (1714–74) and Tommaso Traetta (1727–79). A more intellectually rigorous reformation was undertaken consciously by Christoph Willibald Gluck in collaboration with the librettist Ranieri de' Calzabigi, beginning with *Orfeo ed Euridice* (1762).

Comic opera. Comic opera meanwhile had expanded from its shadowy existence within and between the acts of opera seria. From the early, tentative efforts of several 17th-century Roman and Florentine composers, it had moved into a bustling, rude, independent vitality of its own, often in the form of satirical opera buffa (Italian: "comic opera"), generally shaped in two acts rather than the usual three of opera seria. Expelled from the precincts of opera seria by the librettos of Zeno and Metastasio, the comic spirit had taken refuge in such an expanded intermezzo as *La serva padrona* (*The Maid Mistress,* 1733), by Giovanni Battista Pergolesi. When it matured, the style borrowed back some of the more serious emotional qualities of opera seria, often including "serious" roles among those of the comedians. This led to a hybrid nature in many operas, including two works using librettos derived from the plays of Pierre de Beaumarchais—*Il barbiere di Siviglia* (*The Barber of Seville,* 1782), by Giovanni

Paisiello, and Mozart's *Le nozze di Figaro* (1786)—as well as *Il matrimonio segreto* (*The Secret Marriage,* 1792), by Domenico Cimarosa.

One of the determining characteristics of this mixed style was the elaboration of ensemble numbers concluding acts. These operas dispensed almost entirely with the magnificent display and grandeur of staging increasingly required of opera seria. Another of the drawbacks of the mixed style was well summed up by the 20th-century Italian musicologist Andrea Della Corte:

> With few exceptions among the great composers dedicated to instrumental music or to teaching, almost all the serious composers also collaborated in the comic theatre. Not so the literary men. The best dramatists were not equally tempted by this tendency.

The natural result was that the large majority of opera buffa librettos remained inferior to the serious texts by Metastasio and his imitators and successors, though not necessarily less workable in their own way.

Early opera in France. Opera was imported into France from Italy before 1650, but it long failed to take firm hold there with royal and other audiences, at first having to compete on unequal terms with the spoken drama (often with musical interludes) and the ballet. The *Pomone* (1671) of Robert Cambert, to a pastoral libretto by Pierre Perrin, is commonly called the first French opera. Its premiere almost certainly inaugurated the Académie Royale de Musique (now the Paris Académie de Musique or Paris Opéra) on March 3, 1671. Only fragments of the music of *Pomone* still exist.

Lully's important role

Opera really did not become a French art until the time of Jean-Baptiste Lully (1632–87). This highly talented, very shrewd, and dictatorial man borrowed freely from both the spoken French drama and the court ballet. Though himself an Italian, he played down the extended, formalized Italian aria in favour of shorter, more instantly captivating "airs." He formed recitative after the declamatory manner of the Comédie-Française theatre company and also evolved the "French overture" (one movement with a slow and a fast section) as distinct from the "Italian overture" (one movement with a fast, slow, and another fast section). His operas and those of his imitators and followers assigned great importance to dancing, choruses, instrumental interludes, and a dazzlingly complex stage setting. Lully became the virtual dictator of music in France partly because of the strengths of his literary collaborators: first the dramatist Molière (1662–73) in *comédie-ballet,* then the exceedingly able librettist Philippe Quinault (1635–88).

The pervasive Lullyan style, altered surprisingly little except in the direction of still more imposing grandeur, attained its culmination in the magnificent operas of Jean-Philippe Rameau (1683–1764), especially in his *Hippolyte et Aricie* (1733; libretto by Simon-Joseph de Pellegrin), *Les Indes galantes* (*The Courtly Indies,* 1735; libretto by Louis Fuzelier), and particularly *Castor et Pollux* (1737; libretto by Pierre-Joseph-Justin Bernard), which was performed at the Paris Opéra 254 times in 48 years. Except for the special instance of *Les Indes galantes,* which was billed as a *ballet héroïque,* Rameau's chief operas were each divided into a prologue and five acts, a pattern that many later French composers favoured. Rameau confirmed the still-enduring insistence of French operatic composers on setting their language to music with such probity and clarity that it can be understood properly when sung. His operatic works are regarded widely as the apogee of 18th-century French opera.

Early opera in Germany and Austria. Although Heinrich Schütz composed *Dafne,* the first known opera with a German text, and heard it played at Torgau on April 23, 1627, the active history of opera in Germany began with the Italian composers residing there. A remarkable Venetian composer-diplomatist-ecclesiastic, the Abbé Agostino Steffani, carried much of his native city's early operatic manner to Munich, Hanover, and other German centres, beginning his operatic production with *Marco Aurelio* (Munich, 1681), and continued thereafter to compose operas for 28 years. In his use of both Italian and French procedures, particularly in handling overture and recitative, Steffani evolved a sort of international Italian style that clearly influenced other "transplanted" composers.

For the next 100 years the influence of Italian opera was so pervasive that even native German composers adopted the Italian operatic style and used texts in Italian.

The German word *Singspiel* was originally used for all sorts of opera. The earliest known entertainments so designated were composed by a pupil of Heinrich Schütz, Johann Theile (1646–1724). One of them, *Adam und Eva,* eminently "serious" as to story, inaugurated the Hamburg Opera in 1678. During the mid-18th century the term singspiel came to be reserved for what the English called "ballad opera," the French *opéra-comique* light, usually comic operas including spoken dialogue. The comic singspiel of the 18th century was born with *The Devil to Pay* (London, 1731) and its sequel, *The Merry Cobbler* (London, 1735), English ballad operas with texts by Charles Coffey. These had pasticcio scores capitalizing, not very successfully, on the great popularity of *The Beggar's Opera* (1728), which had a text by John Gay and an assembled (pasticcio) score brought together by John Christopher Pepusch. The Coffey texts having been translated into German, scores were composed to them by J.C. Standfuss (died 1759?) as *Der Teufel ist los* (Leipzig, 1752) and *Der lustige Schuster* (Lübeck, 1759); they later were restaged as arranged by Johann Adam Hiller (1728–1804), who also composed several other singspiels and brought to culmination the so-called Leipzig School. Both Berlin and Vienna inevitably took up the singspiel, examples of which, composed in those cities and elsewhere, included *Der neue krumme Teufel* (Vienna, 1752, music lost), by Joseph Haydn; Mozart's *Die Entführung aus dem Serail* (*The Abduction from the Seraglio,* Vienna, 1782) and *Die Zauberflöte* (*The Magic Flute,* Vienna, 1791); *Doktor und Apotheker* (Vienna, 1786), by Karl Ditters von Dittersdorf; Beethoven's *Fidelio* (Vienna, 1805), which, like *Die Zauberflöte,* immeasurably transcends the common artistic scope of the singspiel; and *Die Zwillingsbrüder* (*The Twin Brothers,* Vienna, 1820), by Schubert.

Popularity of *The Beggar's Opera*

The most important opere serie composed in Germany during the early 18th century were created for the Hamburg Opera, at which both Reinhard Keiser (1674–1739) and, for a brief interval, the young George Frideric Handel worked. Keiser composed more than 125 operas, mostly to German texts. Of Handel's large operatic output, only two works with Italian texts—*Almira* and *Nero* (both 1705, the second now lost)—were staged during his Hamburg stay. Keiser doggedly tried to attract the widest possible public. His operas often succeeded in charming audiences, but most of them have vanished, and those that survive appear to possess only superficial allure, although they are historically of interest for their skillful exploitation of the orchestra and of solo instruments tellingly used during arias.

Handel went from Italy to England in 1710. In London, with the opera *Rinaldo* (1711), he began 30 years of stubborn dedication to the by then moribund (but still dominant) traditions of Neapolitan opera seria. He created, however, a dozen or more of the most inspired operas of the first half of the century, including *Giulio Cesare* (*Julius Caesar,* 1724), *Tamerlano* (1724), *Rodelinda* (1725), *Sosarme* (1732), *Orlando* (1733), *Ariodante* (1735), and *Alcina* (1735). Handel transcended the formal style of opera seria by his melodic inspiration and harmonic daring. He even managed an immense variety of characterization within the cramped style with which he had to comply.

Handel's operatic style

German by birth, but almost wholly Italianate by disposition, Johann Adolph Hasse (1699–1783) successfully carried on the Metastasian traditions of opera seria in a plethora of operas to Italian texts. The intensely Italian sensuousness of his best melodies, supported by some attractive adventurousness in harmonic placement and in instrumentation, did almost as much as Handel's operas to prolong past its true prime the glory of the Neapolitan style.

FROM THE "REFORM" TO GRAND OPERA

The "reform." Christoph Willibald Gluck (1714–87) has become an ambivalent figure in the evolution of opera:

he has been loosely and often incorrectly categorized, and both praised and condemned, for mistaken reasons. His operas to Italian texts that he composed up to about 1756 were conventional settings of Metastasian librettos. After settling in Vienna in 1750, though not abandoning the composition of traditional opere serie in Italian, Gluck began to react to the French operatic styles popular there. At first he merely added a few new numbers to trivial one-act opéras-comiques brought to Vienna from Paris, which he arranged and conducted for the court at Schönbrunn and Laxenburg. Then he began to compose similar operas in French.

Thanks to the enthusiasm of the superintendent of the imperial Vienna theatres, Conte Giacomo Durazzo, Gluck had been absorbing the example of the outstanding French dancer-choreographer Jean-Georges Noverre (1727–1810). Seminal in Noverre's call for reform was the insistence that a ballet should not be left as a simple collection of unconnected episodes but should be shaped into a mimed dance drama. Gluck then composed the ballet *Don Juan* (1761), the earliest of his scores to place him among the great composers. In the same year a very talented poet-librettist-adventurer, Ranieri Calzabigi, reached Vienna from Paris. Falling in with the anti-Metastasian intellectuals spearheaded by Durazzo, Calzabigi thereafter brought his acquaintance with Rameau's stately operas to the writing of three librettos for Gluck, for whose signature he also drew up the renowned preface to the publication of the Calzabigi–Gluck *Alceste* in 1769. That dedication is the central document of "operatic reform," summing up one side of the unending debate between supporters of the primacy of the opera libretto and supporters of the primacy of the music. The *Alceste* preface emphasized that superfluous, florid da capo arias were to be dispensed with: simplicity of expression and emotional truth were to take their place.

The influence of *Alceste*

Although some of the most accomplished composers of opera certainly would not have agreed that, as Calzabigi–Gluck stated, the "true office" of music is "serving poetry," and though a strict obedience to all the precepts of the *Alceste* dedication would have impoverished much of the richest operatic music (Gluck himself did not follow them with iron strictness), the pronouncement unquestionably summoned opera back temporarily to its best condition: as musicotheatrical drama. The most obvious, as well as the greatest, results of the attitudes it expressed were the magnificent Calzabigi–Gluck operas first staged in Vienna: *Orfeo ed Euridice* (1762), *Alceste* (1767), and *Paride ed Elena* (*Paris and Helen,* 1770). The two earliest of these became even more stately and Rameau-like when Gluck reconstituted them to French librettos for Parisian audiences.

A little below *Orphée* and the French *Alceste* in austere dramatic force stands the somewhat mixed, only partially "reformed" *Armide* (Paris, 1777). But Gluck was to produce his best results in *Iphigénie en Aulide* (*Iphigenia in Aulis,* 1774; libretto adapted from Racine's tragedy by Bailli du Roullet) and in his masterpiece, *Iphigénie en Tauride* (*Iphigenia in Tauris,* 1779; libretto adapted from Euripides by Nicholas-François Guillard).

Gluck's extraordinary power at his best derives from a reasonable, pliable adherence to the precepts of the *Alceste* dedication; a lean sparseness of means, particularly of harmonic density, with the result that the smallest shifts arrive with great power; and the ability to make the most of the dramatic strengths of the often excellent librettos he used. Yet Gluck did not really "reform" opera, for opera is an incorrigible art form. Its mood and manners shift with changes in society, dramaturgy, techniques of composition, and taste.

Followers and imitators of the Gluck reform

Gluck had some immediate followers and imitators, notably Antonio Salieri, who gave lessons to Beethoven, Schubert, and Liszt, was friendly with both Haydn and Rossini, and was ridiculously accused of having poisoned Mozart. Another, belated, Gluckian was Gluck's onetime "rival" in a Parisian polemic "war," Niccolò Piccinni (1728–1800), whose masterpiece, *Didon* (*Dido,* 1783; libretto by Jean-François Marmontel, Fontainbleau), joined a peculiarly Italianate melodiousness to Rameau-like solemnity and the massive simplicities of Gluck's style. Finally, there was Antonio Sacchini, remembered chiefly for his *Oedipe à Colone* (*Oedipus at Colonus,* 1786; libretto by Nicolas-François Guillard). On the highest level, however, the Gluckian "reform" produced only his own masterpieces, although it led indirectly to certain of the "international," though very French, operas of Gasparo Spontini (1774–1851), particularly *La Vestale* (*The Vestal Virgin;* Paris, 1807), and Luigi Cherubini, particularly *Médée* (1797). In part, Gluck also influenced the vast masterwork of Hector Berlioz, *Les Troyens* (*The Trojans,* composed 1856–58).

Opera in England. Just as immediate acceptance of opera had been made difficult in France by the entrenched ballet and the 17th-century drama of Jean Racine and Pierre Corneille, so it was delayed in England by the court masque, an aristocratic 16th- and 17th-century entertainment derived largely from ballet. Most often dealing with allegorical and mythical subjects, the masque mixed poetic text, instrumental and vocal music, dancing, and acting. The most familiar masque is *Comus* (text by John Milton and music by Henry Lawes), which was staged at Ludlow Castle in 1634. Many other embryonic operas were produced in the middle decades of the 17th century, often being more like plays with incidental music. The first (and, in the view of many, still the finest) English opera, *Dido and Aeneas,* by Henry Purcell (*c.* 1659–95), was originally sung about 1689 by the pupils at a girls' school in London. This musical masterpiece, with libretto by a future poet laureate, Nahum Tate, contains the earliest operatic aria (apart from "Lasciatemi morire" from Monteverdi's *Arianna*) still frequently heard: Dido's lament "When I am laid in earth." In this opera, Purcell succeeded in writing a real, albeit brief, music drama, breaking down the formal barriers between recitative and song.

The first English opera

England, however, was not ready for opera. Although later Purcell works, including *The Fairy Queen* (1692), *The Indian Queen,* and *King Arthur* (1691), have been called operas, they were actually suites of incidental music for plays. No other composer in England of Purcell's genius turned his attention to opera, and before many decades had passed after the scarcely noticed performance of *Dido and Aeneas,* the rage for Italian opera (particularly when the singers included a good castrato) barred that road to English composers. The arrival of Handel from Italy in 1710 decided the direction of opera in London for many decades. Beginning in 1711 with *Rinaldo* (libretto by Giacomo Rossi, indirectly derived from Tasso's epic *Gerusalemme liberata*) and continuing intermittently until *Deidamia* (libretto by Paolo Rolli) in 1741, Handel provided English audiences with his own remarkable variant of Neapolitan opera seria, acting as both composer and, most often, impresario. The greatest composer of opera in his age, Handel eventually outlasted his popularity in London's opera houses and turned to the creation of a magnificent series of oratorios set to English texts. His operatic reign was challenged at its height only by a faction that set up the very gifted Modenese composer Giovanni Bononcini in an unequal battle against him. Handel's operas all but vanished from the repertory in the 19th century, but after a burst of German interest in them in the 1920s, they began to be increasingly revived by some major opera houses, smaller opera companies, students, musicologists, and recording companies.

An event that contributed to the defeat of Handel as an opera impresario was the London production in 1728 of *The Beggar's Opera.* That bawdy, rollicking satire in English became phenomenally popular and spawned a family of imitations that finally accustomed audiences in London and elsewhere in the British Isles to hearing a staged play sung in the vernacular.

Viennese masters. Italian opera buffa strongly attracted Viennese audiences, and Austrian composers were naturally influenced by it. Perhaps the most interesting of the Vienna-born composers of 18th-century comic opera was Karl Ditters von Dittersdorf, whose Italianate *Doktor und Apotheker* (1786; libretto by Gottlieb Stephanie), though successful and lively, was overshadowed by the contemporary works of Mozart.

Haydn, who lacked a strong theatrical bent, nonetheless

composed about 20 musicodramatic scores: a singspiel, five short operas for marionettes, and several very Italianate opere buffe and opere serie for private performance in the Eisenstadt palace theatre of his employer-patrons, the Esterhazy princes. Several of Haydn's dramatically undistinguished operas have had modern revivals, including *Il mondo della luna* (*The World on the Moon,* 1777; libretto by Carlo Goldoni), *L'isola disabitata* (*The Deserted Island,* 1779; libretto by Metastasio), and *La fedeltà premiata* (*Faithfulness Rewarded,* 1780; libretto by Giovanni Battista Lorenzi).

Vienna, however, was to be one of the centres of the operatic career of Mozart, one of the greatest masters of opera. Mozart began to write theatrical music when only 10 years old and brought out the first of his important operas at Munich in 1781, when only 25. This was *Idomeneo.* Its libretto, by Giambattista Varesco, is an imitation of Metastasio's style. But Mozart rose above the conventional operatic patterns and filled them with richly expressive music so that the result is scarcely recognizable as an opera seria. As a work of musical (though not of dramatic) art, *Idomeneo* is as fine as Gluck's *Iphigénie en Tauride* and ranks as the supreme Italian opera seria of the late 18th century.

One year after *Idomeneo,* Mozart, with the versatility of his unique genius, wrote a masterly, charming singspiel to a German text: *Die Entführung aus dem Serail* (libretto by Christoph Friedrich Bretzner as edited by Gottlieb Stephanie). A sentimental farce full of immediately attractive music and graced with a fine part for a comic bass (Osmin), *Die Entführung* also contains in "Martern aller Arten," a soprano aria so extensive in plan and difficult to sing that it has challenged the foremost sopranos down to the present. The opera has been called the greatest of all truly comic singspiele, and it is notable for the seriousness with which it treats the relationship between its two principal characters and for the human nobility of its "moral."

Mozart's next completed opera—except for *Der Schauspieldirektor* (*The Impresario,* 1786), a trifling one-act comedy—is one of the treasures of Western civilization, the greatest of all seriocomic operas, *Le nozze di Figaro* (libretto by Lorenzo da Ponte, after Pierre de Beaumarchais's *Le Mariage de Figaro,* 1786), produced at Vienna. In addition to its purely musical beauty, this work shows Mozart to be a creator of individual characters of almost Shakespearean calibre; he goes far beyond the opportunities offered by his able librettist and creates, by musical means, believable, rounded human beings, often employed in ensembles as well as in solos and in elaborately constructed finales.

Production of *Figaro* at Vienna

In 1787 Mozart's next opera, written for Prague, was *Don Giovanni* (libretto by da Ponte, based on earlier Don Juan librettos and other writings related to plays by Tirso de Molina, Thomas Corneille, and others). The 19th century tended to regard *Don Giovanni* as the greatest opera ever composed, in part because musical elements in it foretold operatic romanticism. Aspects of da Ponte's libretto disturb some 20th-century critics—particularly the grim, morally justifiable ending of what up to then has been a comedy, followed by the "vaudeville" postlude, during which the singers step out of character to underline the "moral," in line with a then long-established convention. Musically, *Don Giovanni* shares many of the supreme virtues of *Le nozze di Figaro,* in beauty, in characterization, and in dramatic power.

In his last collaboration with Da Ponte, Mozart created another opera buffa, *Così fan tutte* (1790). Most musical opinion today considers it to be an opera of flawless workmanship reconciled with the dramatic claims of a seemingly artificial and cynical libretto, which in fact exposes the foibles of mankind. Farcical productions too often destroy its knife-edge balance between artificiality and reality. Too richly scored, too erotic, and too intense for Viennese taste of the time, it was not a success with the easy-going Viennese, but it now ranks as one of Mozart's greatest stage works.

In 1791, returning to the singspiel in German, Mozart composed *Die Zauberflöte* (libretto by Emanuel Schikaneder), an allegorical and Masonic opera with a seemingly nonsensical but in fact elaborately significant libretto in strong contrast with *Così fan tutte*'s cynicism about women. Here, Mozart created some of the most radiantly beautiful music ever composed, assigning it lavishly to both the serious and the comic, both the admirable and the vicious characters. George Bernard Shaw once said that the two arias given to the benevolent Sarastro in *Die Zauberflöte* were the only music he knew that would not sound out of place in the mouth of God—and they are but two of many numbers in this opera that have helped to place Mozart's theatrical works, together with his concertos, at the very apex of his astonishing and endlessly varied output.

Also in 1791 Mozart composed, to a Metastasio libretto slightly revised, another outdated opera seria, *La clemenza di Tito.* Created in 18 days for festivities surrounding the coronation of Emperor Leopold II as king of Bohemia in Prague, *La clemenza* provides numerous examples of Mozart's musical mastery, none of his mastery of dramatic creation through music.

Like *Die Zauberflöte,* Beethoven's *Fidelio* (1805, revised 1806 and 1814) rose above the limitations of the singspiel pattern, becoming something bigger and grander. In most of this, his only opera, Beethoven is musically at nearly his greatest. The libretto has never satisfied anyone entirely; also, some of the writing for the voices is instrumental rather than truly vocal. Beethoven lacked Mozart's theatrical sensibility and his ability to mix the comic-frivolous with the solemn and near tragic, as the text required. Yet the grandeur of much of the *Fidelio* music and the noble humanity of the central character (a wife, Leonore, who disguises herself as a young man, Fidelio, in order to rescue her husband, at terrible risk, from political incarceration in a dungeon) irradiates the opera from the moment of Leonore's first appearance. Its theme of the triumph of the human spirit over oppression has helped to place *Fidelio* among the world's most popular operas.

France, 1752–1825. Political changes and that intensity of intellectual discussion that has always played a role in determining the nature of artistic production in Paris led, in the early 1750s, to one of those polemic "wars"—this one called the *Guerre* (or *Querelle*) *des Bouffons* (War of the Buffoons)—that delight the French. This was a mainly literary confrontation of the solemn past of opera seria and *tragédie lyrique* with the farce and sentiment of opera buffa, though many of the writers saw it in nationalistic terms. It had a happy outcome: the subsequent composition by both French composers and resident foreigners of excellent examples of opéra comique, which became a French amalgam of the English ballad opera, the German singspiel, and the Italian opera buffa.

The *Guerre des Bouffons*

In 1752, the year of the first battles of the *Guerre des Bouffons,* Jean-Jacques Rousseau staged at Fontainebleau his one-act comic opera *Le Devin du village* (*The Village Soothsayer*). The libretto was his own. In the score he had brought together, in the pasticcio manner, melodies reflecting the very popular romances and vaudevilles being heard at the Paris fairs. It pleased battlers on both sides of the operatic war, being very French in manner and sentiment but Italian in being through-composed (continuously set) and employing recitative. Rousseau hoped to establish this combination as a standard for French comic opera, but his plan was not immediately successful. In 1755, however, a Naples-trained Italian, Egidio Duni, settled in Paris and began to compose (or perhaps, at first, merely to assemble) recognizably Rousseauesque opéras comiques. French and Belgian composers gladly adapted the new variety of opéra comique (not always with comic subject matter) and soon established its reign in the Paris and provincial theatres (nearly all of them simultaneously composed other sorts of musicodramatic works as well). Among them, several names stand out, together with the finest or most renowned of their operas. One of the most interesting of these opéra comique composers was François-André Danican (1726–95), called Philidor, also a famous chess player, who wrote about 20 works in the evolving manner.

More sentimental—in fact, tending toward the tenderly tearful—was Pierre Alexandre Monsigny (1729–1817),

never thoroughly trained in music but endowed with the ability to create winning melodies and to exploit for dramatic purpose the timbres of individual instruments. Probably the finest of the 18th-century composers of opéra comique was a Belgian, André Grétry (1741–1813), who most happily balanced the French and Italian styles. He was a very original and extremely productive composer over a 30-year period spanning the French Revolution.

Étienne-Nicolas Méhul (1763–1817), who used opéra comique conventions including the retention of spoken dialogue, also had a career spanning the Revolution. A devoted Gluckian, Méhul had composed numerous works in many genres when, in 1807, he produced his masterpiece, *Joseph,* which is a rarity among operas in several ways: its libretto by Alexandre Duval is derived from the Bible, a source of drama usually reserved for the oratorio; it has no female characters; and it mixes the most solemn classicism with the sentiment of the popular romances.

Boieldieu's immense success

Early in the 19th century, French opéra comique achieved a new equilibrium of classical tint in the best works of François-Adrien Boieldieu (1775–1834). He won truly astonishing and, to several composers (Berlioz included), maddening popularity with *La Dame blanche* (*The White Lady,* 1825; libretto by Eugène Scribe, based upon Sir Walter Scott's novels *Guy Mannering* and *The Monastery*). There were 1,669 performances of this work at the Opéra-Comique, Paris, between 1825 and 1926.

Le Pré aux clercs (*The Field of Honour,* 1832; libretto by François de Planard), the most accomplished opera of Louis-Joseph-Ferdinand Hérold (1791–1833), all but equalled the popularity of *La Dame blanche;* it had received 1,600 performances at the Paris Opéra-Comique by 1939. Hérold's other outstanding success was *Zampa* (1831; libretto by Anne-Honeré Mélesville), so much like the work of Carl Maria von Weber that it became vastly popular in Germany. An extraordinarily prolix composer, Hérold never succeeded in working out a dependable, unified manner of his own, with the result that his French operas are structurally weak. Opéra comique after Boieldieu became more Italianized, reflecting very largely Rossini's influence.

Italy in the first half of the 19th century. The splendid musical achievements of the classicial Viennese style during the late 18th century and early 19th threatened to leave Italy, opera's native home, to one side of the operatic highroad. Two accidents—one the voluntary expatriation to northern Italy of a German, Johann Simon Mayr, the other the unpredictable eruption of a genius, Gioacchino Rossini—saved the day for Italian opera in Italy and outside it.

Mayr, known in Italy as Giovanni Simone Mayr, composed nearly 70 operas in Italian between his first (1794) and his last (1815). He appears to have been influenced deeply by Mozart, and his intensely keen dramatic sense, together with the extraordinary pliability with which he employed the conventions of opera seria and his varied use of the orchestra (particularly of solo woodwinds and horns within it), would have made him a major composer of opera had he not lacked major gifts as a melodist. Many of his operas were for a long time extremely popular throughout Italy, and his immediate influence was beneficial, particularly on the practice of his most famous pupil, Gaetano Donizetti, and on another, less talented, but still admirable operatic composer, Saverio Mercadante.

The operas of Nicola Zingarelli (1752–1837) and of Ferdinando Paer (1771–1839) were transitional, between Classical and grand opera in mode and manner. Zingarelli's conventional opere buffe displayed a genuine humour and some liveliness of musical imagination; his most enduringly performed work, however, was an opera seria, *Giulietta e Romeo* (1796; libretto by Giuseppe Maria Foppa). He is now remembered chiefly as a teacher of Vincenzo Bellini. Paer, who composed more than 40 operas, worked mostly in Vienna, Dresden, and Paris; his musical style changed with his surroundings.

The production at Venice in 1810 of the first performed opera of Rossini, *La cambiale di matrimonio* (*The Bill of Marriage;* libretto by Gaetano Rossi), announced a new operatic genius. Into the genteel, often charming atmosphere of lingering 18th-century operatic manners, Rossini brought genuine originality marked by rude wit and humour and an entire willingness to sacrifice all "rules" of musical and operatic decorum. Both his opere buffe and his now sadly neglected opere serie soon became so popular throughout Italy and then throughout the Western world that they all but blotted out his unfortunate contemporaries—Donizetti and Bellini excepted.

Rossini's originality and wit

Rossini's dazzling career marked the zenith of the bel canto style, a singer-dominated manner of composition (and at times improvisation) that played to audiences' delight in vocal agility, smoothness of voice, and long, florid phrasing. From the period of Rossini's greatest Italian triumphs (he had a second career in Paris) and of Donizetti and Bellini come the names of now legendary voices such as Isabella Colbran (Rossini's first wife), Giuditta Pasta, Maria Malibran, Giovanni David, Giovanni Battista Rubini, Domenico Donzelli, Antonio Tamburini, and Luigi Lablache. For appearances by these singers, composers altered their scores; when they sang, they interpolated extraneous arias that displayed their prowess. Rossini tried to insist that his operas be sung as he himself composed or revised them, but it was a losing battle. The polished artistry and extreme technical training and technique of such singers, as well as their extraordinarily wide ranges, have left performance of the bel canto operas bristling with nearly insoluble problems for latter-day singers.

Perfection of Rossini's comic operas

Rossini's most famous opera is *Il barbiere di Siviglia* (*The Barber of Seville,* 1816; based on the libretto by Cesare Sterbini after the 18th-century play by Beaumarchais), the most nearly flawless of all opere buffe. Several others among his comedies rank only a little lower in musical invention, genuine comic brio, and opportunities for trained singers of vocal display and for farcical characterization: *L'Italiana in Algeri* (*The Italian Girl in Algiers,* 1813; libretto by Angelo Anelli), *Il Turco in Italia* (*The Turk in Italy,* 1814; libretto by Felice Romani); *La cenerentola* (*Cinderella,* 1817; libretto by Jacopo Ferretti), and the half Italian opera buffa and half French opéra comique *Le Comte Ory* (*Count Ory,* 1828; libretto by Scribe and Charles-Gaspard Delestre-Poirson). Rossini prefaced several of these operas with swift, witty overtures that have held a place in the repertory of symphony orchestras.

His style began to have a more serious bent with *Otello* (*Othello,* 1816; libretto by Francesco di Salsa), the opera semiseria (a serious opera with a happy ending), *La gazza ladra* (*The Thieving Magpie,* 1817; libretto by Giovanni Gherardini), and *Armida* (1817; libretto by Giovanni Schmidt), all of which show the composer adapting his florid style to more dramatic, and often eloquent, purposes. But it was only in his Parisian pieces, such as *Semiramide* (1823; libretto by Gaetano Rossi), *Le Siège de Corinthe* (*The Siege of Corinth,* 1826; a revision of the earlier opera, *Maometto II* [1820]; libretto by Alexandre Soumet and Luigi Balocchi), and *Guillaume Tell* (*William Tell,* 1829; libretto by Étienne de Jouy and Hippolyte Bis), his last opera, that his talent for works on a bigger scale, presaging Parisian grand opera, found its full flowering. Some of these later operas owe their revival in the middle of the 20th century to the appearance of a few singers able to project meaningfully their difficult vocal lines.

Gaetano Donizetti first composed a series of very Rossinian, well-made, and largely undistinguished operas but gradually developed dramatic strength, a latent gift for memorable melody, and a forceful deployment of the orchestra for theatrical drama. In 1830, the year after Rossini's farewell to operatic composition, Donizetti produced at Milan the first of his forward-tending, less Rossinian, dramatically remarkable operas: *Anna Bolena* (*Anne Boleyn*), with a libretto by Felice Romani, who worked with so many opera composers of the time. It immediately placed him with Bellini as an inevitable successor to Rossini. What became clear only in retrospect was that it also showed him to be the most important immediate predecessor—in some sense, teacher—of Giuseppe Verdi. Donizetti clung to the long, legato (smoothly flowing) melodies and the ornamented vocal lines of bel canto, but he also unmistakably foreshadowed Verdi's dramatic vigour and many of the younger man's compositional

methods. Several unconscious borrowings from Donizetti have been noted by students of Verdi's operas.

Like Rossini, but unlike Bellini, Donizetti moved freely back and forth between serious and comic subjects. He composed about 70 stage works in 25 years. After the success of *Anna Bolena,* with speed and facility that remain astonishing, he composed numerous operas of enduring quality. They include the sentimental comedy *L'elisir d'amore* (*The Elixir of Love,* 1832; libretto by Felice Romani); *Lucrezia Borgia* (1833; libretto by Romani) and *Maria Stuarda* (*Mary Stuart,* 1834; libretto by Giuseppe Bardari); the popular *Lucia di Lammermoor* (1835; libretto by Salvatore Cammarano was derived from Sir Walter Scott's *The Bride of Lammermoor*)—an opera that reflects Donizetti's acquaintance with the music of Bellini; *Roberto d'Evereux* (1837; libretto by Cammarano); the delightful opéra comique *La Fille du régiment* (*The Daughter of the Regiment,* 1840; libretto by Jules-Henri Vernoy de Saint-Georges and Jean-François-Alfred Bayard); the grand opera *La Favorite* (1840; libretto by Alphonse Royer, Gustave Vaëz, and perhaps Scribe); the opera semiseria *Linda di Chamounix* (1842; libretto by Gaetano Rossi); and—judged by many to be Donizetti's masterwork—the ever fresh and vivid opera buffa, *Don Pasquale* (1843; libretto by Giacomo Ruffini and Donizetti).

Altogether different from either Rossini or Donizetti was Vincenzo Bellini. His operas have come to seem the natural habitat of bel canto, of the unchallenged supremacy of vocal melody in amazingly long-breathed and highly decorated lines. Only his first student opera contains even a trace of humour. He and his librettists filled their collaborations with intensely amorous and other subjective emotion, ethical confrontations, and usually tragic involvements (of the seven finest among his 10 operas, only two—*La sonnambula* and *I puritani*—conclude happily for the principal characters). Bellini cultivated with meticulous care his unrivalled, native gift for convincingly melancholy melody, especially in arias and duets; he gave much less attention to ensembles, choruses, and the expressive potentialities of the orchestra. His orchestra, in fact, might have been what it was had Haydn, Mozart, Mayr, and Rossini never existed.

Bellini's innate gift of melody

Beginning in 1827 with *Il pirata* (*The Pirate,* libretto by Felice Romani, who thereafter supplied all of Bellini's librettos except that for *I puritani*), Bellini made his presence felt throughout Italy and then gradually throughout Europe and the Americas. In 1831 two of Bellini's enduring masterworks were produced: the pastoral opera semiseria *La sonnambula* (*The Sleepwalker*) and the heroic tragedy *Norma.* Bellini's previously faithful public temporarily deserted him when, in 1833, he gave it *Beatrice di Tenda.* In the year of his death after his final removal to Paris, he won another triumph with an opera very loosely connected with Cromwellian times in England, *I puritani* (*The Puritans;* libretto by conte Carlo Pepoli).

Unlike Rossini and Donizetti, Bellini exercised little or no influence upon the style of his successors: the most noticeable of his compositional means, his exclusively personal sort of melody, could only be debased in imitation by others. With these three men, both the late period of bel canto and the second period of opera buffa drew to a close. After the onset of Donizetti's crippling illness in 1847, the Italian opera houses in Italy, Paris, London, and elsewhere could look to Giuseppe Verdi.

GRAND OPERA AND BEYOND

French grand opera. Nineteenth-century Paris was to foster and witness the birth of "grand opera," an international style of large-scale operatic spectacle employing historical or pseudohistorical librettos and filling the stage with elaborate scenery and costumes, ballets, and phalanxes of supernumeraries. Dispensing almost entirely with the delicacies of bel canto, it vastly enlarged both the orchestra itself and its role in the dramatic happenings. Grand opera naturally had roots in the past, particularly in the Venetian "machine operas" of the 17th century, such as Cesti's *Il pomo d'oro,* as well as in the stately scores of Rameau and Gluck. But the immediate drive toward this new style of opera was instituted in Paris by Italian expatriates: Luigi Cherubini, who spent the last 54 years of his life in France, and Gasparo Spontini, whose most impressive operas were designed for Paris.

Cherubini was a greatly learned composer in almost all musical forms who won the admiration of Beethoven. His two most imposing operas were the embryonic grand opera *Médée* (1797; libretto by François-Benoît Hoffman) and a *comédie lyrique, Les Deux Journées* (*The Two Days,* 1800; libretto by Jean-Nicolas Bouilly). *Les Deux Journées* became something like a national German opera under its German title, *Der Wasserträger* (*The Water Carrier*). Spontini, in his French operas, ranged far beyond Cherubini and his other contemporaries in his demands for complex staging, finally reaching a sort of splendid megalomania. Daniel-François-Esprit Auber brought out a nearly total grand opera; *La Muette de Portici* (*The Mute Girl of Portici,* also known as *Masaniello,* 1828; libretto by Scribe). The popularity of *La Muette* became phenomenal in both France and Germany. This opera remains unique on several counts. Its title character neither sings nor speaks, the role being performed by a mime. A performance of it at Brussels on August 25, 1830, set off disorders that led to the separation of Belgium from The Netherlands. Eighteen months after the premiere of Auber's opera, the appearance of Rossini's *Guillaume Tell* showed that master of opera buffa and bel canto responding to the new genre. Auber's later operas include several charming comedies, among them *Fra Diavolo* (1830; libretto by Scribe).

The final, official birth of grand opera occurred in 1831, with the first French opera of another Parisian expatriate, the German Giacomo Meyerbeer: *Robert le Diable* (libretto by Scribe and Germain Delavigne). The popularity of this work became a sort of frenzy (by August 1893 it had been sung 751 times at the Paris Opéra). Although Meyerbeer's operas are rarely performed in the late 20th century, he remains a controversial figure. Using an expanded, powerful orchestra, with much emphasis placed on individual instrumental colours, requiring almost every kind of singing, filling huge stages with dazzling pageantry, employing characters who pretend to be actual figures from history, four of his operas held their leading positions even through the Wagnerian revolution and into the early 20th century. Besides *Robert le Diable,* they were *Les Huguenots* (1836; libretto by Scribe with the collaboration of Émile Deschamps), *Le Prophète* (1849; libretto by Scribe), and the posthumously staged *L'Africaine* (libretto by Scribe). The author of all of these, Eugène Scribe, was the most phenomenally productive librettist of his time, writing (with the help of various collaborators) a huge number of librettos for many composers, including Auber, Boieldieu, Cherubini, Donizetti, Gounod, Halévy, Meyerbeer, Rossini, and Verdi. He was, in fact, a major force in the evolution of French grand opera.

Imitators of Meyerbeer's successes naturally sprang up immediately. Later, numerous men totally unlike him stylistically—including Berlioz, Wagner, and Verdi—were influenced unwittingly by his practices. The first of the imitators was Fromental Halévy, whose works included at least one grand opera that could almost be mistaken for Meyerbeer's: *La Juive* (*The Jewess,* 1835; libretto by Scribe). After the times of Meyerbeer and Halévy, grand opera began to respond to new musical and intellectual currents, evolving into a variety of mixed forms.

Like most of Hector Berlioz's other compositions, his three operas stand apart from the mainstream of historical evolution. When first staged at the Paris Opéra in the shadow of *Robert le Diable* and *La Dame blanche,* his first opera, *Benvenuto Cellini* (1838; libretto by Léon de Wailly and Auguste Barbier), was a complete failure. The second, the lighthearted *Béatrice et Bénédict* (his own libretto, based upon Shakespeare's *Much Ado About Nothing*), finally was given its premiere at Baden-Baden in 1862 by Franz Liszt. And Berlioz's masterpiece, *Les Troyens* (his own libretto), is based on Virgil's *Aeneid* and divided into *La Prise de Troie* (*The Capture of Troy*), two acts, and *Les Troyens à Carthage* (*The Trojans at Carthage*), three acts. It was not performed complete during his lifetime; he

Modern revival of *Les Troyens*

heard only the second part as staged in Paris in 1863. Mid-20th-century complete (or very nearly complete) performances of *Les Troyens,* notably in London, showed it to be a great, noble, idiosyncratic work not without traces of grand opera, but in seriousness and scope much closer to the Wagner of *Der Ring des Nibelungen.* Berlioz's operas, like his other music, are distinguished by the individual arch of his melody, his revolutionary orchestration, and the dramatic thrust of the whole.

Even more popular than Auber as a purveyer of light operatic comedy was Jacques Offenbach, a German émigré to Paris who supplied the Second Empire and the early years of the Third Republic with a long series of very tuneful, witty, and satiric operettas of deliberate frivolity. Remembered among them are *Orphée aux enfers* (*Orpheus in the Underworld,* 1858; libretto by Hector Crémieux and Ludovic Halévy), *La Belle Hélène* (*Beautiful Helen,* 1864; libretto by Henri Meilhac and Halévy), *Barbe-Bleue* (*Bluebeard,* 1866; libretto by Meilhac and Halévy), *La Vie Parisienne* (*Parisian Life,* 1866; libretto by Meilhac and Halévy), *La Grande-Duchesse de Gérolstein* (1867; libretto by Meilhac and Halévy), and *La Périchole* (1868; libretto by Meilhac and Halévy). Left incomplete at Offenbach's death was his major serious opera, *Les Contes d'Hoffmann* (*The Tales of Hoffmann;* libretto by Jules Barbier and Michel Carré, after their play of the same name based on tales by the German Romantic writer E.T.A. Hoffmann). Recitatives replacing the original dialogue were provided by Ernst Guiraud, and the opera was staged posthumously in 1881. This fantasy involving supernatural interventions rapidly became a worldwide favourite.

German Romantic opera. Romanticism, part philosophical, part literary, part aesthetic, made one of its first appearances, and certainly its earliest overt appearance, in opera, in three works composed between 1821 and 1826 by Carl Maria von Weber. Beginning with his masterpiece, *Der Freischütz* (*The Freeshooter,* 1821; libretto by Friedrich Kind), Weber successfully challenged the outdated dictatorship of Spontini at Berlin. For the Italian's stiff grandeurs he substituted, in singspiel form, tender sentiment, grisly horrors, manly choruses, moral nicety, and music of extraordinary instrumental and vocal allure. *Der Freischutz* illustrates the German Romantic writers' love for dark forests, the echoes of hunters' horns, the threatening supernatural, the frustrations of pure young love. Its popularity in Germany and elsewhere was enormous.

Elements of German Romanticism

Weber smarted under the anti-Romantic criticism of *Der Freischütz* as a mere singspiel (a work with spoken dialogue) rather than a musically continuous opera. His next major composition, *Euryanthe* (1823; libretto by Helmina von Chézy), was something like a proto-grand opera and therefore contained no spoken dialogue. Almost since its premiere, writers have attacked the remarkable silliness (on paper) of its libretto, but most of them have never witnessed the work in performance and therefore cannot judge how the libretto works on stage with Weber's fine score. His last opera, *Oberon,* or *The Elf King's Oath* (1826; libretto, in English, by James Robinson Planché), returns to the singspiel form. Like *Euryanthe,* it has not held the stage, and again the libretto has been blamed. The overtures to all three of these operas are still played frequently, and whatever future opinion of the operas themselves may be, *Der Freischütz* opened the floodgates of musical Romanticism in Germany.

Louis Spohr (1784–1859), a violinist, conductor, and composer of instrumental music, sounds pallidly Romantic if compared with Weber, but certain of his harmonic innovations taught something to Wagner, of whose early operas he was a defender. Heinrich August Marschner (1795–1861), more Romantic by nature than Spohr, borrowed sufficiently from Weber's style to serve as one bridge to Wagner. He displayed talent as orchestrator and melodist, and he applied his gifts to intensely Romantic and equally Teutonic librettos. The finest of his now unheard operas is *Hans Heiling* (1833; libretto by Eduard Devrient).

The other German-language composers of opera active during the Weber–Spohr–Marschner period were less important. Albert Lortzing composed several operas that have been likened to genre painting. He travelled in the direction of operetta in his popular sentimental comedies, such as *Zar und Zimmermann* (*Tsar and Carpenter,* 1837; his own libretto) and *Der Waffenschmied* (*The Armourer,* 1846; his own libretto). The same direction was taken by Friedrich, Freiherr von Flotow, whose operetta-like *Martha* (1847; libretto by Friedrich Wilhelm Reise) continues to be performed frequently. This trend toward operetta as a less intense variety of Romanticism continued in *Die lustigen Weiber von Windsor* (1849; libretto by Salomon Hermann Mosenthal, based on Shakespeare's *Merry Wives of Windsor*), the major success of Otto Nicolai, and in the extremely popular works of Franz von Suppé, a Dalmatian of Belgian ancestry. It culminated in operetta on the highest level of musical accomplishment in the masterworks of Johann Strauss the Younger. Many of Strauss's operettas are known now only by their overtures and waltzes, but one of them, *Die Fledermaus* (1874; libretto by Carl Haffner and Richard Genée), has never left the stage for long. Only the finest opéras comiques and opéras bouffes of Auber and Jacques Offenbach match Strauss's elegance, wit, humour, musical invention, and scrupulous workmanship.

Strauss's operettas

Verdi. When, in 1839, an opera called *Oberto, conte di San Bonifacio* (libretto by Antonio Piazza, revised by Bartolomeo Merelli and Temistocle Solera) was staged at the leading Italian opera house, the Teatro alla Scala (La Scala) at Milan, its first audiences received it reasonably well. Rossini had not offered a new opera for 10 years, Bellini was dead, and Donizetti was composing for Paris, so the debut of a new talent was welcome. Those early audiences, however, could not know that *Oberto* had opened the active career of the greatest of all later Italian composers of opera, Giuseppe Verdi. Verdi's second opera, *Un giorno di regno* (*King for a Day,* 1840; libretto by Felice Romani), was a failure and was to remain his only comedy for 53 years. It was followed by *Nabucodonosor,* known as *Nabucco* (1842; libretto by Solera), which displayed the emergence of a musical dramatist of enormous vigour and rich melodic invention.

Verdi long suffered from his inability to obtain librettos worthy of his special talents, but each of the six operas that he wrote between *Nabucco* (1842) and *Macbeth* (1847) includes scenes and numbers of great power and immediately winning, memorable melody. Even *Macbeth* (libretto by Francesco Maria Piave, revised in 1865 by Verdi to a libretto in French), although it is marked both dramatically and musically by passages of astonishing vitality, has structural weaknesses.

Another period of lesser achievement by Verdi stretched from 1847 to 1851, the best of his five operas of those years having been *Luisa Miller* (1849; libretto by Salvatore Cammarano). Meanwhile, Verdi was on the way to becoming a public symbol of the risorgimento, the Italian movement of rebellion against foreign domination and toward political unification, both because of the patriotic emphasis in several of his librettos and because of his staunchly liberal public character (he was eventually to become a true national hero).

Beginning in 1851, Verdi produced three masterpieces, having found three librettos that fired aspects of his genius. The first of them was *Rigoletto* (libretto by Piave), in which his abundant creation of melody was at the service of his gift for musical characterization. *Rigoletto* was followed, less than two years later, by *Il trovatore* (*The Troubadour,* 1853; libretto by Cammarano), perhaps unmatched among his operas for its profusion of strong and memorable melodies.

Less than two months after the premiere of *Il trovatore* came *La traviata* (1853; libretto by Piave, after Alexandre Dumas *fils*'s *La Dame aux camélias*). At first a failure, it later came to be accepted as a masterpiece. It also established a composer's right to set librettos dealing with contemporary life and with characters not of exalted station. By comparison with the thunderous melodrama of *Il trovatore, La traviata* seems an intimate, quiet, almost chamber-music opera. The musical portrait of Violetta, the tubercular courtesan heroine, remains extraordinary for its depiction of the effects of love and sorrow on her character.

Production of *La traviata*

After *La traviata* came a comparative failure, a grand opera composed in French for Paris, *Les Vêpres siciliennes* (*The Sicilian Vespers,* 1855; libretto by Scribe and Charles Duveyrier). It was succeeded only two years later by *Simon Boccanegra* (1857; revised 1881), a gloomy opera of great power. Then came *Un ballo in maschera* (*A Masked Ball,* 1859; libretto by Antonio Somma, after Scribe's libretto for Auber's 1833 opera *Gustave III, ou Le Bal Masqué*), no less gloomy and powerful but including, in the page Oscar (sung by a soprano), a ray of light and youthful humour, and *La forza del destino* (*The Force of Destiny,* 1862; libretto by Piave), a kaleidoscopic mixture of the tragic and the farcical, with touches of matter not far from operetta and opera buffa.

For Paris, and again to a libretto in French, Verdi next composed *Don Carlos* (1867; libretto by François-Joseph Méry and Camille du Locle, revised by Verdi in 1884 to an Italian translation and again in 1887). This long opera, and particularly its fourth act, is majestic and subtle, its various musical confrontations—many of them duets—displaying a depth of characterization hitherto unknown in Italian or French opera, in spite of faults in the libretto.

By 1869 Verdi's fame had become so international that the Khedive of Egypt invited him to compose an opera for Cairo to mark the opening of the new Cairo Opera House (and possibly the opening of the Suez Canal). In fact, the canal began to operate in 1869, but the opera received its premiere at Cairo only in 1871. This was *Aida* (libretto by Antonio Ghislanzoni, based on a scenario by Auguste Mariette, the French Egyptologist, and Camille du Locle, with the collaboration of Verdi). The masterly libretto and its four well-delineated principal characters evoked from Verdi a Meyerbeerian opera of such unfailing melodic, orchestral, and dramatic richness that many have called *Aida* his masterpiece. For pageantry, combined as it is with harmonic, melodic, and instrumental skills and convincing, if generalized, characterization, it remains unrivalled—and probably has been sung more often than any other opera.

Verdi's Shakespearean operas

In 1869 the public and the writers on opera assumed that Verdi would continue to produce a new opera every few years. But 16 elapsed before the premiere of his next opera, *Otello* (1887; libretto by Arrigo Boito). Verdi's varied, intensely dynamic, compressed, and tragic score was the result not only of his ripened genius but also of nearly 50 years of operatic practice. Many critics consider it the finest tragic opera ever composed.

In the following six years, rumours grew that the aged Verdi not only was composing still another opera but that it was to be a comedy. The comic masterpiece *Falstaff* (libretto by Boito, derived largely from Shakespeare's *Merry Wives of Windsor* and *Henry IV*) was performed in 1893 at La Scala, where Verdi's first opera had been staged more than 53 years before. An opera buffa with serious overtones, *Falstaff* always has been praised by critics and enthusiasts, but it has never become a true popular favourite.

Arrigo Boito not only wrote the librettos of Verdi's last two operas but was also himself a composer, as well as a poet, polemicist, and man of letters. He completed only one opera, *Mefistofele* (1868; his own libretto, derived from Goethe's *Faust*). It was at first a failure and then became more popular. His command of technical musical resources was vast. Unfortunately, he placed them at the service of lofty but diffuse philosophical concepts and ideals mostly beyond his range of expressiveness. *Mefistofele,* for instance, is more impressive and admirable than theatrically convincing.

Wagner and his successors. Richard Wagner (1813–83) is a unique figure in the history of both opera and music. A concentrated egoist gifted with a powerful, tenacious, and at times stubbornly confused intellect, he wrote both the music and librettos of his operas. He began his career, except for a youthful attempt, *Die Feen* (*The Fairies,* completed, 1834; first performed, 1888), with two grand operas mixing the influences of Meyerbeer, Marschner, and Weber: *Das Liebesverbot* (*The Ban on Love,* 1836) and *Rienzi* (1842). In 1843, with *Der fliegende Holländer* (*The Flying Dutchman*), he began to develop what was to become an extremely personal, powerful manner of operatic construction. Turning to mythic legend for his subjects and making unacknowledged bows to the operas of Weber and Marschner, while dispensing with the trappings of grand opera, he composed an intensely German, Romantic opera. In it he instituted the use of brief melodic and other motifs as materials for evolving a more-or-less continuous web of music in which the separate numbers of earlier opera appeared only when the libretto demanded them. Already, at the age of 30, he was giving harmony, in very unclassical guise, a central constructive role in the creation of both drama and characterization.

Wagner's personal operatic style

Patiently and challengingly elaborating a vast, interlocked system of theories in many published books and essays, Wagner continued the ripening of his style in two large, transitional operas, *Tannhäuser* (1845) and *Lohengrin* (1850). *Tannhäuser* again displays some grand-opera characteristics (particularly in the revision of it that Wagner prepared for the 1861 Paris performance); *Lohengrin,* the last of Wagner's serious operas peopled by human beings of recognizable dimensions, has been called the Romantic opera par excellence.

The earliest example of what Wagner called "music drama" (a term he preferred to "opera") was the monumental *Tristan und Isolde* (1865), the libretto of which illustrates his obsession with the idea of man's redemption through woman's love. *Tristan und Isolde* advances harmonic language. The score is woven in a harmonic idiom so advanced chromatically that it speeded the destruction of orthodox concepts of harmony. *Tristan* requires singers possessed of powerful voices capable of penetrating a vastly enlarged orchestra. It came to be regarded as the greatest German opera of the late 19th century, and its influence upon compositional methods and techniques continued into the 20th century.

In *Die Meistersinger von Nürnberg* (*The Mastersingers of Nürnberg,* 1868) he partly deserted his most "advanced" style because central episodes in the libretto required self-contained numbers. Warmhearted, overflowing with young love and the bitter wisdom of age, *Die Meistersinger* ranks with Verdi's *Falstaff* among late-19th-century comic operas. From 1853 until 1874 Wagner worked intermittently on the four poems and the scores of *Der Ring des Nibelungen.* It is an epic, based on Teutonic myths, of such proportions and implications that it cannot be summarized. Musically, Wagner uses leitmotivs—constantly recurring fragments—and weaves them into a large, elaborate pattern. Performed in its entirety, and without intermissions, the *Ring* would last about 12 hours; many listeners, almost bewitched, would have been and now would be willing to attend such a continuous performance, so compelling is the musical power of this unique, all but inhuman, masterpiece.

The last of Wagner's operas, *Parsifal* (1882), introduced few structural elements not used in *Tristan und Isolde* and *Der Ring des Nibelungen.* Wagner called it *Ein Bühnenweihfestspiel*—a sacred festival drama—and it is heavy with religious and ethical messages. It perfectly illustrated both his musicodramatic theories and the unsmiling solemnity with which he approached operatic composition and demanded, successfully, that his audience absorb the results. *Parsifal* closed a career unparalleled in its aggressive demands on society and on operagoers, a career that would have seemed a form of madness if it had not produced some of the most lastingly impressive of all operatic creations and many pages of music of the greatest beauty.

Operatic composers influenced by Wagner

Curiously, Wagner's influence has been felt more in the evolution of post-Romantic harmony than in the constructive practices of later operatic composers. An adaptation of his leitmotiv usage marked the delightful fairytale opera *Hänsel und Gretel* (1893; based upon the tale by the Brothers Grimm), by Engelbert Humperdinck. Wagner's early theories about both libretto and music played a constructive part in the excellent comic opera *Der Barbier von Bagdad* (*The Barber of Bagdad,* 1858), by Peter Cornelius, and his mature style was wholly adopted in *Guntram* (1894), the first opera of Richard Strauss. Otherwise, the Wagnerian revolutions (in contrast with his at times unrevolutionary practice) are clearly seen in the

operas of some ardent French Wagnerians such as Ernest Reyer and Vincent d'Indy.

Later opera in France. The history of French opera contemporary with and later than Berlioz includes many talented composers and stageworthy works, but it degenerates quickly into a catalog of pieces of considerable charm and some originality seldom made arresting by the appearance of operas unmistakably of the first rank. Charles Gounod, who composed many operas, had a unique gift for sentimental melody but an uncertain sense of what is theatrically viable. In his ever-popular *Faust* (1859; libretto by Jules Barbier and Michel Carré), his talents were most creatively gathered together, but *Faust* took no place in the steady evolution of operatic styles. Among Gounod's other operas, the best, mixing in different proportions the virtues and flaws of *Faust,* are probably *Mireille* (1864; libretto by Carré, derived from Frédéric Mistral's Provençal poem *Mirèio*) and *Roméo et Juliette* (1867; libretto by Barbier and Carré).

The works of Georges Bizet are on a higher level in both their vigour and variety. He began to display his considerable ability with *Les Pêcheurs de perles* (*The Pearl Fishers,* 1863; libretto by Eugène and Carré) and *La Jolie Fille de Perth,* (1867; libretto by Jules-Henry Vernoy de Saint-Georges and Jules Adenis, based on Sir Walter Scott's *Fair Maid of Perth*). In 1875 Bizet produced his masterpiece, *Carmen* (libretto by Henri Meilhac and Ludovic Halévy, after a tale by Prosper Mérimée). Its then savage realism, broad but convincing characterization, and dazzling pseudo-Spanish ambience shocked its first audiences and strongly influenced Italian *verismo.* A lonely masterpiece, *Carmen* remains one of the steady props of operatic repertory everywhere.

Production of *Carmen*

Ambroise Thomas, as prolific as Gounod but not as gifted in emotional or musical persuasion, had composed many operas when Paris first welcomed his *Mignon* (1866; libretto by Barbier and Carré), probably his best opera. Two years later he composed *Hamlet* (1868; libretto by Barbier and Carré). Thomas, like Gounod, interlarded his operas with florid, often essentially undramatic and "showy" arias for a new type of lyric-coloratura soprano. One of the most frequently heard of such vacuous arias is the "Bell Song" from Léo Delibes' *Lakmé* (1883; libretto by Edmond Gondinet and Philippe Gille). Although Camille Saint-Saëns composed numerous operas, the only work by him to remain in the repertory is *Samson et Dalila* (libretto by Ferdinand Lemaire), originally sung under Franz Liszt's aegis in 1877 in German. It is lusciously melodic but so lacking in drama as to seem half oratorio.

Phenomenally popular when first composed were many of the operas of Jules Massenet, who had a surer sense of the stageworthy than Saint-Saëns but often made saccharine what to many had seemed too sweet in the earlier French opera of the 19th century. At his best however, Massenet was something better than "the daughter of Gounod": in *Manon* (1884) he produced not only one of the most enduringly popular of operas but also a stylistically unflawed reflection of the tragicosentimental 18th-century novel by the Abbé Prévost on which Henri Meilhac and Philippe Gille had based the libretto. Much the same qualities have kept alive Massenet's *Werther* (1892; libretto by Édouard Blau, Paul Milliet, and Georges Hartmann, derived from Goethe's *Leiden des jungen Werthers*), first performed at Vienna in a German translation. Some other operas by Massenet, particularly *Thaïs* (1894; libretto by Louis Gallet, after the novel by Anatole France), are important for their sensuous portrayals of seductive female characters.

Gustave Charpentier's *Louise* (1900; libretto by the composer) has remained in opera house repertories because of its loving, romanticized portrait of "Bohemian" Paris, the sentiment and surface allure, and the popularity of Louise's hymn to love, "Depuis le jour."

Claude Debussy, the greatest French composer after Berlioz and a decisive influence upon 20th-century music, completed only one opera: *Pelléas et Mélisande* (1902), an almost verbatim setting of Maurice Maeterlinck's play. Like *Tristan und Isolde*—which, having helped to shape Maeterlinck's drama, inevitably and against Debussy's will also shaped some of his compositional procedures—*Pelléas* remains unique. Listeners immune to the attraction of its aristocratic sensuality often find it monotonous. Nonetheless, it is a masterwork in its wholly apt amalgamation of text and score, the inescapable rightness for its quiet dramatic purposes of Debussy's individual harmonies, the marvelous manner with which he made the sounds of Maeterlinck's French an integral element in a shimmering orchestral web. In *Pelléas,* the Wagnerian ideal of continuous music without separate numbers was attained. Although *Pelléas* remains one of the handful of important operas composed in the 20th century, it has had few descendants. One of those few is Paul Dukas' *Ariane et Barbe-Bleue* (*Ariadne and Bluebeard,* 1907)—like *Pelléas,* an almost verbatim setting of a Maeterlinck play. It, however, is notably noisy where *Pelléas* is quiet, and it lacks Debussy's thematic invention.

The achievement of *Pelléas*

Maurice Ravel wrote one opera, *L'Heure espagnole* (*The Spanish Hour,* 1911; libretto by Maurice Legrand), and a *fantaisie lyrique* (really a ballet-pantomime-opera), *L'Enfant et les sortilèges* (*The Child and the Enchantments,* 1925; text by Colette). The former is opéra bouffe in Spanish dance rhythms overlaid with vocal lines that seem indebted to the works of Richard Strauss. The latter reverses the orchestra's domination over the voices in *L'Heure espagnole.* It is an edifying and hilarious fantasy about a child being punished for his mistreatment of his toys and other objects. Perhaps only its uncomfortable mixture of genres has kept it from widespread performance.

Of the professedly anti-Debussyan, anti-Impressionist group known as Les Six, three have places in the history of opera: Arthur Honegger, Darius Milhaud, and Francis Poulenc. Honegger, a Swiss, employed a somewhat Teutonic "neoclassical modern" idiom in thickly dissonant, heavily percussive operas that have failed to hold the stage. Milhaud's once sensational *opéras-minutes* (1927–28), three brief one-act compositions, were first staged in German translation in Germany. They parody Greek myths and have music composed in a jazz manner that inevitably has lost effectiveness with the passing decades. Milhaud also composed large modern versions of grand opera, but his persistently undramatic and often busily indecisive musical style have kept them from popularity. Poulenc composed one comic monodrama and one serious opera that seem likely to endure. The first, *Les Mamelles de Tirésias* (1947), is a wildly nonsensical opéra bouffe, the sardonic music of which is humorously appropriate to the text by the French poet Guillaume Apollinaire. The second, *La Voix humaine* (*The Human Voice,* 1959; text by Jean Cocteau), has as its only visible character a distraught young woman conversing by telephone with her lover. Poulenc's only large serious opera, *Dialogues des Carmélites* (*Dialogues of the Carmelites,* 1957; libretto by Georges Bernanos), appears to be the most impressive French opera since *Pelléas et Mélisande.* It makes telling operatic use of Poulenc's instantly identifiable style of melody, harmony (only very gently dissonant), and rhythm to tell a moving and tragic story of nuns martyred during the French Revolution.

Tragic and sardonic themes

Later opera in Italy. Viewed broadly, the story of Italian opera contemporary with and following Verdi parallels that of French opera after Berlioz, in the appearance of talented composers and stageworthy operas as well as in quickly becoming a tally of pieces of considerable charm and some degree of originality responding to shifting musical techniques and manners. It includes only two or three composers of the first rank.

Amilcare Ponchielli, shining clearly in light reflected from Verdi, composed one opera that remains in the international "standard" repertory—*La Gioconda* (1876; libretto by Arrigo Boito). The general turn toward realism began on a Roman stage in 1890 with Pietro Mascagni's dazzlingly successful one-act opera *Cavalleria rusticana* (*Rustic Chivalry,* libretto by Guido Menasci and Giovanni Targioni-Tozzetti). It soon evoked the descriptive term *verismo* (realism) and set a vogue for raw, violent, melodramatic librettos matched to music clearly descended from the middle-period operas of Verdi. Mascagni went on composing operas for 50 years after *Cavalleria,* but none won a permanent place on the stage. The best of them

is *L'Amico Fritz* (*Friend Fritz,* 1891; libretto by Nicolo Despure). And, two years after the premiere of *Cavalleria rusticana,* an equally successful product of *verismo* was staged in Milan: *I pagliacci* (*The Clowns,* 1892; libretto by the composer), by Ruggero Leoncavallo, who had no more staying power than Mascagni, though he produced operas for the remainder of his life.

The Italian counterpart of Massenet in France made his first important contribution to the operatic stage the year after *I pagliacci.* He was Giacomo Puccini, whose work is characterized by emotional directness of appeal and colourful, rich orchestration; the opera was *Manon Lescaut* (1893), based on the novel by the Abbé Prévost from which the libretto of Massenet's *Manon* had been derived.

Establishment of Puccini's reputation with *La Bohème*

Puccini established himself unmistakably as the most important post-Verdian Italian operatic composer with *La Bohème* (1896; libretto by Giuseppe Giacosa and Luigi Illica, after Henri Murger's *Scènes de la vie de bohème*). It, too, remains "standard," as do *Tosca* (1900; libretto by Giacosa and Illica) and *Madama Butterfly* (1904; libretto by Giacosa and Illica), which again capitalized upon Puccini's attraction to, and ability to characterize in music, sorrowing, attractive young women. Returning closer to violent *verismo,* Puccini (who always had to struggle to find librettos germane to his purposes) next composed an opera of the American "Wild West," *La fanciulla del west* (*The Girl of the Golden West,* 1910; libretto by Guelfo Civinini and Carlo Zangarini).

Fumbling for apposite literary materials, Puccini next proposed to write an operetta for Vienna; the outcome was a mixed, uncertain operetta-like piece, *La Rondine* (1917; libretto by Giuseppe Adami), produced by Monte Carlo, instead of Vienna, because of World War I. It was followed by a trio of one-act operas given its premiere at the Metropolitan, in 1918. *Il trittico* (*The Triptych*) consisted of the veristic and powerful *Il tabarro* (*The Cloak;* libretto by Adami), the sweetly sad, all-female *Suor Angelica* (*Sister Angelica;* libretto by Giovacchino Forzano) and the opera buffa of medieval Florence, *Gianni Schicchi* (libretto by Forzano). *Gianni Schicchi,* in its sarcastic humour and musical vitality, is the finest Italian operatic comedy after *Falstaff.*

Puccini died before finishing *Turandot* (libretto by Adami and Renato Simoni based on the Italian writer Carlo Gozzi's fable of the same name). It was produced posthumously in 1926. *Turandot* shows Puccini taking note of the then-recent developments in harmony, while giving them an Eastern flavour. The bloodthirsty story with a happy ending (for the two characters who least deserve it) alienates some operagoers, but many of those who accept *Turandot* as the brilliant, extremely melodious, highly pictorial representation of a legend consider it the finest of Puccini's operas. The music of *Turandot* was completed after the composer's death by the Italian composer Franco Alfano.

The other Italian operatic composers of the late 19th century and early 20th displayed neither the brash originality of the young Mascagni and Leoncavallo nor the varied theatrical genius of Puccini. They included Alfredo Catalani, whose best-known opera, shaped with extreme melodic refinement and mildly interesting orchestral commentary, is *La Wally* (1892; libretto by Luigi Illica). Another of these minor men was Umberto Giordano (1867–1948), whose bombastic *Andrea Chenier* (1896; libretto by Illica) and *Fedora* (1898; libretto by Arturo Colautti) are still staged. Francesco Cilea overtly copied the more sentimental aspects of Puccini in his biggest success, *Adriana Lecouvreur* (1902; libretto by Colautti). The 20th-century music critic Donald Jay Grout made an accurate description of nearly all of the post-Verdian Italian operas except *Cavalleria rusticana, I pagliacci,* and the best of Puccini when he wrote of *Adriana Lecouvreur* as "expertly contrived music of a lyrical-tragic sort . . . unadventurous harmonically or rhythmically, but good theatre and grateful for the singers."

Of much greater interest (though not of equal popularity) were two contrasted half-Italian, half-German composers active early in this century: Ferruccio Busoni and Ermanno Wolf-Ferrari. Busoni, a learned musician, wrote, in a then-advanced harmonic idiom and using his own librettos, four operas that have had scattered enthusiasts but no large public: *Die Brautwahl* (*Choice of a Bride,* 1912); two commedia dell'arte parodies—*Turandot* (1917; libretto after Gozzi) and the equally short *Arlecchino* (*Harlequin,* 1917)—and his major work, *Doktor Faust,* left incomplete at his death and completed by Philipp Jarnach (1925). Busoni's operas, and *Doktor Faust* in particular, are notable for their intellectual mastery, spiritual elevation, and other operatically peripheral virtues, but their almost total lack of dramatic cogency and musical allure have probably kept them from frequent performance.

At the other end of the operatic spectrum, Wolf-Ferrari possessed a fine talent for opera buffa of an especially light, airy sort, and also composed one of the rawest later examples of *verismo.* There is enormous charm in his comedies *Le donne curiose* (*The Curious Women,* 1903; libretto by Luigi Sugana), *I quattro rusteghi* (*The Four Ruffians,* 1906; libretto by Giuseppe Pizzolato), and *Il segreto di Susanna* (*The Secret of Susanna,* 1909; libretto by Enrico Golisciani). All three were first given in German translation. The melodrama *I gioielli della Madonna* (*The Jewels of the Madonna,* 1911; by Golisciani and Zangarini) has been well described as Donizetti plus *verismo.*

The "big three" Italian composers of the 1920s and '30s—Ottorino Respighi, Gian Francesco Malipiero, and Alfredo Casella—all composed operas and operalike works of considerable musical interest but little theatrical vitality. What historical influence they have had has operated largely outside the opera house.

Russian opera. After long subjection to imported Italian, French, and German composers, opera in Russia by Russians asserted itself in two well-known works by Mikhail Ivanovich Glinka (1804–57): *Zhizn za tsarya* (*A Life for the Tsar*), also known as *Ivan Susanin* (1836; libretto by Baron Georgy Fyodorovich Rosen), and *Ruslan i Lyudmila* (*Ruslan and Lyudmila,* 1842; libretto by Valeryan Fyodorovich Shirkov and others). Basically old-fashioned Italianate operas, they—*Ruslan* in particular—determined the nature of much future Russian music because of Glinka's approximations of Slavic folk music, his pre-Wagnerian use of a tentative leitmotiv technique, and the clarity and shifting colours of his orchestration. Glinka's operas, weakened by evidence of his lifelong dilettantism, remain in the repertory only in Russia, but their stylistic importance was decisive.

Glinka as father of Russian nationalism

Almost as influential as Glinka in shaping future Russian opera was his much less successful disciple Aleksandr Sergeyevich Dargomyzhsky. His *Rusalka* (1856; his libretto, after a fairy tale by Pushkin) illustrated his strong emphasis on a declamation midway between recitative and aria, as well as his musical amateurism. Even more influential, although left incomplete at Dargomyzhsky's death, was *Kamenny gost* (*The Stone Guest,* an integral setting of Pushkin's short Don Juan play; completed by César Antonovich Cui and Nikolay Rimsky-Korsakov and staged posthumously in 1872). It is couched in what were then advanced harmonic terms, powerful in characterization but musically all but sterile. Dargomyzhsky remains more interesting to historians than to operagoers.

The operas of Aleksandr Borodin, Rimsky-Korsakov, and Modest Mussorgsky are still performed. Borodin's incomplete *Knyaz Igor* (*Prince Igor,* his own libretto; completed and edited by Rimsky-Korsakov and Aleksandr Glazunov) was staged posthumously in 1890. It is dramatically shapeless but is splashed with Slavic and Oriental colours. Most of Rimsky-Korsakov's numerous fairy-tale operas have the nature of brilliantly illustrated books, but what may be his finest work is "the Russian *Parsifal,*" *Skazaniye o nevidimom grade Kitezhe i deve Fevroni* (*The Legend of the Invisible City of Kitezh,* 1907; libretto by Vladimir Ivanovich), a work of marked emotional strength. Of his lighter works, the best known are *Snegurochka* (*The Snow Maiden,* 1882; his own libretto), *Sadko* (1898; libretto by the composer and Byelsky), and the fantastic opera buffa, *Zolotoy petushok* (*Le Coq d'or,* or *The Golden Cockerel,* 1909; libretto by Byelsky, after Pushkin). Like *Prince Igor,* Rimsky-Korsakov's operas contributed largely to what many music lovers came to consider typically "Russian"

music, though the splashily coloured world they create was in reality Rimsky-Korsakov's own invention.

Mussorgsky composed all or part of several operas. Among them, *Khovanshchina* (to his own libretto; the score completed and orchestrated by Rimsky-Korsakov; posthumous premiere in 1886) bears a family resemblance to *Prince Igor,* particularly in its employment of real and simulated Orientalism, but is more serious and much more confident in tone. Mussorgsky's greatest achievement, and the most worthwhile Russian opera, is *Boris Godunov* (1874; his own libretto, based upon Pushkin's drama and a history of Russia by Nikolay Mikhailovich Karamzin). Boris, the guilty usurper of the throne, dominates this glittering but dour pageant in which the Russian people are present in remarkably forceful choral writing. Mussorgsky's ability to transmit textual points in very condensed music has possibly never been matched. Except at a few weak moments, he made a virtue out of amateurishness and naïveté, fearlessly extracting intense power and theatrical effectiveness from his newly developed techniques. The influence of *Boris Godunov* has been strong on numerous composers of opera both in Russia and elsewhere.

Greatness of *Boris Godunov*

The operatic practice of Peter Ilich Tchaikovsky was very different. For dramatic vigour he substituted clear characterization expressed lyrically, creating, among others, two highly idiosyncratic operas: *Eugene Onegin* (1879; libretto by the composer and Konstantin S. Shilovsky, after Pushkin) and the stronger melodrama *Pikovaya dama* (*The Queen of Spades,* 1890; libretto by Modest Ilich Tchaikovsky, after Pushkin). The personal emotion and the characterization of hero and heroine in *Eugene Onegin* are vivid. In all of Tchaikovsky's operas the highly subjective emotion that long made him the most often performed of orchestral composers is tellingly present. Many consider his other operas, containing much fine music, all unjustly neglected.

Igor Stravinsky turned to opera three times during his long composing career, to near-opera more often. First came *Solovey* (*The Nightingale,* 1914; libretto by the composer and Stepan Nikolayevich Mitusov, after Hans Christian Andersen), which clearly reveals the influence of Rimsky-Korsakov, who had been Stravinsky's teacher. Next among his true operas came *Mavra* (1922; libretto by Boris Kochno, derived from Pushkin), an opera buffa in the unmistakable musical style that made Stravinsky the foremost composer of his era. Then a long period marked by several near-operas (among them the urgent opera-oratorio *Oedipus Rex,* 1927) elapsed before the appearance of Stravinsky's full-length opera in English, *The Rake's Progress* (libretto by the poets W.H. Auden and Chester Kallman, after Hogarth's engravings, 1951), a neoclassical, austere, but compassionate work.

Sergey Prokofiev composed numerous operas both in his "modern" musical manner and in a harmonically less advanced "socialist realist" style after his return to the Soviet Union in 1934. Among the former, the best and most often staged are the opera buffa, *L'Amour des trois oranges* (*The Love for Three Oranges,* Chicago, 1921; his own libretto), in a musical style that might be called Rimsky-Korsakov updated, and the lurid opera of hallucination, *Angel of Fire* or *The Fiery Angel* (radio premiere 1954; his own libretto after a story by Valery Yakovlevich Bryusov). Of Prokofiev's Soviet-period operas, the most winning is the gay *Betrothal in a Monastery,* also known as *The Duenna* (1946; libretto by Mira Mendelson based on a play of that name by the 18th-century Irish-born dramatist Richard Brinsley Sheridan). The most ambitious is the massive *War and Peace* (1946; revised, condensed version, 1955; libretto by the composer and Mira Mendelson).

Prokofiev's Soviet-period operas

The best-known Soviet-period opera outside its homeland, however, is a grim tale of sexual repression and violence by Dmitry Shostakovich originally called *Ledi Makbet Mtsenskogo Uyezda* (*Lady Macbeth of the Mzensk District,* 1934; libretto by the composer and Y. Priess, after a story by Leskov), later revised, after a long period of eclipse caused by government disapproval, as *Katerina Ismaylova* (1963). Numerous other Russian operas have not been staged outside the country or have proved substantially unexportable when so staged.

Later opera in Germany and Austria. Richard Strauss was greeted as the obvious "heir to Wagner" (and Liszt). His worldwide reputation was being established by his orchestral music and lieder (songs) before he turned to opera for the first time. But his preeminence among non-Italian composers of opera was established by two "shocking" one-act operas: *Salome* (1905; libretto taken from Oscar Wilde's drama, translated into German by Hedwig Lachmann) and *Elektra* (1909). With the latter work Strauss began a long and fruitful association with the poet and dramatist Hugo von Hofmannsthal as his librettist. Couched in a violent harmonic idiom, requiring huge orchestral forces and leading singers of great vocal power and stamina, *Salome* and *Elektra* seemed to many critics to be Straussian tone poems with added voices, but they soon became, and have remained, part of the standard repertory. They were followed by an altogether different sort of opera, *Der Rosenkavalier* (1911), again with a libretto by Hofmannsthal, a bittersweet comedy notable for the superb musical creation of the central character (the Marschallin) and for three-quarter rhythms that placed this Strauss alongside Johann the Younger as a composer of Viennese waltzes. It marks Strauss's invention of a subtle *parlando* (conversational) style all his own, which he also used to great effect in his later opera.

Strauss's collaboration with Hofmannsthal

Strauss composed 10 operas after *Der Rosenkavalier.* All but one or two of them won wide popularity; none of them displays any constructive or musical characteristics not present in his earlier works. The most successful have been the "chamber opera" *Ariadne auf Naxos* (*Ariadne on Naxos,* 1912; revised 1916); the giant allegory *Die Frau ohne Schatten* (*The Woman Without a Shadow,* 1919), which some writers have called Strauss's masterpiece, whereas others denounce it as confused, even megalomaniac; and *Arabella* (1933), which closely resembles *Der Rosenkavalier* in many details. *Capriccio* (1942), his last opera, is an absorbing characterization of the old argument as to whether words or music should take precedence in opera.

Several harmonically conservative German composers active during and just after Strauss's long career were much less gifted and also less successful. Probably the most notable of them were Hans Pfitzner and Paul Hindemith. The antimodern Pfitzner, partly a belated Wagnerian, composed several operas of melodically long-lined, subjective, at times mystical content which have not reached beyond the German-speaking countries. The best-known is *Palestrina* (1917; his own libretto), dealing with the great Italian composer, in which the austerities of 16th-century counterpoint are oddly mixed with Pfitzner's often abrupt dissonances.

Hindemith damagingly lacked theatrical insight but was admired for his technical wizardry and lofty aims. He composed some satiric comedies but his work came to be heard in opera houses only with the serious *Cardillac* (1926, revised 1952; libretto by Ferdinand Lion, after a tale by E.T.A. Hoffmann) and *Mathis der Maler* (*Mathias the Painter,* 1938; his own libretto on the life of Matthias Grünewald).

If "modernism" seems to be struggling toward birth in the operas of Strauss, Pfitzner, Hindemith, and some others, it sprang fully armed from the music of three Viennese composers: Arnold Schoenberg, Alban Berg, and Anton von Webern, propagators and chief practitioners of what came to be called atonality and 12-tone composition. Webern composed no operas. Schoenberg's first theatrical works—the one-act *Erwartung* (*Expectation,* composed in 1909, performed in 1924; single-character libretto by Marie Pappenheim) and the one-act *"Drama mit Musik" Die glückliche Hand* (*The Hand of Fate,* 1924; his own libretto)—are extremely discordant, thickly and earnestly romantic, even expressionistic, and occasionally use *Sprechstimme,* a variety of vocal emission between speech and song that Schoenberg himself described as "the voice rising and falling relative to the indicated intervals, and everything being bound together with the time and rhythm of the music except where a pause is indicated." Their harmony is unremittingly chromatic.

Schoenberg's first theatrical works

Schoenberg's only comedy, the one-act *Von Heute auf*

Morgen (*From Today to Tomorrow,* 1930; libretto by Max Blonda), is in strictly construed 12-tone texture; following the theories attending that technique, it therefore returned to separate-number construction. Schoenberg's largest opera, left incomplete at his death, was the powerful, oratorio-like *Moses und Aron* (1957; his own libretto).

(H.We.)

The two operas of Alban Berg—*Wozzeck* (1925; libretto by the composer, after Georg Büchner's play *Woyzeck*) and *Lulu* (1937, libretto by the composer after Frank Wedekind's plays *Erdgeist* [*Earth-spirit*] and *Die Büchse der Pandora* [*Pandora's Box*])—are among the most powerful, effective music dramas of the 20th century. Well described as "expressionistic, morbid, neurotic, hysterical" as to story, *Wozzeck* seamlessly joins an intensely learned and appropriate score to a melodrama of a poor soldier's helplessness at the hands of his fate. *Wozzeck* is such an intense work that audiences who might be expected to be alienated by its extreme dissonance and "tunelessness" have accepted it as the great opera it is. *Lulu,* virtually finished at the time of Berg's death and later completed by others, is a part-tragic, part-comic drama; it adds film clips and spoken dialogue to the means employed in *Wozzeck.* Although Berg's score was elaborated from a single "tone-row" (arrangement of the 12 tones of a chromatic scale) and though the resultant tonal clashing is not bilked, many passages in *Lulu* appear to show Berg tending toward less dissonance.

Intensity of *Wozzeck*

The most appreciable Germanic musicodramatic composer outside the Viennese orbit has appeared to be Carl Orff (1895–1982), who has juggled many varieties of almost-operatic forms. Best known for his absorption of bawdy medieval student songs into a "scenic oratorio," *Carmina Burana* (1937), Orff worked that singular exploitation of repetitive rhythms, bare harmonies, *ostinati,* and crying vocal colours into a trilogy called *Trionfi* by adding to it *Catulli Carmina* (1943) and *Il Trionfo d'Afrodite* (1953). More conventionally operatic is his one-act comedy *Die Kluge* (*The Clever Girl,* 1943; his own libretto, after a tale by the Brothers Grimm). Probably his major effort in musical drama is another trilogy, consisting of *Antigonae* (1949), *Oedipus der Tyrann* (1959), and *Prometheus* (1968). In it a texture of spoken and declaimed texts is spaced out with incidental music of almost brutal force. Bernd Alois Zimmermann's opera *Die Soldaten* (*The Soldiers,* 1969) is the most successful of the multi-media operas.

Hans Werner Henze is the most recent major operatic composer to come out of Germany. His best-known works are *Elegy for Young Lovers,* his first collaboration with the poets W.H. Auden and Chester Kallman, and *Der junge Lord* (*The Young Lord*), which satirizes German provincial life. He has experimented with other forms of musicodramatic experiment.

Czechoslovakia. The specifically Russian operas of Glinka, Dargomyzhsky, and the Five have parallels in other countries. In what is now Czechoslovakia, the national school effectively began with Bedřich Smetana, best known outside his homeland for the vigorous, highly coloured folk comedy *Prodaná nevěsta* (*The Bartered Bride,* 1866; libretto by Karel Sabina), which determined many aspects of future Czech musical usage as clearly as Borodin and Mussorgsky had set Russian styles. Several of Smetana's other operas, both comic and tragic, remain on Czech stages—most notably the overtly patriotic *Dalibor* (1868) and *Libuše* (1881), both to librettos in Czech translation of originally German texts by Joseph Wenzig, and his comedy *Hubička* (*The Kiss,* 1876). The other leading Czech composer of Smetana's period, Antonín Dvořák, wrote nine operas but remained preponderantly an instrumental composer, never matching the older composer's stage success. Of Dvořák's mature operas, the best known outside Czechoslovakia is the melancholy fairy tale *Rusalka* (libretto by Jaroslav Kvapil), made attractive by his considerable melodic and harmonic gifts.

Production of *The Bartered Bride*

Leoš Janáček was specifically Moravian in musical background, far more harmonically advanced than Smetana and Dvořák, though less adroit technically. He was clearly a 20th-century composer, whose highly individual music, typified by a short-phrased melodic idiom used to catch the speech-rhythm of his native language, was rediscovered after World War II. A follower of Mussorgsky, whose much-discussed "dilettantism" his closely resembles, Janáček is now represented intermittently in non-Czech opera houses chiefly by *Její pastorkyňa* (*Her Foster Daughter,* 1904; changed to *Jenůfa* for Janáček's 1916 revision; his libretto derived from a story by Gabriela Preissová), *Kát'a Kabanová* (1921; libretto by Vincenc Červinky), *Příhody lišky bystroušky* (*The Cunning Little Vixen,* 1924; libretto by the composer), and *Věc Makropulos* (*The Makropoulos Case,* 1926; libretto by the composer), each of which has a character and milieu of its own while preserving the peculiarly individual setting of the Czech language.

Hungary and Poland. The most important Hungarian operas of the early 20th century, neither of them representing its composer at his finest, are the one-act *Duke Bluebeard's Castle* (1918; libretto by Béla Balázs), by Béla Bartók, and the ballad opera *Háry János,* by Zoltán Kodály (1926; libretto by Béla Paulini and Zsolt Harsányi), both of which have become more familiar in concert performance or excerpts than in staged productions. The most influential and popular of Polish nationalist operas, *Halka* (1854; libretto by Włodzimierz Wolski), was composed by Stanisław Moniuszko; he also wrote an admirable comedy, *The Haunted Manor* (1865; libretto by Jan Chichiński). Of 20th-century Polish operas, perhaps the most substantial is the much less popular *Król Roger* (*King Roger,* 1926; libretto by Jarosław Iwakiewicz) by Karol Szymanowski.

Spain. Spanish operatic nationalism began with Felipe Pedrell, more influential as teacher-propagandist than as producing composer. Of his 10 operas, the most imposing were to have been contained in a trilogy, based on a Catalan libretto by Victor Balaguer, but only the first two sections, *Los Pirineos* (*The Pyrenees*) and *La Celestina,* were completed and only the first was staged (1902). Of the more familiar Spanish composers, both Isaac Albéniz and Enrique Granados composed operas of strongly Spanish colour that have lapsed from the repertory—Albéniz particularly in the comic one-act *Pepita Jiménez* (1896), Granados in the semi-veristic *Goyescas* (1916; libretto by Fernando Periquet y Zuaznabar), the score of which clearly reveals its origin in a suite of piano pieces. The best results of Spanish operatic nationalism (possibly because more than a little tinged with internationalism) are two very different operas by Manuel de Falla: the specifically Andalusian *La vida breve* (*Brief Life;* libretto by Carlos Fernández Shaw; first staged in French translation, 1913) and the one-act *El retablo de Maese Pedro* (*Master Peter's Puppet Show,* 1923; text by the composer, after a scene in *Don Quixote*), in effect a chamber opera for marionettes.

(H.We./Ed.)

England. English opera, which had languished for centuries, was revitalized by the theatrical talent of the eclectic Benjamin Britten, whose stage works show a remarkable sympathy for the human predicament expressed in readily accessible, deeply felt music. His masterpiece is the gloomy, forceful *Peter Grimes* (1945; libretto by Montague Slater). Among Britten's other operas to win widespread stagings are the chamber operas *The Rape of Lucretia* (1946; libretto by Ronald Duncan) and *Albert Herring* (1947; libretto by Eric Crozier), the all-male *Billy Budd* (1951; libretto by E.M. Forster and Crozier; based upon Herman Melville's story), the eerily effective *Turn of the Screw* (1954; libretto by Myfanwy Piper, after the Henry James story), *A Midsummer Night's Dream* (1960; libretto by Britten and Peter Pears, from Shakespeare), three church operas to librettos by William Plomer (1964–68), and *Owen Wingrave* (1971; libretto by Myfanwy Piper). So far, less popular outside England are the idiosyncratic operas, to his own complex librettos, of Sir Michael Tippett: *The Midsummer Marriage* (1955), *King Priam* (1962), and *The Knot Garden* (1970).

Benjamin Britten's works

United States. American contributions to international opera, after a 19th-century desert of imitation German and French operas, became much more numerous after World War II. It is possible here to mention only one composer and a few isolated operas that have evoked enduring resonance. The most often performed of contemporary op-

Menotti's works

eratic composers has been the Italo-American Gian Carlo Menotti. Using his own librettos, he has produced, in a variety of structural styles, a series of Puccini-derived melodramas and sentimental tragedies of considerable popular appeal, among them *The Medium* (1946), *The Consul* (1950), *Amahl and the Night Visitors* (composed for television performance, 1951), and *The Saint of Bleecker Street* (1954). He also wrote the libretto for the first, mildly successful, opera of Samuel Barber, *Vanessa* (1958; awarded 1958 Pulitzer Prize). Barber's second large opera, *Antony and Cleopatra* (1966; libretto derived from Shakespeare by Franco Zeffirelli), commissioned to inaugurate the second Metropolitan Opera House in New York, was a failure and vanished quickly from performance.

A unique niche is occupied by the two operas that Virgil Thomson composed to texts by Gertrude Stein arranged by Maurice Grosser: the Spanish-tinted *Four Saints in Three Acts* (1934) and *The Mother of Us All* (1947), a delicious flow of invention around the figure of Susan B. Anthony. Their fragile but real durability has resulted from Thomson's singable, apt folk-based setting of texts that alternate among the apparently nonsensical, the satiric, and the emotionally moving. Perhaps the most important national opera consistently in repertory is George Gershwin's *Porgy and Bess* (1935; libretto by DuBose Heyward and Ira Gershwin), a blending of folk opera and American musical comedy, which has had no recognizable descendant of high quality. Within the United States—not to count the "workshop operas" and simplified semi-folk near-operas that many American composers recently have favoured—two of the most frequently performed recent American operas are the folklike "Western" *Ballad of Baby Doe* (libretto by John Latouche, 1956), by Douglas Moore (1893–1969) and the melodramatic, "Southern" *Susannah* (libretto by the composer, 1955) by Carlisle Floyd.

(H.We.)

Jazz

The difficulty of definition

Any attempt to arrive at a precise, all-encompassing definition of jazz is probably futile. Jazz has been, from its very beginnings at the turn of the 20th century, a constantly evolving, expanding, changing music, passing through several distinctive phases of development; a definition that might apply to one phase—for instance, to New Orleans style or swing—becomes inappropriate when applied to another segment of its history, say, to free jazz. Early attempts to define jazz as a music whose chief characteristic was improvisation, for example, turned out to be too restrictive and largely untrue, since composition, arrangement, and ensemble have also been essential components of jazz for most of its history. Similarly, syncopation and swing, often considered essential and unique to jazz, are in fact lacking in much authentic jazz, whether of the 1920s or of later decades. Again, the long-held notion that swing could not occur without syncopation was roundly disproved when trumpeters Louis Armstrong and Bunny Berigan (among others) frequently generated enormous swing while playing repeated, unsyncopated quarter notes.

Jazz, in fact, is not—and never has been—an entirely composed, predetermined music, nor is it an entirely extemporized one. For almost all of its history it has employed both creative approaches in varying degrees and endless permutations. And yet, despite these diverse terminological confusions, jazz seems to be instantly recognized and distinguished as something separate from all other forms of musical expression. To repeat Armstrong's famous reply when asked what *swing* meant: "If you have to ask, you'll never know." To add to the confusion, there often have been seemingly unbridgeable perceptual differences between the producers of jazz (performers, composers, and arrangers) and its audiences. For example, with the arrival of free jazz and other latter-day, avant-garde manifestations, many senior musicians maintained that music that didn't swing was not jazz.

Most early classical composers (such as Aaron Copland, John Alden Carpenter—and even Igor Stravinsky, who became smitten with jazz) were drawn to its instrumental sounds and timbres, the unusual effects and inflections of jazz playing (brass mutes, glissandos, scoops, bends, and stringless ensembles), and its syncopations, completely ignoring, or at least underappreciating, the extemporized aspects of jazz. Indeed, the sounds that jazz musicians make on their instruments—the way they attack, inflect, release, embellish, and colour notes—characterize jazz playing to such an extent that if a classical piece were played by jazz musicians in their idiomatic phrasings, it would in all likelihood be called jazz.

Nonetheless, one important aspect of jazz clearly does distinguish it from other traditional musical areas, especially from classical music: the jazz performer is primarily or wholly a creative, improvising composer—his own composer, as it were—whereas in classical music the performer typically expresses and interprets someone else's composition.

WEST AFRICA IN THE AMERICAN SOUTH: GATHERING THE MUSICAL ELEMENTS OF JAZZ

The elements that make jazz distinctive derive primarily from West African musical sources as taken to the North American continent by slaves, who partially preserved them against all odds in the plantation culture of the American South. These elements are not precisely identifiable because they were not documented—at least not until the mid- to late 19th century, and then only sparsely. Furthermore, black slaves came from diverse West African tribal cultures with distinct musical traditions. Thus, a great variety of black musical sensibilities were assembled on American soil. These in turn rather quickly encountered European musical elements—for example, simple dance and entertainment musics and shape-note hymn tunes, such as were prevalent in early 19th-century North America.

The music that eventually became jazz evolved out of a wide-ranging, gradually assimilated mixture of black and white folk musics and popular styles, with roots in both West Africa and Europe. It is only a slight oversimplification to assert that the rhythmic and structural elements of jazz, as well as some aspects of its customary instrumentation (*e.g.*, banjo or guitar and percussion), derive primarily from West African traditions, whereas the European influences can be heard not only in the harmonic language of jazz but in its use of such conventional instruments as trumpet, trombone, saxophone, string bass, and piano.

The element of syncopation

The syncopations of jazz were not entirely new—they had been the central attraction of one of its forerunners, ragtime, and could be heard even earlier in minstrel music and in the work of Creole composer Louis Moreau Gottschalk (*Bamboula,* subtitled *Danse des Nègres,* 1844–45, and *Ojos Criollos,* 1859, among others). Nevertheless, jazz syncopation struck nonblack listeners as fascinating and novel, because that particular type of syncopation was not present in European classical music. The syncopations in ragtime and jazz were, in fact, the result of reducing and simplifying (over a period of at least a century) the complex, multilayered, polyrhythmic, and polymetric designs indigenous to all kinds of West African ritual dance and ensemble music. In other words, the former accentuations of multiple vertically competing metres were drastically simplified to syncopated accents.

The provenance of melody (tune, theme, motive, riff) in jazz is more obscure. In all likelihood, jazz melody evolved out of a simplified residue and mixture of African and European vocal materials intuitively developed by slaves in the United States in the 1700s and 1800s—for example, unaccompanied field hollers and work songs associated with the changed social conditions of blacks. The widely prevalent emphasis on pentatonic formations came primarily from West Africa, whereas the diatonic (and later more chromatic) melodic lines of jazz grew from late 19th- and early 20th-century European antecedents.

Harmony was probably the last aspect of European music to be absorbed by blacks. But once acquired, harmony was applied as an additional musical resource to religious texts; one result was the gradual development of spirituals, borrowing from the white religious revival meetings that African Americans in many parts of the South were urged to attend. One crucial outcome of these musical acculturation

ations was the development by blacks of the so-called blues scale, with its "blue notes"—the flatted third and seventh degrees. This scale is neither particularly African nor particularly European but acquired its peculiar modality from pitch inflections common to any number of West African languages and musical forms. In effect these highly expressive—and in African terms very meaningful—pitch deviations were superimposed on the diatonic scale common to almost all European classical and vernacular music.

Unique to the United States

That jazz developed uniquely in the United States, not in the Caribbean or in South America (or any other realm to which thousands of African blacks were also transported) is historically fascinating. Many blacks in those other regions were very often emancipated by the early 1800s and thus were free individuals who actively participated in the cultural development of their own countries. In the case of Brazil, blacks were so geographically and socially isolated from the white establishment that they simply were able to retain their own African musical traditions in a virtually pure form. It is thus ironic that jazz would probably never have evolved had it not been for the slave trade as it was practiced specifically in the United States.

Jazz grew from the African American slaves who were prevented from maintaining their native musical traditions and felt the need to substitute some homegrown form of musical expression. Such composers as the Brazilian mulatto José Maurício Nunes Garcia were fully in touch with the musical advances of their time that were developing in Europe and wrote music in those styles and traditions. American slaves, by contrast, were restricted not only in their work conditions and religious observances but in leisure activities, including music making. Although slaves who played such instruments as the violin, horn, and oboe were exploited for their musical talents in such cities as Charleston, South Carolina, these were exceptional situations. By and large the slaves were relegated to picking up whatever little scraps of music were allowed them.

FIELD HOLLERS AND FUNERAL PROCESSIONS: FORMING THE MATRIX

Jazz, as it finally evolved as a distinct musical style and language, comprised what Max Harrison calls, in the *New Grove Dictionary of Music and Musicians,* a "composite matrix" made up of a host of diverse vernacular elements that happened to come together at different times and in different regions. This matrix included the field hollers of the cotton plantations; the work songs on the railroads, rivers, and levees; hymns and spirituals; music for brass bands, funeral processions, and parades; popular dance music; the long-standing banjo performing tradition (starting in the 1840s), which culminated half a century later in the banjo's enormous popularity; wisps of European opera, theatre, and concert music; and, of course, the blues and ragtime. These last two forms began to flourish in the late 19th century—blues more as an informal music purveyed mostly by itinerant singers, guitarists, and pianists and ragtime becoming (by 1900) America's popular entertainment and dance music.

Ragtime and jazz

Ragtime differs substantially from jazz in that it was (1) a through-composed, fully notated music intended to be played in more or less the same manner each time, much like classical music, and (2) a music written initially and essentially for the piano. Jazz, by contrast, became a primarily instrumental music, often not notated, and partially or wholly improvised. Ragtime had its own march-derived, four-part form, divided into successive 16-bar sections, whereas jazz, once weaned away from ragtime form, turned to either the 12-bar (or occasionally 8-bar) blues or the 32-bar song forms. What the two music genres had in common was their syncopated (thus "irregular") melodies and themes, placed over a constant "regular" $\frac{2}{4}$ or $\frac{4}{4}$ accompaniment.

The years from 1905 to 1915 were a time of tremendous upheaval for black musicians. Even the many musicians who had been trained in classical music but had found—as blacks—no employment in that field were now forced to turn to ragtime, which they could at least play in honky-tonks, bordellos, and clubs; many of these musicians eventually drifted into jazz. Hundreds of other musicians, unable to read and write music, nonetheless had great ability to learn it by ear, as well as superior musical talent. Picking up ragtime and dance music by ear (perhaps not precisely), they began almost out of necessity to embellish these syncopated tunes—loosening them up, as it were—until ornamentation spilled over quite naturally into simple improvisation. This process took on a significantly increased momentum once the piano rags of such master composers as Scott Joplin, Joseph Lamb, and James Scott appeared in arrangements performed regularly by bands and orchestras.

Jelly Roll Morton

That the pianist-composer Jelly Roll Morton was a braggart who claimed to be "the inventor of jazz" should not obscure his major role in the development of that music. As early as 1902 Morton played ragtime piano in the vaunted bordellos of Storyville, New Orleans's famous red-light district. Later he began working as an itinerant musician, crisscrossing the South several times and eventually working his way to Los Angeles, where he was based for several years. As the first major composer of jazz, Morton seems to have assimilated (like a master chef making a great New Orleans bouillabaisse) most of the above-mentioned matrix, particularly blues and ragtime, into a single new, distinct, coherent musical style. Others, such as soprano saxophonist Sidney Bechet, trombonist Kid Ory, and cornetists Bunk Johnson and Freddie Keppard—four of the most gifted early jazz musicians—arrived at similar conclusions before 1920.

Johnson and others regarded themselves as ragtime musicians. In truth, in the cases of many musicians of that generation—both black and white—who grew up with ragtime, the listener would be hard put to determine when their playing turned from embellished rags to improvisatory jazz. Musicians confirmed the tenuousness and variety of these early developments in statements such as that of reedman Buster Bailey (speaking of the years before 1920): "I . . . was embellishing around the melody. At that time [1917–18] I wouldn't have known what they meant by improvisation. But embellishment was a phrase I understood." And reedman Garvin Bushell said, "We didn't call the music jazz when I was growing up [in Springfield, Ohio]. . . . Ragtime piano was the major influence in that section of the country. . . . The change to jazz began around 1912 to 1915."

RAGTIME INTO JAZZ: THE BIRTH OF JAZZ IN NEW ORLEANS

In spite of the wide dissemination and geographic distribution of these diverse musical traditions, New Orleans was where a distinctive, coherent jazz style evolved. Between 1910 and 1915 a systematization of instrumental functions within an essentially collective ensemble took shape, as did a regularization of the repertory. Despite the fact that a limited set of instruments was available to black musicians (at that time, typically, cornet, clarinet, trombone, tuba or bass, piano, banjo, and drums—the saxophone did not become common in jazz for about another decade), they arrived at a brilliant solution emphasizing independent but harmonically linked and simultaneous lines. Each of the seven instruments was assigned a clearly defined individual role in the established polyphonic collective ensemble. Thus, the cornet was responsible for stating and occasionally embellishing the thematic material—the tune—in the middle range, the clarinet performed obbligato or descant functions in a high register, the trombone offered contrapuntal asides in the tenor or baritone range, and the four rhythm instruments provided a unified harmonic foundation.

Inability to read music

That this formation, which emphasized independent but harmonically linked simultaneous lines, was not only a brilliant solution but a necessity is confirmed by the inability of most players in those early years to read music. It was not long before musicians began to expand upon these materials and to improvise fresh new melodies and obbligatos of their own making. However, these explorations remained within the collective ensemble concept of New Orleans jazz. Few musicians before 1925 could have created independent, extended, improvised solos. And when the solo as an integral element of a jazz performance

arrived, the New Orleans format of a tightly integrated ensemble improvisation went out of fashion.

By approximately 1915 New Orleans had produced a host of remarkable musicians, mostly cornet and clarinet players, such as the legendary Buddy Bolden (legendary in part because he never recorded), Buddy Petit, Keppard, Johnson, and Bechet. Most New Orleans musicians, including scores of pianists, found steady employment in the entertainment palaces of Storyville, where, incidentally, the term *jazz,* initially spelled "jass," was the commonly used slang word for sexual intercourse. It is ironic that the first jazz recordings were made in New York City on January 30, 1917, by a second-rate group of white musicians from New Orleans called the Original Dixieland Jazz Band. Those recordings, with their entertaining but substanceless barnyard sound effects, present a misleading picture of true New Orleans jazz.

VARIATIONS ON A THEME: JAZZ ELSEWHERE IN THE UNITED STATES

New Orleans was not the only place where jazz was being developed. Depending on how narrowly jazz is defined, some early form of it was practiced in places as far-flung as Los Angeles, Kansas City, Missouri, Denver, Colorado, and the Colorado mining towns—not to mention Baltimore, Maryland, and New York City. The two last-mentioned cities were major centres of ragtime, early pre-stride piano, vaudeville entertainment, large-sized dance orchestras, and musical theatre, including theatre created exclusively by black performers. Several other at least embryonic jazz groups and musicians were active in New York during 1913–19, such as James Reese Europe and his various orchestras, Earl Fuller's Jass Band, Ford Dabney's band, and the pianists James P. Johnson, Abba Labba, and Willie "The Lion" Smith.

The closing of Storyville in 1917 was a disaster for New Orleans musicians, many of whom went on to play in Mississippi riverboat orchestras; Fate Marable's orchestra was the best and most famous of these and included, at times, the young Louis Armstrong. Others headed directly north to Chicago, which rapidly became the jazz capital of the United States. King Oliver, the much-heralded cornet champion of New Orleans, migrated to Chicago in 1918, and in 1922 he sent for his most talented disciple, Armstrong, to join his Creole Jazz Band as second cornetist. The two made history and astounded audiences with their slyly worked out duet breaks, and Armstrong had a chance to cut his musical teeth by freely improvising melodic counterpoint to Oliver's lead cornet. More important still, Oliver's band was able to forge a remarkably unified and disciplined style, integrating at a very high level the players' collective and individual instrumental skills, all couched in an irresistible, wonderfully stately, rolling momentum.

Chicago as jazz capital

LOUIS ARMSTRONG AND THE INVENTION OF SWING: THE CORNETIST BREAKS AWAY

In late 1924 Armstrong was wooed away by Fletcher Henderson in New York City. In his year there Armstrong matured into a major soloist and at the same time developed—indeed, single-handedly invented—a compelling, propulsive, rhythmic inflection in his playing that came to be called swing. Early examples of this feeling can be heard in Henderson band recordings and even more clearly on Armstrong's Hot Five and Hot Seven recordings of 1926–27—*e.g.,* "Potato Head Blues," "Big Butter and Egg Man," "S.O.L. Blues," "Hotter than That," and "Muggles." In effect, Armstrong taught the whole Henderson band, including the redoubtable tenor saxophonist Coleman Hawkins, how to swing.

More than that, Armstrong taught the whole world about swing and had a profound effect on the development of jazz that continues to be felt and heard. In that sense alone he can be considered the most influential jazz musician of all time. And beyond his artistic and technical prowess, Armstrong should be remembered as the first superstar of jazz. By the late 1920s, famous on recordings and in theatres, he more than anyone else carried the message of jazz to America; eventually, as entertainer supreme and jazz ambassador at large, he introduced jazz to the whole world. In this crusade Armstrong's unique singing style, in essence a vocalization of his improvisatory trumpet playing, played a crucial role. By often singing without words or texts, he popularized what came to be called scat, a universally comprehensible art form that needed no translation.

Armstrong and scat

After Armstrong's spectacular breakthrough recordings, such as "West End Blues" (1928), he embarked on a solo career for 10 years, fronting bands whose general mediocrity made him sound by comparison even more brilliant. In the 1940s he formed the Armstrong All-Stars, a group of older New Orleans-style musicians that included trombonist Jack Teagarden. Although by then well past his prime, Armstrong, through his physical vitality and uncompromisingly high musical standards, was able to preserve his art almost to the end of his life in 1971.

That Armstrong's playing, both technically and conceptually, was many levels above that of most of his contemporaries can be heard on virtually every recording he made between 1925 and 1940, whether he was paired with other soloists or with orchestras. He exerted a wide-ranging influence on all manner of players—not only trumpeters but trombonists, saxophonists, singers (such as Billie Holiday), and even pianists (such as Earl Hines and Teddy Wilson). Armstrong's influence was also absorbed by white musicians, including some of the better ensembles of the time, such as the New Orleans Rhythm Kings, Red Nichols and his Five Pennies, and, above all, the outstandingly gifted Bix Beiderbecke. Inheriting a lyrical, romantic bent from his German background, Beiderbecke presented another view of the Armstrong revolution, not only in his superb recorded improvisations of "I'm Coming Virginia" and "Singin' the Blues" (both 1927) but also in such pieces as the simply stated, virtually unimprovised "Oi' Man River" (1928).

ORCHESTRAL JAZZ

Fletcher Henderson, the originator. It was in the 1920s that the first forms of true orchestral jazz were developed, most significantly by Fletcher Henderson and Duke Ellington. Although large aggregations had begun to appear in the late teens, these were dance orchestras playing the popular songs and novelty pieces of the day, with nary a smattering of jazz. The credit for being the first to perform and record orchestral jazz must go to Henderson, who, starting in about 1923, gathered together from the small beginnings of quintets and sextets a growing number of notable New York-based players and formed a full orchestra. By the mid- to late 1920s, Henderson could boast a 13- or 14-piece band and had the arranging services of the outstanding alto saxophonist and multi-instrumentalist Don Redman. It was Redman who developed antiphonal call-and-response procedures in orchestral jazz, juxtaposing the two main choirs of brass and reeds in ever more sophisticated and challenging arrangements.

Duke Ellington, the master composer. Although he was very much aware of Redman's and Henderson's work, Duke Ellington took a somewhat different approach. From the start more truly a composer than an arranger, Ellington blended thematic material suggested to him by some of his players—in particular trumpeter Bubber Miley and clarinetist Barney Bigard—with his own compositional frameworks and backgrounds (*e.g.,* "East St. Louis Toodle-oo" [1926] and "Black and Tan Fantasy" [1927]). Once ensconced in Harlem's famous Cotton Club as the resident house band (a tenure that lasted three years, until early 1931), Ellington had the opportunity to explore, in some 160 recordings, several categories of compositions: (1) music for the club's jungle-style production numbers and pantomime tableaus, (2) dance numbers for the 16-girl chorus line, (3) dance pieces for the club's patrons (all white—blacks were allowed only as entertainers), (4) arrangements of the pop tunes or ballads of the day, and (5) most important, independent nonfunctional instrumental compositions—in effect, miniature tone poems for presentation during the shows. The most celebrated of these was "Mood Indigo" (1930), the first of many pieces with a blueslike character, usually set in slow tempos. In these and in such other song and dance numbers as "So-

Cotton Club house band

phisticated Lady" (1932) and "Solitude" (1934), Ellington was able not only to exploit the individual talents of his musicians but to extend and vary the forms of jazz. In addition, he expanded upon his already highly developed feeling for instrumental timbres and colours and his extraordinary forward-looking harmonic sense. In early works such as "Mystery Song" (1931), "Delta Serenade" (1934), and "In a Sentimental Mood" (1935), Ellington experimented with never-before-heard brass sonorities (using mutes peculiar to jazz, including the lowly bathroom plunger) and unusual blendings of brass and reeds, as in his grouping of saxophones and Juan Tizol's light valve trombone sound. Ellington's instinctive genius for harmonic invention, using the outer extensions of basic triadic and dominant seventh chords, led him to use bitonality (two keys at once) or polytonality (several keys) at least a decade before anyone else. Striking examples of this aspect of his work are, to name only a few, "Eerie Moan" (1933), "Reminiscing in Tempo" (1935), "Alabamy Home" (1937), and "Azure" (1937), the last verging on atonality at several points.

Harmonic invention

All these Ellington innovations, nuanced and fulfilled as they were by the extraordinary cast of characters and individual soloists in his orchestra, served to create a more personal expression and emotional depth than had previously been achieved in jazz. The heterogeneity of personalities and talents in Ellington's orchestra virtually guaranteed that even the least of their efforts would be superior to the best of most other orchestras of the time. Motored by a remarkably cohesive rhythm section, each instrumental choir boasted dramatically different, individualistic personalities (*e.g.*, Arthur Whetsol and Cootie Williams on trumpet; Rex Stewart on cornet; Lawrence Brown, Joe "Tricky Sam" Nanton, and Juan Tizol on trombone; and Johnny Hodges, Barney Bigard, Otto Hardwick, and Harry Carney on reeds) who nevertheless whenever needed would blend instantly into perfect ensembles.

Other notables of the 1920s. As remarkable as Ellington's innovations were, they had relatively little impact on the field in general. In the racially still-very-divided world of the 1930s, not only were white bands such as the Casa Loma and Benny Goodman orchestras much more popular than the great black orchestras of Ellington, Jimmie Lunceford, Chick Webb, and Bennie Moten, but Ellington's music in particular was considered formally and harmonically too challenging and at the same time too subtle for the tastes of the average 1930s swing fan. Ellington's big, worldwide success with the public did not come until the 1960s, when he and his orchestra made lengthy annual tours all over the world, had some hugely popular successes with "Satin Doll" (1953) and other compositions, and began to consistently receive accolades—including a Presidential Medal of Freedom and the French Legion of Honour—from the broader musical, artistic, and intellectual community.

Three other musical groups met with outstanding success in the 1920s: Jelly Roll Morton's Red Hot Peppers, Paul Whiteman's Orchestra, and William McKinney's Cotton Pickers. The 17 sides Morton and his Red Hot Peppers recorded for RCA Victor in 1926–27 are among the finest classics of early jazz. Blending late ragtime with the rapidly burgeoning improvisational advances of the time, Morton gathered a group of veterans of New Orleans-style jazz, then in their prime. By avoiding a random succession of solos—indeed, by careful structural planning that astutely distributed the seven players' efforts over the three-minute limit allowed by a 10-inch 78-rpm disc—and by painstakingly rehearsing the group before the recording sessions, Morton achieved an almost perfect balance of ensemble and solo. Miraculously, the improvisations and compositions enhanced each other; thus, solos were integrated into arrangements in a way that remained uncommon in jazz for decades thereafter. Morton recorded both multithematic ragtime pieces (including "Black Bottom Stomp" and "Grandpa's Spells"), each piece with several strains in different chord progressions, and monothematic 12- and 32-bar pieces featuring a single passacaglia-like repetitive harmonic sequence (such as "Smokehouse Blues," "Jungle Blues," and "Dead Man Blues"). These recordings had nothing to do with the typical dance music of the period. Moreover, by balancing compositional unity with a maximum of textural and timbral variety—to an extent that was remarkable in a three-minute miniature form, with only a small band—and by reconciling composition and improvisation as well as polyphonic and homophonic ensembles in one fell swoop, Morton pointed a way toward the future of jazz. Alas, in the quasi-commercial and career-driven world of the late 1920s and 1930s, his comprehensive lesson was learned by only a handful of musicians. But Morton's example may have influenced Ellington, who for reasons never made clear considered Morton his musical archenemy.

Morton's RCA Victor recordings

The case of Whiteman, though completely different, is almost equally important, and certainly Whiteman was of enormous influence. Although he is ignored or maligned by most jazz historians, Whiteman made considerable contributions to jazz, not only because of his orchestra's enormous popularity. More important, Whiteman explored hitherto uninvestigated avenues of expression.

By the mid-1920s Whiteman had expanded his band beyond the size of the standard jazz orchestra—five or six brass, five saxophones, a four- or five-piece rhythm section—to include a small violin section and had incorporated into his dance repertory a number of pieces associated with "serious" and "semiclassical" music. The accusations hurled at Whiteman—that he was "contaminating" jazz with classical affectations and trying to "make a lady out of jazz"—were patently unfair. He not only brought into his orchestra such bona fide jazz musicians as Beiderbecke, violinist Joe Venuti, saxophonist Frankie Trumbauer, and guitarist Eddie Lang but also hired such outstandingly gifted orchestrators and arrangers as Ferde Grofé, Bill Challis, William Grant Still, and Lennie Hayton. Furthermore, by adding multiple wind instruments—even oboe, bassoon, heckelphone, and bass clarinet—Whiteman expanded the registral range of his orchestra from the highest piccolo to the lowest tuba and thereby enriched the orchestra's timbral palette. In this way Whiteman's conception of a jazz orchestra was as original and unique as Ellington's, although entirely different. That the orchestra's arrangements and compositions sometimes suffered from severe instrumental and homophonic overweight cannot be denied. But at their best, when conceived by the likes of Challis and Grofé and imbued by Whiteman's improvisers with a true jazz spirit, his musical contributions are surely not to be sneered at.

McKinney's Cotton Pickers

Both Ellington and Henderson considered McKinney's Cotton Pickers, a Detroit-based band, their only serious rival. The distinctiveness of the Cotton Pickers' work during the band's heyday is attributable primarily to the remarkable leadership and the composing and arranging talents of John Nesbitt, whose work was mistakenly credited to Redman for many decades. Nesbitt was obviously aware and respectful of Ellington's fast-tempo "stomp" pieces. And like Morton, Nesbitt was intent on utilizing his 10- or 11-piece jazz orchestra to produce the most varied yet balanced integration of solo improvisation and arranged ensemble, as well as a maximum of textural and structural variety. In such recordings as "Put It There," "Crying and Sighing," and "Stop Kidding," Nesbitt and the band demonstrated their virtuosic command of what were for their time rather complex scores, replete with implied metre permutations, challenging rhythmic overlays, hard-driving solos, daring modulations, and—as Morton often urged—"plenty of solo breaks."

In these ways the orchestras of Morton, Whiteman, and McKinney (as well as that of Ellington) went considerably beyond Henderson's and Redman's method of setting solos off against arranged ensembles, showing that composition, and not mere arrangement, was completely compatible with jazz.

THE PRECURSORS OF MODERN JAZZ

Bennie Moten, Casa Loma Orchestra, and Benny Goodman. In the early 1930s two bands made important contributions to jazz: Bennie Moten's, with the recordings of "Toby," "Lafayette," and "Prince of Wails," and the Casa Loma Orchestra, with "Casa Loma Stomp" and "San Sue

Strut." The black Moten band had little immediate effect on the greater jazz scene, instead influencing an inner circle of black contemporaries, rivals, and jazz insiders. The driving, explosive, rhythmic energy of the Moten pieces, combined with an unprecedented instrumental virtuosity as well as a splendid balance of solos—by saxophonists Ben Webster and Eddie Barefield, trumpeter "Hot Lips" Page, and others—with riff-based ensembles, forged a breakthrough in orchestral jazz that can be seen as a precursor of modern jazz.

The white Casa Loma band exerted a tremendous influence on a host of dance bands (including, temporarily, some black orchestras, notably those of Jimmie Lunceford, Fletcher Henderson, and Earl Hines). The Casa Lomans' role in the history of jazz remains controversial, but it is clear that they were, at the very least, the first white orchestra to try to swing, though their rhythms were more often peppy than swinging. The Casa Loma Orchestra was also the first white band to feature jazz instrumentals consistently, rather than playing politely arranged dance tunes with an occasional hot solo. In these respects they influenced newly formed swing orchestras, including those led by Benny Goodman, Charlie Barnet, Artie Shaw, and Larry Clinton.

As far as the average jazz fan was concerned, the next big breakthrough occurred with Goodman's band, particularly on August 21, 1935, in the Palomar Ballroom in Los Angeles. On that night, after a weeks-long, dismally unsuccessful westward trek across the country, Goodman's band suddenly became a huge hit. That August night at the Palomar became the event that officially ushered in the swing era, with Goodman soon being hailed as the "King of Swing." That must have been interesting news to the bands of such black bandleaders as Ellington, Moten, Lunceford, Webb, Cab Calloway, and especially Henderson, who had been swinging for some five to seven years. Scores that Henderson had introduced in the late 1920s and early 1930s—"King Porter Stomp," "Wrappin' It Up," and "Down South Camp Meeting"—suddenly became big hits for Goodman, who had acquired both Henderson's arrangements of these numbers and the services of Henderson himself when Henderson's orchestra was forced to disband in 1934. As reinterpreted and energized by the Goodman forces, including the stellar trumpeter Bunny Berigan and the flashy drummer Gene Krupa, these pieces suddenly took on a new life. The Henderson-Redman formula of pitting soloists against ensembles and constantly juxtaposing the different choirs of the orchestra in call-and-response patterns became the widely emulated norm. When the Count Basie band from Kansas City, the successor to Moten's orchestra, reintroduced the riff as another extremely useful structural element, the scene was set for the hundreds of orchestras that had sprung up in the wake of Goodman's success to feed the enormous appetite for swing music of a generation of dance-crazy college-age jazz fans. By the late 1930s the country was awash with dance bands, all adhering to generic swing tenets: antiphonal section work, juxtaposition of solos and ensembles, and increasingly riff-based tunes. Though this led to a great quantity of dross, many talented young arrangers now rushed into the field and produced an impressive amount of astonishingly good music. This excellence is all the more remarkable since the music was created primarily to be danced to, with no pretensions (except in the case of bandleader Artie Shaw) to anything one might call art.

The "King of Swing"

Count Basie's band and the composer-arrangers. Among the innumerable orchestras that populated the jazz scene, Count Basie's achieved enormous importance. Perhaps the most magnificent "swing machine" that ever was, the Basie band strongly emphasized improvised solos and a refreshing looseness in ensemble playing that was usually realized through "head arrangements" rather than written-out charts. Its incomparable rhythm section—Walter Page (bass), Freddie Green (guitar), Jo Jones (drums), and Basie (piano)—supported an outstanding cast of soloists, ranging from the great innovative tenor saxophonist Lester Young and his section mate Herschel Evans to trumpeters Buck Clayton and Harry "Sweets" Edison, trombonists Dicky Wells and Vic Dickenson, and blues singer Jimmy Rushing. The Basie band's steadfast popularity can be measured by the fact that, except for a brief period in the early 1950s, it performed and toured successfully right up to Basie's death in 1984. Even after the height of the swing era, Basie continued to introduce swing masterpieces (including "Shiny Stockings," "The Kid from Red Bank," "Li'l Darling," and "April in Paris"), often featuring extraordinary solos by trumpeter-arranger Thad Jones and vocals by Joe Williams.

It was perhaps inevitable that in the excitement of the burgeoning swing era, jazz fans became obsessed with the reigning bandleaders, the new superstars of music. Little did swing fans realize that the music to which they kicked up their heels was the creation not of orchestra leaders but of arrangers who, behind the scenes, forged each band's distinctive style. The history of jazz has too often been described as the story of the improvising soloists, virtually ignoring the important contributions of the composer-arrangers who provided the soloists' framework. These included Sy Oliver (with the Jimmie Lunceford and Tommy Dorsey bands), Mary Lou Williams (with Andy Kirk's band), Walter Thomas (with Cab Calloway), Eddie Durham, Fletcher Henderson, Jimmy Mundy, Edgar Sampson, Eddie Sauter, Jerry Gray, and Benny Carter.

The swing soloists. Major swing soloists also emerged in the 1930s—most notably tenor saxophonists Coleman Hawkins, Lester Young, and Ben Webster; pianists Art Tatum and Teddy Wilson; and singer Billie Holiday. Hawkins had left the Henderson band in 1933 for what turned out to be a six-year stay in Europe, during which he not only taught most Europeans about jazz and swing but honed and perfected his personal style, which culminated—upon his return to the United States in 1939—in his recorded masterpiece, "Body and Soul." During that period Hawkins's slightly younger contemporaries Young and Webster developed quite divergent and highly distinctive improvisational styles. Webster exerted a powerful influence on Ellington during his 1939–42 tenure with the Ellington orchestra, while Young spawned an important new school of saxophone playing (epitomized by Stan Getz, Zoot Sims, and Al Cohn). In contrast to Hawkins's hyperenergetic, primarily chord-based approach, Young featured a more relaxed, sleek, linear, Southwestern blues-oriented style. Unlike Hawkins's pre-1940s improvisations, which were solidly anchored to their underlying harmonies, Young's lines glided over the harmonies and thereby freed those lines rhythmically.

Tatum and Wilson were both initially inspired by Hines but soon moved in directions different from Hines and from each other. Tatum, the supreme virtuoso technician, developed an astonishingly rich and advanced harmonic vocabulary, which he lavished on his solo improvisations on popular songs. Wilson, more of an ensemble player, led a memorable series of recordings between 1935 and 1937, featuring not only an elite of swing soloists in spontaneously created performances but also the incomparable Holiday.

Billie Holiday

Holiday's singing style was crafted out of an original amalgam of the vocal stylings of Armstrong and Bessie Smith as well as her own vocal-technical limitations—her range was barely more than an octave. With her unique timbre and diction, she reconstructed dozens of popular songs, streamlining and contracting the original melodies and embellishing them with highly personal ornamentations, many of which she absorbed from some of the great instrumentalists of her time. In this sense she was a true jazz singer, constantly re-creating, improvising, and inventing. Moreover, Holiday brought to her art a level of expression and philosophical depth unprecedented in jazz, ranging from abject melancholia and tragedy to the most joyous evocations.

The return of the combo and the influence of the territory bands. In the first decade of jazz, roughly 1915–25, almost all jazz worth considering had been played by small groups, but these were driven away in the 1930s by the arrival of the big bands. Later in the decade there was a return to smaller groups, ranging in size from trios to septets. Foremost among these new small groups were the various Goodman-led combos, starting in 1935. These were the

first racially mixed jazz groups to tour the United States: Goodman and Krupa were white, Wilson and vibraphonist Lionel Hampton black. By 1939–40 permutations of Goodman's small groups included guitarist Charlie Christian and trumpeter Cootie Williams. Among the several dozen recordings produced by these groups, the superb "Body and Soul," "Avalon," "Breakfast Feud," and "Seven Come Eleven" must be singled out.

In 1937 the 20-year-old Nat King Cole formed a trio, initially featuring himself as pianist; it was not until 1940 that Cole began singing and the trio began recording. Their big hits "Straighten Up and Fly Right" (1943) and "Route 66" (1946) made the group one of the top attractions of the mid-1940s, a success that eventually led to Cole's equally brilliant solo singing career. Piano trios and quartets—such as those of Page Cavanaugh, Clarence Profit, Barbara Carroll, Dorothy Donegan, Art Tatum, Lennie Tristano, and Joe Mooney—were among the many successful small groups of the 1940s.

The success of Goodman's small groups not only affirmed the artistic and commercial viability of a true chamber-jazz concept but inaugurated the notion of extracting a small combo from a larger orchestra. This "band within a band" idea spawned many successful groups, such as Shaw's Gramercy Five, Basie's Kansas City Seven, Tommy Dorsey's Clambake Seven, and, of course, Ellington's many small ensembles led alternately by Hodges, Williams, Stewart, and Bigard. Possibly the most perfect small group recordings are the four sides recorded in Paris in 1939 by three Ellingtonians—Stewart, Bigard, and Billy Taylor (bass)—and the great Belgian Gypsy guitarist Django Reinhardt.

The "band within a band"

Also important in the 1930s were the territory bands, notably Walter Page's Blue Devils (out of Oklahoma City, Oklahoma), the Jeter-Pillars band (based in St. Louis, Missouri), and those of Nat Towles (Omaha, Nebraska), Alphonse Trent (Dallas, Texas), Don Albert (San Antonio, Texas), Jesse Stone and Jay McShann (Kansas City), Zack Whyte (Cincinnati, Ohio), and others. Although their music was only sporadically recorded, these nomadic orchestras had considerable influence, for by roaming the Midwestern and Southern hinterlands in trains and broken-down buses and cars, they brought superb jazz to the public, especially the black population. In addition, these bands functioned as traveling music conservatories in which young talent could grow, develop, and gain vital experience.

Several major innovative soloists emerged during this period, among them trumpeters Roy Eldridge and Dizzy Gillespie, singer Pearl Bailey, xylophonist Red Norvo, alto saxophonist Charlie Parker, and Ellington's bassist Jimmy Blanton. With this roster of solo talent and the era's orchestral, compositional, and arranging developments—all inspired by a high sense of professionalism and an unprecedented artistic (but often also commercial) competitiveness—it was inevitable that a new jazz idiom would soon evolve. Ellington's harmonic lessons were finally beginning to be appreciated as arrangers forged beyond simple triadic and dominant harmonies into the various types of 9th, 11th, and 13th chords, all manner of substitute harmonizations, and wide-ranging modulations. On the rhythmic side, $\frac{4}{4}$ swing had by now completely taken over, providing the basis for a new fluency, freedom, and (as desired) complexity in rhythm sections; this in turn freed the soloists and ensembles to explore new structural territories—and all of these developments were expressed with a radically new virtuosity.

JAZZ AT THE CROSSROADS

Bebop takes hold. The first signs of these fresh musical sounds could be heard as early as 1941, particularly in works by such composer-arrangers as Buster Harding, Neal Hefti, Gerry Valentine, and Budd Johnson. Especially explorative and prophetic are such pieces as "The Moose" (1943; by Ralph Burns for the Charlie Barnet band), "Shady Lady" (1942; by Andy Gibson for Barnet), and "To a Broadway Rose" and "'S Wonderful" (1941 and 1944, respectively; both by Ray Conniff for Artie Shaw). Unfortunately, most of what was germinating at that time never got recorded because of a recording ban imposed by the American Federation of Musicians during much of 1942–43. This missing auditory link may have made the arrival of bebop seem more abrupt than it actually was.

While much of what happened between 1941 and 1945 may have appeared revolutionary to musicians and the public alike, the process was actually evolutionary and inevitable. The older guard held on as long as possible, dominating the airwaves well into the mid-1940s. But ultimately the experiments and forward thrusts of bebop—many of them initiated in such places as Minton's Playhouse in Harlem, in small lounges and obscure nightclubs, on tours, and in even more private situations such as homes and hotel rooms—had to break through to an expanding public via record companies and the larger, more popular club venues.

The leading figure in jazz was now Charlie Parker, who, along with his colleagues Dizzy Gillespie (trumpet), Bud Powell and Thelonious Monk (piano), Kenny Clarke and Max Roach (drums), Oscar Pettiford and Ray Brown (bass), and later Lucky Thompson (tenor saxophone), Milt Jackson (vibraphone), J.J. Johnson (trombone), and Miles Davis (trumpet), reshaped jazz on all three important fronts: harmonically, melodically, and rhythmically. Perhaps the most radical advance was rhythmic, when Parker, with his dazzling technique and fluency, turned the former $\frac{1}{4}$ metric substructures into $\frac{1}{8}$; quavers now superseded the basic quarter-note beats, and in effect the audible speed of the music doubled. Parker was, for all his startling innovations, a great blues player, as can be heard not only in his constant reference to earlier blues traditions but also in the depth and beauty of his tone and its often anguished expression. His co-innovators Gillespie and Powell, equipped with both a prodigious technical mastery and a keen sense for harmonic exploration, set dramatically new standards of improvisation. Drummers, too, became more intrinsically involved in the total ensemble effect by introducing a certain contrapuntal independence, expressed polyrhythmically and even melodically.

Charlie Parker

The new, onomatopoetically named bebop, or bop, used more chromatically convoluted melodic lines. Played at high speed, it was no longer aurally related to the sedate song repertory of the 1930s, and it required a greater variety of chord substitutions and passing harmonies. It also built a whole new jazz repertory by superimposing brand new themes onto older, well-known chord progressions, particularly on such standards as "I Got Rhythm" and "How High the Moon." This new repertoire was created mostly for small combos but also for larger ensembles such as Gillespie's, Billy Eckstine's, and Woody Herman's orchestras. As bebop took hold after World War II, the entire jazz scene changed dramatically. Many big bands, even those that tried to make the transition to modern jazz, began to falter both financially and artistically. Touring costs and musicians' salaries skyrocketed. The best musicians preferred to stay in Los Angeles, New York, and Chicago, where they could do the suddenly lucrative studio work. In any case, bebop was played mostly by small combos—quartets, quintets, and sextets. And bebop was made for listening, not dancing; it was not intended to be played to the accompaniment of clinking glasses and nightclub merrymaking.

Swing hangs on, soloists take off. Essentially, the audience for the more or less homogeneous jazz of the 1930s and early '40s (swing) was split three ways. A majority rejected bop and clung to swing, if and wherever they could still find it, or to even earlier styles, such as Dixieland and Chicago-style jazz. Another segment shifted its allegiance entirely to a new breed of singers—Frank Sinatra, Nat King Cole, Sarah Vaughan, Ella Fitzgerald, Mel Tormé, and Billy Eckstine—who came out of the bands and embarked on full-time careers as highly paid "single" acts. The third and smallest faction stayed with the boppers, relishing the music's technical and conceptual challenges and returning jazz to a minority art.

Two singular pianists emerged at this time: Thelonious Monk and Erroll Garner. After Morton and Ellington, Monk was the first major composer to enter the field, contributing in such pieces as "Criss Cross," "Misterioso," and

"Evidence" (all 1948) a uniquely individual repertory. Partly because he had developed a totally unorthodox piano technique, Monk created an inimitable style and touch, as well as highly unusual voicings and chord formations, as can be heard on his Blue Note quartet and quintet recordings of 1947–51 and on his later solo piano recordings of 1957 and 1959.

Equally sui generis yet completely different in intent, technique, and feeling, Garner had developed from his earliest professional days a prodigious both-hands technique (rivaled or surpassed only by Tatum) that allowed him to play asymmetrical rhythmic and melodic configurations and contours with his right hand while maintaining an absolutely steady beat with his left. Not a composer at all in the Monk or Ellington sense and given at times to a certain pianistic pomposity, Garner nevertheless brilliantly recomposed the hundreds of Broadway songs he played during his long career into astonishingly fresh, extemporized pieces.

Although the emphasis of this period was primarily on improvisation—a quintet or sextet did not require an arranger—a number of big bands did try to translate the newfound musical gains into orchestral terms. The results were uneven, inconsistent, and mostly commercially short-lived. Although the best efforts of the Woody Herman, Stan Kenton, Boyd Raeburn, Charlie Barnet, and Harry James bands of the mid- to late 1940s were not without considerable merit, it fell to the Claude Thornhill Orchestra, especially with its many scores by Gil Evans, to produce the only fully original contribution to orchestral jazz apart from Ellington's ongoing work. By adding French horns and woodwinds (including piccolo, bass clarinet, and at times multiple clarinets) and reinstating the tuba in a more melodic and contrapuntal role, Thornhill's orchestra acquired a totally fresh and subtle sound, one considerably softer and more opaque than the bright, loud, brash sonorities of the late swing-era bands. Moreover, with his extraordinary penchant for warm, dark instrumental colours and rich, bitonal harmonizations set in sparkling bop rhythms, Evans went quite beyond mere arranging into recomposing. The best examples can be heard in such pieces as "Robbins Nest," "Lover Man," and the Parker themes "Anthropology" and "Donna Lee."

Gil Evans

COOL JAZZ ENTERS THE SCENE

Chamber jazz and the Modern Jazz Quartet. Perhaps in reaction to the hot, more strident, more frenetic expressions of the postwar bands, or perhaps as a direct influence of the Thornhill-Evans approach, a cool strain entered the jazz scene in the late 1940s. Generated by Young and furthered by such reed players as Lee Konitz and Gerry Mulligan, cool jazz, along with its structural corollary—contrapuntal, harmonically slimmed-down (often pianoless) chamber jazz—was suddenly in. Understatement and a more relaxed expression replaced extroversion and high-tension virtuosity. Examples abound, beginning with the Miles Davis Nonet (1948–50)—a direct offspring in instrumentation and musical intent of the Thornhill band. In such pieces as "Boplicity," "Israel," "Move," and "Moondreams," fine improvised solos by Davis, Konitz, and Mulligan were meaningfully integrated into the arrangers' scores. Various octets, nonets, and other small ensembles soon followed suit, as did such West Coast-based quartets and quintets as those led by Mulligan, Chet Baker, Shelly Manne, Shorty Rogers, Jimmy Giuffre, and Chico Hamilton.

On a slightly different tack, the Modern Jazz Quartet (made up of John Lewis, piano; Milt Jackson, vibraphone; Percy Heath, bass; and Kenny Clarke, soon replaced by Connie Kay, drums) was formed in 1953. After his years with Gillespie, Lewis had been inspired further by his study of classical music, especially the work of Johann Sebastian Bach. Thus, Lewis brought a new kind of compositional (often contrapuntal) integration to the group's repertory, particularly in fugal or quasi-fugal pieces, such as the early "Vendome" or the later "Three Windows" and the album-length work *The Comedy*. Above all, in these performances Lewis sought to bring collective improvisation back from earlier times; many striking examples can be heard on the recordings made by the Modern Jazz Quartet over a period of 20 years, especially in the frequent, remarkable same-register duets of Lewis and Jackson.

Jazz meets classical and the "third stream" begins. It was also in the 1950s that a greater rapprochement between jazz and classical music began to emerge. Like Lewis, many other jazz musicians were studying much of the great classical literature, from Bach to Béla Bartók, to expand their musical horizons. Classical musicians, too, were listening more seriously to jazz and taking a professional interest in it. The ideological and technical barriers between jazz and classical music were beginning to break down. In that climate an apparently new concept or style, termed "third stream" by Gunther Schuller [Editor's note: the author of this article], arose. But third stream music was only apparently new, since European and American composers—including Claude Debussy, Igor Stravinsky, Charles Ives (using ragtime), Darius Milhaud, Maurice Ravel, Aaron Copland, John Alden Carpenter, Kurt Weill, and many others—had employed elements of jazz since early in the century. The difference in the 1950s and '60s was that (1) the third stream amalgams began to include improvisation and (2) the traffic was now no longer on a one-way street from classical music toward jazz but was flowing in both directions. Spearheaded by Lewis and Schuller, the movement produced a wide variety of works and varying approaches to the process of cross-fertilization. Third stream began, particularly in the cultivated hands of pianist Ran Blake, to mate classical concepts and techniques with all manner of ethnic and vernacular musics and traditions as well as with jazz.

Though the term is now seldom used, the concept of third stream remains alive and well; Charlie Haden and Carla Bley's Liberation Music Orchestra works and Randy Weston and Melba Liston's African-influenced compositions are cases in point. Third stream music is also called by other names: crossover, fusion, or world music. So lively and penetrating has the stylistic intercourse been that it is nowadays often impossible to identify a piece as jazz, classical, or ethnic, proof that the third stream ideal of a true and complete fusion (not always technically possible in the 1960s) has at least partially been achieved.

Inter-penetration of styles

Among the myriad contributions to third stream music over the years, Robert Graettinger's works for various Kenton orchestras are crucial. Major atonal, polyphonically complex Graettinger compositions such as *City of Glass* (first performed in 1948) and his remarkable arrangements of standard popular songs reveal a talent of astonishing originality—showing little influence of Stravinsky, Arnold Schoenberg, Bartók, or any major jazz figures—especially unusual for a man so young (he died at the age of 34).

THE MAINSTREAM ENLARGED: MILES DAVIS, JOHN COLTRANE, CHARLES MINGUS, AND OTHERS

In the meantime, the jazz mainstream continually broadened and expanded through the contributions of a wide range of talents from saxophonists Sonny Rollins, John Coltrane, and Eric Dolphy, bassist-composer Charles Mingus, and composer-theorist George Russell to pianists Cecil Taylor, Bill Evans, and Dave Brubeck. Miles Davis and Coltrane exerted the greatest influence, Coltrane especially; he inadvertently bred thousands of clones who copied his sound and turned his every move into a cliché. Much more difficult to imitate and to absorb was the music of Dolphy, who, along with his unequaled mastery of alto saxophone and flute, was the first to conquer the bass clarinet as a jazz instrument. "Stormy Weather" (1960), his nearly 14-minute-long duet improvisation on alto with Mingus, must be counted as one of the greatest creative efforts in all of jazz.

The great wonder of jazz is its open-endedness, allowing truly talented musicians to explore new stylistic and conceptual avenues. Such was the case with Rollins, who—instead of merely releasing a string of unrelated musical ideas—was the first to develop thematic improvisation in such a way that themes or motifs were varied and revisited within a single performance. Equally important was the work of Lennie Tristano, who not only as early as 1945 was successfully exploring the possibilities of atonal im-

provisation but later through his students (saxophonists Lee Konitz and Warne Marsh and composer Bill Russo) created yet another school of jazz playing that emphasized contrapuntal and polyphonic linearity and lean and clear textures of, at times, almost classical austerity.

Although he was a remarkably gifted musician with a deep humility regarding jazz and his art, Coltrane (probably under the influence of Davis) abandoned his earlier fascination with the burgeoning harmonic language of bop—especially Monk's unique tonal explorations—and fell into the trap of modal and single chord confinement. This led to extended improvisations, often lasting as long as an hour, that some observers regarded as "practicing in public."

Art Blakey's Jazz Messengers

Art Blakey's Jazz Messengers, the most renowned and respected of the "traveling conservatories," held forth in the world's jazz clubs and concert halls for more than three decades, hatching a long line of talented players ranging from Horace Silver, Kenny Dorham, and Lee Morgan (in the 1950s) to Freddie Hubbard, Keith Jarrett, Woody Shaw, and (in the 1980s) Wynton Marsalis.

Initially a loyal disciple of Gillespie, Davis by the late 1950s knew that he had neither the embouchure nor the ear for Gillespie's pyrotechnics. Under the benign influence of Gil Evans, John Lewis, and others, he turned to an opulent, more lyrical style with which he and Evans were to make dramatic musical history in such recordings as *Miles Ahead* (1957) and Evans's inspired recomposing of George Gershwin's *Porgy and Bess* (1958). Davis abandoned conventional major and minor harmonies for modal and pentatonic patterns (first fully aired in 1959 on the album *Kind of Blue*), a plunge into a vagrant harmonic no-man's-land that unfortunately infected much of jazz. Modal playing, with its endless pedal points and one-chord bass ostinatos, allowed by definition no harmonic progression or forward movement and resulted in a structural stasis that only, maybe, the greatest improvisers could overcome.

Mingus, together with Parker and Gillespie, was among the most gifted of all the postwar giants. A major composer in the full creative sense as well as a brilliant bass virtuoso and formidable bandleader, Mingus experimented with extended forms as early as the late 1940s ("Mingus Fingers" with Lionel Hampton). His oeuvre ranges from early simple blues and atonal free-form pieces to such poetically named jazz instrumentals as "Pithecanthropus Erectus" (1956), "Haitian Fight Song" (1957), "Fables of Faubus" (1959), and "Peggy's Blue Skylight" (1961) to the monumental two-and-a-half-hour, posthumously premiered *Epitaph*. Accumulated between the early 1940s and 1962 and composed for 31 instruments, *Epitaph* is a gigantic summation of everything Mingus felt and heard in music, from the gentlest lyric ballads and earthy blues to the most complex and advanced Ivesian and Stravinskian orchestral excursions.

FREE JAZZ: THE EXPLORATIONS OF ORNETTE COLEMAN

Whereas most of these postwar musicians worked out their individual styles through personal explorations within the central modern tradition, the arrival of saxophonist Ornette Coleman and trumpeter Donald Cherry constituted an even more radical break from the recent past. Eschewing conventional key and time signatures, Coleman also abandoned all the traditional jazz forms, arriving quickly at something that was to be called "free jazz."

Although partially inspired by the Parker revolution, Coleman's music also harkened back in its linear fragmentation, wailing blues sonorities, and unconventional intonation to a much older, primitive, folklike blues and work song tradition, incidentally more or less cleansed of jazz's earlier European borrowings. Given Coleman's abandonment of traditional forms such as 12-bar blues and 32-bar song forms, it would be wrong to conclude that such works as "Change of the Century" (1959) or *Free Jazz* (1960) are therefore formless. Rather, they are simply subject to a new kind of organization where—in *Free Jazz*, for example—the eight players are each assigned "solo" sections accompanied by all the other players, with the various sections partitioned from each other by predetermined, collectively played motivic materials and the overall formal subdivisions thus clearly delineated.

Though others who followed in Coleman's footsteps—for example, the saxophonists Albert Ayler, Archie Shepp, and George Adams—sought to expand on his free-form innovations, they lacked his innate talent and inherent musical discipline. A creative stasis set in during the 1970s and '80s that eventually led, on the one hand, to a gigantic eclecticism where no style or conception took priority and, on the other hand, to a profound sea change that dramatically altered the face of jazz. This fundamental shift can be seen in the fact that, in contrast to past decades when jazz produced a succession of highly individual artists whose musical styles and personalities could be recognized instantly, by the end of the 20th century jazz had no such distinctive artists.

JAZZ AT THE END OF THE 20TH CENTURY

Whether the past was inherently better than the present is questionable. Something was gained and something was lost. The personal, instantly recognizable distinctiveness of the great jazz players of the past was replaced by an astonishing technical assurance and stylistic flexibility. Most younger players in the 1990s sounded very much alike—with the exception of a few standouts such as trumpeters Wynton Marsalis, Tom Harrell, Randy Brecker, and Dave Douglas, saxophonists Steve Lacy and Joe Lovano, trombonist Albert Mangelsdorff, pianist Gonzalo Rubalcaba, and bassist John Patitucci. Whereas later players functioned well in any stylistic context—even beyond jazz in ethnic and classical realms—the earlier players, great as they were, could not reach out into other stylistic regions. The players of yore did not—could not, in most cases—go to music schools and were in essence self-taught, having learned on the job and to a large extent from each other and from their seniors.

Whether the eclectic versatility of these later generations is good for the future of jazz is as yet hard to say. One fact, however, is clear: in the wake of these changes, composition moved much more into the front and centre of activities—as in the works of Leo Smith, Henry Threadgill, and Dave Douglas—which suggests that the long-standing conflict between improvisation and composition may have finally been resolved. A good part of the reason for this is that most later jazz musicians went to music school—conservatories and university or college music departments—where they took theory, music history, and general music survey courses, and in most cases they also studied with teachers who were themselves major jazz figures. In addition, starting in the 1970s, the enormously expanding number of recordings made available an infinite variety of musical traditions encompassing all jazz styles as well as a rainbow of ethnic, popular, and vernacular musics of all persuasions and philosophies. The younger generations took advantage of this plethora of musical and stylistic resources.

Where this leaves jazz and where jazz goes in the future—indeed, whether jazz can endure as a distinct musical idiom or language—were unanswerable questions at the end of the 20th century. The one truism about jazz is that it remains distinguishable not by *what* is played but by *how* it is played. (G.Sch.)

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(F.E.Ki./D.Er./H.U./L.A.R./W.S.N./La.L./B.Ja./L.Hi./W.V.P./D.W.S./N.Go./H.We./G.Sch.)

Musical Instruments

Musical instruments are almost universal components of human culture: archaeology has revealed pipes and whistles in the Paleolithic Period and clay drums and shell trumpets in the Neolithic age. It has been firmly established that the ancient city cultures of Mesopotamia, the Mediterranean, India, East Asia, and the Americas all possessed diverse and well-developed assortments of musical instruments, indicating that a long previous development must have existed. As to the origin of musical instruments, however, there can be only conjecture. Some scholars have speculated that the first instruments were derived from such utilitarian objects as cooking pots (drums) and hunting bows (musical bows); others have argued that instruments of music might well have preceded pots and bows; while in the myths of cultures throughout the world the origin of music has frequently been attributed to the gods, especially in areas where music seems to have been regarded as an essential component of the ritual believed necessary for spiritual survival.

Whatever their origin, the further development of the enormously varied instruments of the world has been dependent on the interplay of four factors: available material, technological skills, mythic and symbolic preoccupations, and patterns of trade and migration. Thus, residents of Arctic regions use bone, skin, and stone to construct instruments; residents of the tropics have wood, bamboo, and reed available; while societies with access to metals and the requisite technology are able to utilize these malleable materials in a variety of ways. Myth and symbolism play an equally important role. Herding societies, for example, which may depend on a particular species of animal not only economically but also spiritually, often develop instruments that look or sound like the animal or prefer instruments made of bone and hide rather than stone and wood, even when all the materials are available. Finally, patterns of human trade and migration have for many centuries swept musicians and their instruments across seas and continents, resulting in constant flux, change, and cross-fertilization and adaptation.

The sound produced by an instrument can be affected by many factors, including the material from which the instrument is made, its size and shape, and the way that it is played. For example, a stringed instrument may be struck, plucked, or bowed, each method producing a distinctive sound. A wooden instrument struck by a beater sounds markedly different from a metal instrument, even if the two instruments are otherwise identical. On the other hand, a flute made of metal does not produce a substantially different sound from one made of wood, for in this case the vibrations are in the column of air in the instrument. The characteristic timbre of wind instruments depends on other factors, notably the length and shape of the tube. The length of the tube not only determines the pitch but also affects the timbre: the piccolo, being half the size of the flute, has a shriller sound. The shape of the tube determines the presence or absence of the "upper partials" (harmonic or nonharmonic overtones), which give colour to the single note.

This article discusses the evolution of musical instruments, their structure and methods of sound production, and the purposes for which they have been used. Although it focuses on the families of instruments that have been prominent in Western art music, it also includes coverage of non-Western and folk instruments.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, section 624, and the *Index*.

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General characteristics

Musical instruments have been used since earliest times for a variety of purposes, ranging from the entertainment of concert audiences to the accompaniment of dances, rituals, work, and medicine. The use of instruments for religious ceremonies has continued down to the present day, though at various times they have been suspect because of their secular associations. The many references to instruments in the Old Testament are evidence of the fact that they played an important part in Jewish worship until for doctrinal reasons they were excluded. It is also clear that the early Christians in the eastern Mediterranean used instruments in their services, since the practice was severely condemned by ecclesiastics, who insisted that the references to instruments in the Psalms were to be interpreted symbolically. Although instruments continue to be banned in Islāmic mosques (but not in religious processions or Ṣūfī ritual) and in the traditional Eastern Orthodox church, they play important roles in the ritual of most other societies.

Belief in the magical properties of instruments is found in many societies. The Jewish shofar (a ram's horn), which is still blown on Rosh Hashana (New Year) and Yom Kippur (Day of Atonement), must be heard by the congregation. The power of the shofar is illustrated by the story of Joshua at the siege of Jericho: when the priests blew their shofars seven times, the walls of the city fell flat. In India, according to legend, when the deity Krishna (Kṛṣṇa) played the flute, the rivers stopped flowing and the birds came down to listen. The birds are said to have done the same in 14th-century Italy when the composer Francesco Landini played his organetto, or portative organ. In China, instruments were identified with the points of the compass, with the seasons, and with natural phenomena. The Melanesian bamboo flute was a charm for rebirth.

Many of the instruments used in medieval Europe came from western Asia, and they have retained some of their original symbolism. For example, trumpets, long associated with military operations, had a ceremonial function in the establishment of European kings and nobles and were, in fact, regarded as a sign of nobility. In the later Middle Ages and for long afterward, they were associated with kettledrums (known originally as nakers, after their Arab name, *naqqārah*), which were often played on horseback, as they still are in some mounted regiments. Trumpet fanfares, heard on ceremonial occasions in the modern world, are a survival of medieval practice.

TECHNOLOGICAL DEVELOPMENTS

The earliest instruments may have been natural objects, such as bones, shells, or gourds, that had been modified slightly. Such instruments probably produced only one note or served only as a means of amplifying the human voice. The discovery that tubes possessed acoustic properties that enabled them, by vibration of the lips, to sound more than one note was a later development. From using natural objects, it was an obvious step to construct instruments that would serve a similar purpose, using wood or terra-cotta or any other available material.

Development of stringed instruments

Another far-reaching development was the discovery that a stretched string could produce a musical note. This resulted in the construction of the musical bow and the bamboo-fibre zither, instruments whose descendants remain important today. The sound produced by the simple string of such instruments is feeble, however, unless it is reinforced by means of a resonator—*i.e.*, a pot placed on the ground beneath the instrument, a gourd attached to the instrument, the player's mouth, or, in the case of the zither, the bamboo tube from which the instrument is made. The resonator vibrates in sympathy with the string, amplifying the sound.

The first step in the building of any instrument is the selection and preparation of material. Wood used for wind or stringed instruments needs to be seasoned, as do the reeds used in oboes, clarinets, and bassoons. Metals, which are widely used for strings, bells, cymbals, gongs, trumpets, and horns, must be manufactured and cast—often originally by secret processes. Next, the construction and tuning of all but the simplest instruments require skill and craftsmanship: the piercing of a tube to a uniform or expanding width, the flaring of the bell of a wind instrument to increase sonority, the measurement of the bars of a xylophone or glockenspiel, the curvature of the back of a lute, the internal and external structure of the body of a violin. All of these involve accurate workmanship from experts in wood and metal and, in many instances, a knowledge of the mathematics of sound.

The mathematical basis of accurate tuning systems has been the subject of philosophical and scientific speculation since ancient times; nevertheless, no single system has been deemed perfect. All practical tuning systems involve a series of compromises, a fact that instrument makers have known for centuries. The instrument maker's skill, like that of the cabinetmaker and the silversmith, was developed by long practice, and the principles that determine both tone and intonation were discovered by trial and error. The growth of instrumental playing in 16th-century Europe stimulated the production of instruments to be used not merely for ceremonial and official entertainment but also for social occasions and private pleasure. From this time, records began to be kept of the names of makers, many of whom established family businesses that lasted for several generations. These include, for example, Andrea Amati (16th century), violin maker in Cremona; Hans Ruckers (late 16th century), harpsichord maker in Antwerp; and Johann Haas (1649–1723), trumpet maker in Nürnberg.

Instrument makers, who usually have been a forgotten link in the musical chain, have always represented a blend of conservatism with the ability to quickly seize on and use a new constructional technique, a new tool, or a new ma-

terial. Their contribution to both the history of music and the history of musical instruments has been enormous and little appreciated. The older makers of instruments—in Europe and elsewhere—were craftsmen who took delight in the appearance of their work. In some cases, as when pictures were painted on the inside of harpsichord lids or elaborate patterns were carved onto Indian vinas, the ornamentation was purely decorative. Sometimes it served a practical purpose, as when rings of ivory concealed and strengthened the joints in woodwind instruments. In still other instances, it might best be termed symbolic or even totemic, as when the bell of a wind instrument was made in the shape of a dragon's head. Modern taste in most cases rejects ornamentation, but overall design and finish are as important as they have always been.

Modern changes in design

Modern technology has in many cases simplified or improved the construction of instruments. In the past, for example, the tubes of horns and trumpets were made from a sheet of brass cut to the right width, which was rolled into shape, leaving the edges to be joined by brazing. In modern manufacture the tube is drawn in one piece, and there is no seam. Evolution of design has been particularly notable in the construction of woodwind instruments, not only in the fixing of the metal keys and the mechanism that controls them but also in the piercing of holes in such a way that they are acoustically correct. This achievement was due mainly to the pioneering work of Theobald Böhm (1794–1881), who was not only a flute maker but also a performer and composer. His system, designed for the flute, was later applied to the clarinet, the oboe, and the bassoon. The early 19th century saw a revolution in the manufacture of brass instruments as well: the addition of pieces of tubing of different lengths through which the air could be directed by the depression of valves (or pistons), enabling an instrument to produce all 12 notes of the chromatic scale, in place of its earlier limitation to the notes of the natural harmonic (overtone) series.

The discovery of plastics in the 20th century also has influenced the manufacturers of instruments; for example, some makers have used plastic instead of quill or leather for the plectra that pluck the strings of the harpsichord, and plastic recorders have been built. Mechanization has made possible the mass production of instruments of all kinds. Insofar as this makes it possible for people to acquire an instrument at a moderate price, mass production is a good thing, and in education it has been beneficial to schools working on a small budget. A natural development has been the provision of kits consisting of the separate parts of an instrument, which can then be assembled by the purchaser. It remains true, however, that the production of an instrument of the finest quality still demands the highest degree of individual skill. A violin glued together from mass-produced parts cannot be the equal of one that has been meticulously constructed from the first by an individual craftsman who will not be satisfied with his work until every detail of it has been tested.

Importance of craftsmen

Technology has been of service to music by providing composers with instruments they have asked for, by eliminating some defects of instruments, and by making instruments more widely available to the community in general. Richard Wagner, for example, suggested the need for a baritone double-reed instrument akin to the oboe; the resulting heckelphone has been featured in Richard Strauss's opera *Salome* (1905) and subsequent works. Wagner also ordered a special type of tuba for use in his music drama tetralogy *Der Ring des Nibelungen* (*The Ring of the Nibelung*, 1869–76). Not all modern changes in construction have been wholly advantageous, however. It is easier to play in tune on a modern woodwind instrument, but the older examples, being less cluttered with metal fittings, had a purer tone. Similarly, the modern horn is inferior in tone quality to its 18th-century predecessor. Among Western orchestral instruments, only the trombone and the string instruments have remained, apart from minor modifications, unchanged in structure over the centuries (though the substitution of wire strings for gut has materially altered the tone of the violin). In contrast, the rate of technological change in electronic instruments has been almost bewilderingly fast.

CLASSIFICATION OF INSTRUMENTS

Instruments have been classified in various ways, some of which overlap. The Chinese divide them according to the material of which they are made—as, for example, stone, wood, silk, and metal. Writers in the Greco-Roman world distinguished three main types of instruments: wind, stringed, and percussion. This classification was retained in the Middle Ages and persisted for several centuries: it is the one preferred by some writers, with the addition of electronic instruments, at the present day. Some 16th-century writers excluded certain instruments from this classification; the musical theorist Ludovico Zacconi (1555–1627) went so far as to exclude all percussion instruments and established a fourfold division of his own—wind, keyed, bowed, and plucked. A different fourfold classification was accepted by Hindus at least as early as the 1st century BC: they recognized stringed instruments, wind instruments, percussion instruments of wood or metal, and percussion instruments with skin heads (*i.e.*, drums). This ancient system—based on the material producing sound—was adopted by the Belgian instrument maker and acoustician Victor-Charles Mahillon (1841–1924), who named his four main classes autophones, or instruments made of a sonorous material that vibrates to produce sound (*e.g.*, bells, rattles); membranophones, in which a stretched skin is caused to vibrate (*e.g.*, drums); aerophones, in which the sound is produced by a vibrating column of air (wind instruments); and chordophones, or stringed instruments. In their highly influential studies of musical instruments, the Austrian musicologist Erich von Hornbostel (1877–1935) and his German colleague Curt Sachs (1881–1959) accepted and expanded Mahillon's basic division, creating the classification now used in most systematic studies of instruments. The name idiophones was substituted for autophones, and each class was subdivided according to a method similar to that used by botanists. A fifth class, electrophones, in which vibration is produced by oscillating electric circuits, was added later. The table gives examples of instruments that fall within the various categories.

Sachs-Hornbostel system of classification

Classification and Examples of Some Musical Instruments

Idiophones	
Struck	
against each other	cymbals, castanets
with a beater	triangle, glockenspiel, xylophone, slit drums
Shaken	rattle, jingles
Scraped	scraper
Plucked	Jew's harp, music box
Rubbed	musical glasses
Membranophones	
Struck	side drum, bass drum, timpani
Rubbed	friction drum
Blown	mirliton (or kazoo)
Chordophones	
Zithers	
plucked	harpsichord
struck	hammered dulcimer, piano
Lutes	
plucked	lute, guitar
bowed	violin, viola da gamba
Lyres	
plucked	Greek kithara, Ethiopian *beganna*
bowed	Welsh crwth
Harp	Celtic small harp, orchestral chromatic harp
Aerophones	
Free (air not confined)	
without keyboard	bull-roarer, harmonica
with keyboard	harmonium, melodeon
Flutes (air blown against an edge)	recorder, flute
Reedpipes	
single reed	clarinet, saxophone
double reed	shawm, crumhorn, oboe, bassoon, sarrusophone
Lipped	horn, cornet, trumpet, trombone, tuba, serpent
Electrophones	
Monophonic (producing a single line of melody)	theremin, trautonium, Ondes Martenot
Polyphonic (producing harmony and simultaneous melodic lines)	many synthesizers

Many instruments can be played using more than one system of tone production and hence might reasonably appear in several subcategories. The double bass, for example, is usually considered a chordophone whose strings may be bowed or plucked; sometimes, however, the body of the instrument is slapped or struck, placing the double bass among the idiophones. The tambourine is a membranophone insofar as it has a skin head which is struck; but, if it is only shaken so that its jingles sound, it should be classed as an idiophone, for in this operation the skin head is irrelevant. Open flue stops are the foundation of organ tone, but the instrument also has a number of free reed stops, so that the organ belongs equally to the first and second order of aerophones. Modern composers not infrequently require players to treat their instruments in unorthodox ways, thus changing their position in the classification system.

It must be understood that the Sachs-Hornbostel system was created for the purpose of bringing order to the massive collections of musical instruments in ethnographic museums. It is directly analogous to the various book classification systems of libraries and, like them, is arbitrary. Musicians themselves generally think of instruments in terms of their technological features and playing method. To them, therefore, it is logical to group keyboard instruments together, ignoring the fact that in the Sachs-Hornbostel system such instruments fit into several categories.

HISTORY AND EVOLUTION

Man has speculated about the origin of instruments since antiquity. Older writers were generally content to rely on mythology or legends. In the 19th century, partly as a result of theories of evolution put forward by Darwin and Herbert Spencer, new chronologies based on anthropological evidence were advanced. The British writer John Frederick Rowbotham argued that there was originally a drum stage, followed by a pipe stage, and finally a lyre stage. The Austrian writer Richard Wallaschek, on the other hand, maintained that, although rhythm was the primal element, the pipe came first, followed by song, and the drum last. Sachs based his chronology on archaeological excavation and the geographic distribution of the instruments found in them. Following this method, he established three main strata. The first stratum, which is found all over the world, consists of simple idiophones and aerophones; the second stratum, less widely distributed, adds drums and simple stringed instruments; the third, occurring only in certain areas, adds xylophones, drumsticks, and more complex flutes.

Chronologies of origin

The development of musical instruments among ancient high civilizations in Asia, North Africa, and the Mediterranean appears to have emphasized stringed instruments. In Central and South America, wind and struck instruments seem to have been most important. It is not always easy to say whether instruments are indigenous to a particular area, however, since their cultivation may well have spread from one country to another through trade or migration. Nevertheless, it is known that the harp was used from early times in Mesopotamia, Egypt, and India and was imported into China after the end of the 4th century AD. In Greece it was regarded as a foreign instrument: the standard plucked instrument was the lyre, known in its fully developed form as the kithara (or cithara). Apart from the trumpet, the only wind instrument in normal use in Greece was the aulos, a double-reed instrument akin to the modern oboe. The Egyptians used wind instruments not only with double reeds but also with single reeds and thus may be said to have anticipated the clarinet. Peculiar to China was the *sheng,* or mouth organ; the Chinese also used as an artistic instrument the panpipes (*hsiao*), which in Greece had merely a rustic function.

In medieval Europe, many instruments came from Asia, having been transmitted through Byzantium, Spain, or eastern Europe. Perhaps the most notable development in western Europe was the practice, originating apparently in the 15th century, of building instruments in families, from the smallest to the largest size. A typical family was that of the shawms, which were powerful double-reed instruments. A distinction was made between *haut* (loud) and *bas* (soft) instruments, the former being suitable for performance out-of-doors and the latter for more intimate occasions. Hence, the shawm came to be known as the hautbois (loud wood), and this name was transferred to its more delicately toned descendant, the 17th-century oboe. By the beginning of the 17th century the German musical writer and composer Michael Praetorius, in his *Syntagma Musicum* ("Musical Treatise"), was able to give a detailed account of families of instruments of all kinds—recorders, flutes, shawms, trombones, viols, and violins.

Percussion instruments. Drum ensembles have achieved extraordinary sophistication in Africa, and the small handbeaten drum is of great musical significance in western Asia and India. The native cultures of the Americas have always made extensive use of drums, as well as other struck and shaken instruments. In Southeast Asia and parts of Africa, xylophones and, since the introduction of metals, their cousins the metallophones play significant roles. Europe, however, has not placed great emphasis on drums and other percussion instruments.

Stringed instruments. Many varieties of plucked instruments were found in Europe during the Middle Ages and the Renaissance; but bowed instruments eventually came to characterize the area, and they played an important role in the rest of Eurasia and in North Africa as well. The idea of playing a stringed instrument with a bow may have originated with the horse cultures of Central Asia, perhaps in the 9th century AD. The technique then spread rapidly over most of the European landmass.

Origin of viols and violins

The European fiddle existed in various forms: by the 16th century these had settled down into two distinct types—the viol, known in Italy as viola da gamba (leg fiddle), and the violin, or viola da braccio (arm fiddle). The viol has a flat back, sloping shoulders, and six or seven strings; the violin has a rounded back, rounded shoulders, and four strings. The viol, unlike the violin, has frets—pieces of gut wound at intervals around the fingerboard—which make every stopped note (*i.e.,* the string being pressed by the finger to produce a higher pitch) sound like an open (unstopped) string. The violin, being the smallest member of the family, came to be known by the diminutive violino: the tenor of the family was called simply viola, while the bass acquired the name violoncello, a diminutive of violone ("big fiddle").

Keyboard instruments. Only in Europe did the keyboard develop—for reasons that are not clear. The principle of the keyboard has been used successfully to control bells (the carillon), plucked and struck stringed instruments (the piano and harpsichord), and wind instruments (the organ, the accordion, and the harmonium).

Of all instruments, the organ showed the most remarkable development from the early Middle Ages to the 17th century. Originally, sound was admitted to the pipes by withdrawing sliders or depressing levers. Both of these methods were clumsy: they gave way to a reduction in the size of the levers, which eventually could be depressed by the fingers, while the larger pipes were controlled by pedals. A further development was to separate the various rows of pipes, so that each row could be brought into action or suppressed by means of a draw stop. Once a manageable keyboard had been produced, it could be applied to the portable organ, carried by the player, which was already in use by the 12th century. Scientific experiments with the monochord, a stretched string that could be divided into various lengths by means of a metal tangent, were followed by the construction of an instrument with a whole range of strings and a keyboard similar to that of the organ—the clavichord. A similar adaptation of the plucking of stringed instruments led to the harpsichord, the ingenious mechanism of which had been perfected by the 16th century. It is curious that a similar method was not applied to the dulcimer, which was struck with hammers, until the early 18th century, when the Italian maker Bartolomeo Cristofori constructed the first pianoforte, so-called because, unlike the harpsichord, it could vary the tone from soft (*piano*) to loud (*forte*).

The clavichord, harpsichord, and piano

Wind instruments. In Europe, the practice of constructing instruments in families continued from the 17th century onward. English composers wrote for the tenor

hautbois, the intermediate oboe d'amore, and the bass, or baritone, oboe. The clarinet (the name means "little trumpet") emerged at the end of the 17th century and, like the oboe, developed into a family extending to a contrabass clarinet in the 19th century and later a subcontrabass. It established itself only gradually in the orchestra in the course of the 18th century.

Trumpets and horns were used in most areas of Eurasia for ceremonial and military purposes. They remained relatively unchanged until the early 19th century, when valves were added to European instruments. This modification also led to the creation of new types. A pioneer in the field was the Belgian instrument maker Antoine Joseph Sax, who in 1845 built a family of valve instruments called saxhorns, using the bugle as the basis for his invention. Similar instruments were widely adopted in military and brass bands, but only the bass, under the name bass tuba, became a normal member of the orchestra. Sax also invented the saxophone, a single-reed instrument like the clarinet but with a conical tube. This, too, was made in various sizes, which came to be used both in military bands and in jazz ensembles. The saxophone never became a normal member of the orchestra, but the alto and the tenor have been used by composers, largely as solo instruments, and occasionally a complete quartet of four different sizes has appeared in an orchestral work.

Use of instruments based on volume of sound

Ensembles. The variety of musical ensembles used throughout the world is vast and beyond description, but the following principles apply nearly everywhere. Outdoor music, often ceremonial, most frequently involves the use of loud wind instruments and drums. Indoor music, for passive listening, emphasizes such quieter instruments as bowed and plucked strings and flutes.

The establishment of orchestras, as opposed to chamber groups, in the early 17th century led to a slight revision of these principles in Europe. The orchestra's sound is founded on a large ensemble of bowed strings, but it adds the once-outdoor instruments (wind and percussion) for colour and climax. As concert halls increased in size and popularity, so too did the sound-volume requirements of so-called indoor instruments. One result was that the violin family was favoured at the expense of the quieter viols. The latter, along with other instruments whose tone was too weak for orchestral music, gradually dropped out of use until the 20th century, when earlier styles of music experienced a revival in popularity.

Automatic instruments. Water power, clockwork, steam, and electricity have all been used at various times to "power" musical instruments, enabling them to produce sound automatically. Examples include church bells, automatic organs, musical clocks, automatic pianos and harpsichords, music boxes, calliopes, and even automatic orchestras. Most of the impetus behind this phenomenon ceased with the development of the phonograph and other recording devices of the 20th century.

Electric and electronic instruments. The development of electricity led not only to its use for mechanical purposes—for example, to control the key action and wind flow in the organ—but also as a means of amplification (*e.g.*, in the vibraphone). With advances in electronics technology, players can now also make use of computers to generate and store tones and musical patterns. The growth of companies manufacturing electronic and digital instruments has been rapid, and the use of electronic equipment such as sound synthesizers and tape recorders to produce and combine sound unrelated to the musical scale has become common. (J.A.W./T.Gr.)

Percussion instruments

CLASSIFICATION

Two distinct groups of musical instruments, namely, idiophones and membranophones, make up the large classification known as percussion instruments. Idiophones are instruments whose own substance vibrates to produce sound (as opposed to the strings of a guitar or the air column of a flute); examples include bells, clappers, and rattles. Membranophones emit sound by the vibration of a stretched membrane; the prime examples are drums. Although many idiophones and some membranophones are tunable and hence may be melody instruments, both groups serve typically to delineate or emphasize rhythm. Percussion instruments form the third section of the modern Western orchestra, stringed and wind instruments making up the other two sections. The term percussion instruments dates to 1619, when Michael Praetorius wrote of *percussa, klopfende Instrument* (German *klopfen*, "to beat") as any struck instrument, including struck chordophones (stringed instruments). The same combination, including pre-bow chordophones, constituted the *divisio rhythmica* in the 7th-century *Etymologiae* of Isidore, archbishop of Seville.

Types of idiophones

Idiophones. Idiophones form a diverse and disparate group. Concussion instruments, consisting of two similar components struck together, include clappers, concussion stones, castanets, and cymbals. Percussion idiophones, instruments struck by a nonsonorous striker, form a large subgroup, including triangles and simple percussion sticks; percussion beams, such as the *semanterion;* percussion disks and plaques, single and in sets; xylophones, lithophones (sonorous stones), and metallophones (sets of tuned metal bars); percussion tubes, such as stamping tubes, slit drums, and tubular chimes; and percussion vessels varying from struck gourds and pots to gongs, kettle gongs, steel drums, bells, and musical cups.

Shaken idiophones, or rattles, include vessels filled with rattling material, such as pellet bells and gourd, basketry, and hollow-ring rattles; strung rattles, such as dancers' leg rattles or anklets; stick rattles, including the sistrum, originally a forked stick with crossbars on which rattling shells, etc., were strung; pendant rattles with suspended rattling objects; and sliding rattles.

Other categories include scraped idiophones, comprising scrapers and cog rattles; split idiophones made of split hollow cane, including the Southeast Asian "tuning fork" idiophones and the chopstick; plucked idiophones, or linguaphones (so named because of their plucked tongues), such as the Jew's harp, sansa, and music box; friction idiophones, including friction sticks, simple or combined, and musical glasses; and blown idiophones, such as the 19th-century *Aolsklavier* and *piano chanteur.*

Membranophones. Musical instruments in which the sound-producing medium is a vibrating membrane fall into four main groups: kettledrums and bowl-shaped drums; tubular drums—whether cylindrical, barrel, conical, double conical, hourglass, goblet, or shallow—and rattle drums, the membranes of which are set in motion by enclosed pellets or by knotted ends of a thong or cord; friction drums, with membranes caused to vibrate by friction; and mirlitons, whose membranes are set in motion by the sound of an instrument or the human voice. Strictly speaking, mirlitons are voice modifiers rather than true musical instruments inasmuch as they have no pitch of their own.

Kettledrums and tubular drums occur in both tunable and nontunable forms; friction drums and mirlitons are not tunable. The membranes of the first two groups are either glued, nailed, lapped, or laced to the body, or shell; if they are glued or nailed, the pitch can be modified by exposure to heat. Lapped and laced heads are readily tunable by tightening the lacings or screws, and wooden wedges may be inserted between the shell and lacings to further increase the membrane's tension and thus raise the pitch. The membranes of such instruments and of friction drums are set in vibration by percussion, while those of mirlitons vibrate by impact of sound waves. In all groups the shell plays a subordinate acoustical part, acting as resonator only. The greater the diameter of a head, the deeper is its sound; and the greater its tension, the higher is the pitch. In Western culture the only drums tuned to a definite pitch are kettledrums (the orchestral timpani).

Methods of sounding membranophones

Kettledrums and tubular drums may be struck with the hands, with beaters, or with both combined or with the knotted ends of a thong or cord. Beaters can be cylindrical, club-shaped, straight, curved, or angled, with or without knobs or padding, or may take the form of a switch or wire brush. Friction drums are sounded by rubbing the membrane with a piece of hide or by the more usual

method of working an inserted friction stick or cord up and down or by rubbing the membrane with a player's wet fingers. Acoustically, they are subject to the same laws as other membranophones, but the speed of friction is an influencing factor. They occur in Africa, America, Europe, Asia (India and Japan), and Hawaii. Mirlitons are sounded by directing against the membrane the vibrating air column of a voice, be it human (as in a kazoo) or instrumental (as when affixed, for example, to African xylophone resonators), or by holding the membrane against the player's vibrating vocal cords.

In addition to the four major categories of membranophones, a small group of "predrums" composed of ground drums and pot drums, can also be distinguished. Ground drums, consisting in their simplest form of an animal skin stretched over the opening of a pit, are still found in many parts of the world. The skin may also be held taut by several players, each beating it with a stick. These and similar ground drums are played by women in Africa and Australia, and in North America usually by men. By their very nature ground drums are nonportable; when need arose for a smaller "drum," a skin was stretched over the opening of a gourd, clay pot, or other object. Among the Swazi of South Africa such skins are not attached but held taut. Pot drums are found in Asia, Africa, and America—in Africa and America often in connection with exorcism.

PERCUSSION INSTRUMENTS IN EUROPE

Antiquity. Europe received most of its percussion instruments either directly or indirectly from the sophisticated cultures of the ancient Middle East or from Egypt, a country regarded by the Greeks and Romans as forming part of Asia rather than Africa.

Idiophones. European antiquity knew many idiophones. Dancers' clappers, held pairwise in the hands of maenads (women participants in Dionysian rites) and other female dancers, often stressed the rhythm of accompanying *auloi* (the ancient Greek reed pipes). The time-beating foot clappers of chorus leaders, attached to the right foot like a sandal, were known in Greece as *kroupezai,* or *kroupala,* and adopted by Rome as the *scabella.* Other idiophones included bells, cymbals, the unidentified *ēcheion,* and an instrument simply called "the bronze" (*chalkos*), probably a metal percussion disk. When the cult of Isis spread to Greece and Rome, her sistrum followed, always in the hands of a priest or—rarely—priestess.

Roles of instruments

With the exception of clappers, all these instruments were of bronze; as such they were credited with the apotropaic powers (the special protective powers against evil) accorded this metal in the East. For example, both in various Asian islands and in Greece it was customary to "sound the *chalkos* at eclipses of the Moon because it has power to purify and to drive off pollutions" (a scholiast, writing on Theocritus). According to the Roman poet Ovid, the annual visit of ghosts of the dead to their former homes was terminated by requests to depart emphasized by the clanging of a bronze plate. The thin, bronze percussion disks were affixed to metal handles; one from Pompeii is even garnished with pellet bells. Small bronze bells, which made a clanging rather than ringing sound, warded off evil spirits, averted the evil eye, served as sentinels' and watchmen's signal instruments, or were attached to the handle of a Greek warrior's shield in order to terrify the enemy by their clamour. Small bells were also frequently worn on anklets by jesters, dancers, and courtesans, particularly in Hellenistic times. In Rome, *tintinnabulae* ("bells") served as signal instruments or were suspended from the necks of herd animals—again to ward off evil.

Deeply cupped cymbals, played together with a frame drum, were sounded in religious rites and at secular dances. Forked cymbals known as *crotala* traveled from Egypt to Greece and Rome, and finger cymbals were introduced from the East, chiefly for dancers, a pair being attached to thumb and middle finger of each hand.

Among the oldest instruments of mankind, rattles originally combined the functions of prophylactic amulets and children's toys, and both functions continued to coexist as late as Roman times.

Membranophones. Only a few kinds of drum, none indigenous, were known to antiquity. The frame drum came from Mesopotamia at an early date. The barrel drum was possibly known in Hellenistic times, for it appears in the Greco-Indian culture of Kushān. A shallow drum is depicted on a Greco-Scythian metal *gorytus,* or bow and arrow case, of the 4th century BC, but no evidence exists of its having been known to Greece. Frame drums, traditionally women's instruments in the Middle East, remained in the hands of female players and dancers in Greece, and the Eastern playing technique was maintained: held upright on edge in the palm of one hand, the drum was tapped with the fingers of the other. Probably introduced into Greece in the 6th century BC with the cult of the great mother-goddess Cybele, the frame drum is depicted as being played by maenads and was also a cult instrument in rites of the Orphic religion. From Greece the frame drum passed into Rome, where it was also associated with Cybele. Romans also had double-headed drums and spread them as far north as the Isle of Wight, in Britain, where one is represented on a mosaic pavement as a dancing girl's instrument. In the late days of the Roman Empire, frame drums became instruments of street musicians and *joculatores* (professional entertainers); the latter are probably responsible for spreading them beyond the Italian Peninsula.

The frame drum

The Middle Ages. *Idiophones.* Greek and Roman idiophones were passed on to postclassical Europe, their distribution undoubtedly aided by *joculatores* and civic or court musicians (minstrels). Whereas prior to the adoption of Christianity most were ritual instruments, their function in medieval times—with the notable exception of the bell—was strictly secular.

Clappers (*tabulae*), flat pieces of bone or wood, were used to flush out birds for hunting and to provide rhythm for popular dancing. Lepers also sounded them to warn others of their approach.

Dancers' castanets, hollow clappers in bivalve form, were played in Spain throughout the Middle Ages; they are illustrated from the 11th century on. Already in Roman times, dancers of Cádiz are known to have played metal castanets, but those of sonorous hardwoods have been preferred since. They are mentioned in the *Cantigas de Santa Maria* by Alfonso X (The Wise). Cymbals remained virtually unchanged throughout the medieval period, resembling closely those used by the Greeks and Romans. Probably cast rather than spun, they were held horizontally, one above the other. Small, cup-shaped cymbals called *acetabulae,* made of brass or silver, are mentioned by Cassiodorus (d. *c.* 580) and Isidore of Seville. Although the modern practice of striking a single cymbal with a stick was anticipated by Isidore and by the *Suda* lexicon (late 10th century), larger cymbals continued to be played pairwise and—at least in the later Middle Ages—were found among the "loud" instruments that accompanied dancing and were played at seigneurial festivities.

Bells were still thought to possess apotropaic powers; with their adoption, the Christian church took over the belief that ghosts and demons could be put to flight by the sound of metal, a power henceforth augmented by the protection afforded by association with the divine cult and, more specifically, by baptism. The rite of baptizing bells is first recorded in a capitulary (civil ordinance) of Charlemagne of 789. Exorcizing celebrants sounded handbells or wore bells on their garments. St. John Chrysostom (d. 407) felt compelled to protest the custom of attaching bells to the clothing or bracelets of children in order to preserve them against demons, yet small bells or pellet bells continued to adorn the vestments of priests, a practice inherited from the ancient Middle East (51 bells ornamented the cope of Lanfranc, an 11th-century archbishop of Canterbury). The tolling of passing bells was intended to ward off evil spirits from dying persons. Church bells announced the time of day, summoned the faithful to worship, sounded alarms, fought off lightning, broadcast the news of peace or the birth of a princeling, and praised God. In secular life handbells were played in mixed instrumental ensembles, usually one bell in each of the player's hands.

Symbolic importance of bells

Tuned bells strung together to form chimes were the

most highly regarded percussion instruments of the Middle Ages. They appear frequently in manuscript illuminations from the 10th century onward, particularly associated with representations of King David. Chimes are generally shown in groups of from four to nine as clapperless, hemispheric bells struck on the outside by a hammer. According to the monk Theophilus (12th century), their pitch was determined by the thickness of the casting rather than the size. From the 13th century, thanks to the wholesale adoption of Islāmic techniques for making astronomical hardware and automata, linkwork, and gearing, chimes were connected to clockwork and struck mechanically. As bells grew larger and the compass of the chime was extended, it became known as a carillon. The distinction today is merely one of compass, any set exceeding $1\frac{1}{2}$ or 2 octaves in compass being considered a carillon.

In secular life, pellet bells were suspended from ladies' belts or worn by jesters. During the 15th century in particular, dancers of the popular moriscas, or Morris dances, attached small bells to their hose.

Before the introduction of bells in the Greek Orthodox church in the 11th century, the *semanterion,* a percussion beam sounded by a striker, summoned the congregation, and in the Roman Catholic church it has been used as a substitute for bells during Holy Week. Triangles first appear in the 14th century; originally a number of loose, rattling rings were threaded on the lower portion, as though the ancient sistrum had projected itself through the centuries. Scraped idiophones, known in Europe since Paleolithic times, are encountered as scraped pots intermittently from the 12th century on; such noisemakers were played—to judge by a 14th-century miniature—with other percussive instruments, such as jingle-rings and pellet bells, for merrymaking. Few instruments are as suitable for personal music making as the Jew's harp; coming from Asia, it passed through Rome, but there is no evidence of its presence in the West before the mid-14th century, although it is unlikely to have disappeared completely during the intervening centuries.

Noise-making and musical improvisation

Most of the above idiophones are nontonal; with the exception of bells and percussion beams, they form part of the *musica irregularis* decried by writers such as the German organologist Sebastian Virdung in 1511 and as such were restricted to popular entertainment or signaling. Written music of this period does not help to determine whether, or how, idiophones were played with voices or with other instruments.

Membranophones. Frame drums, possibly introduced into medieval Europe through Spain, were popular from the era of the Crusades. The most common form was the tambourine, or timbrel, a single head on a shallow body, furnished with four or more sets of jingles placed equidistantly around its rim. Pictorial sources show the instrument being played by both males and females, particularly for accompanying the voice. Literary evidence supports this as well, and in the 14th century Boccaccio writes of it as accompanying singing, too. Jingle rings and pellet bells were also found during this era in popular music making.

Double-headed drums served to provide rhythmic accompaniment in the Middle Ages; and in the 7th century is found the first evidence of their being played with drumsticks, a technique adopted from Asia. The small, rope-strung cylinder drum known as the tabor entered western Europe during the Crusades; the earliest known pictorial evidence is a 12th-century English illumination showing a *jongleur* disguised as a bear striking a barrel drum suspended from his neck. Varied in size and depth, the tabor was provided with a snare (material such as gut stretched across the head to produce a rattling sound) and struck with a stick. Played together with the three-holed pipe, it formed a lively one-man band and was found in both aristocratic and popular circles as an accompaniment for the dance. The larger double-headed cylindrical, or long, drum was associated with the military. Slung at an angle to the player's left, it was played with two sticks and was popularized by Swiss mercenary troops serving in European armies from the 15th century.

The naker

The naker (*naqqārah*), a small kettledrum of Arabic or Saracenic origin, was made of clay, wood, leather, or metal. It was shaped like a kitchen mixing bowl with a diameter ranging from 15 to 25 centimetres. Carried in pairs at the player's waist by means of a belt or harness, each tuned to different indistinct pitches, nakers were played with two short wooden sticks. The skin was tensioned by means of a lattice of ropes, which could be tightened or loosened. Nakers spread rapidly throughout Europe during the 12th and 13th centuries. They are mentioned in epic poems of the time, and records indicate that almost every court employed a nakerer among its regular stable of musicians.

Larger kettledrums were known for some time to the crusaders, merchants, and other travelers to the Middle East, but it was not until the 15th century that the instrument, mounted in pairs on horseback, found its way into western Europe. They created a sensation in 1457 when a Hungarian embassy entered Paris; such "large cauldrons" had never before been seen, and the horses pranced to the rhythm of the drums. The skins, mounted on rims attached to the instrument by screws, could be tensioned precisely, thus producing true musical notes. Henceforth, following Eastern custom, kettledrums were associated with nobility as an adjunct to pomp and circumstance and a symbol of power and prestige.

The less common friction drum first appears in the late 12th-century sculpture of the archbishop's palace at Santiago de Compostela, in Spain, complete with friction rod. Although it undoubtedly continued to be used, it is not known to be either pictured or mentioned again until the 17th century.

The Renaissance, Baroque, and Classical periods. *Idiophones.* Additional idiophones came into use from the Renaissance on. The xylophone, long widespread throughout Asia and Africa, was illustrated in 1529 by Martin Agricola. In 1618 Praetorius depicted an instrument with 15 bars from 6 to 21 inches (15 to 53 centimetres) in length, tuned diatonically. It remained little exploited until the Flemish carillonneurs combined it with a keyboard and transformed it into a practice instrument in the first half of the 17th century. The older form remained a folk instrument, chiefly in and east of Germany.

Gongs were always considered alien instruments: although the word gong was known in the 16th century, its use is not further recorded until the late 18th century. It was first employed in orchestral music by the French composer François-Joseph Gossec in 1791. Since then, gongs of indefinite pitch have been included in orchestral scores by Giacomo Meyerbeer, Tchaikovsky, and others for arresting effect. For generations both flat and bossed (knobbed) gongs also performed the lowly task of summoning the family to meals.

Cymbals were apparently forgotten during the Renaissance; they reappear in the German composer Nicolaus Adam Strungk's opera *Esther* (1680) to provide local colour but seem not to have been in general use until the craze for Turkish Janissary music gripped Europe a century later. Gluck used cymbals in *Iphigénie en Tauride* (1779), as did Mozart in *Die Entführung aus dem Serail* (*The Abduction from the Seraglio,* 1782) and Haydn in his Symphony No. 100 (*Military Symphony*) some 11 years later. By the time of Beethoven they had acquired a permanent place in the orchestra.

Bells grew larger until the largest ever produced, the Tsar Kolokol III (Emperor Bell III; 1733–35) of Moscow, weighing about 400,000 pounds (180,000 kilograms), proved too cumbersome and heavy for hanging. The hemispheric form was abandoned early as chimes became larger, culminating in tower-borne carillons brought into existence by progress in casting methods and mechanization. Chime bells were connected to town clocks and then hung in separate bell towers, along with a mechanism of external hammers—Chinese in origin—for hitting the bells. Carillons in the Low Countries and northern France had in addition one of the first examples of the stored program. A large wooden barrel or metal cylinder revolved by weight and pulley, furnished with appropriately placed iron pegs indicating the melody; the pegs activated the levers and jack work releasing the hammers that struck the bells. Chorale preludes, hymns, and popular melodies

Carillons

announced the time of day in European carillons, while in Britain, short chime sequences activated by a clock fulfilled the same role. In addition, British tower bells could be rung in "changes"—a series of mathematical permutations—on bells hung dead. The role of small bells became negligible, although handbell ringing was (and still is) a hobby in England.

Metallophones reached northern Europe from Indonesia in the second half of the 17th century and, like the xylophones, were promptly adopted by carillonneurs. In both the Low Countries and the regions to which such instruments spread from there, steel was the metal employed for bars. A specially constructed instrument with keyboard-activated hammers was employed by Handel in 1739 in his oratorio *Saul* and in his revival of *Acis and Galatea* (1718); another, struck with a beater, is found in Mozart's *Die Zauberflöte* (*The Magic Flute,* 1791).

Plucked idiophones became more important after the Middle Ages. Jew's harps were part of the regular stock-in-trade of instrument dealers in the 16th and 17th centuries, and in the mid-18th century the playing of multiple Jew's harps is mentioned. Several of these little instruments combined in a single frame were played by virtuosos in the late 18th and 19th centuries and enjoyed enormous popularity. Miniaturization of musical clocks resulted in the creation of the music box, a linguaphone provided with a metal-comb mechanism made from about 1770 on, chiefly in Switzerland. In its heyday—1810 to 1910—it was an immensely popular household instrument with a repertoire of opera arias, folk songs, popular tunes of the day, and waltzes (after the mid-century). In the late 19th century it was transformed into a free-reed wind instrument (aerophone) by the substitution of free reeds for the metal comb, but both forms were rendered obsolete by the phonograph.

Experimental instruments

During the 18th century several friction idiophones were introduced, among them the nail violin of Johann Wilde (*c.* 1740), with its tuned nails bowed by a violin bow. More characteristic of the period were the friction-bar instruments arising as a result of the German acoustician Ernst Chladni's late 18th-century experiments, particularly those concerned with the transmission of vibrations by friction. Chladni's own instrument, the euphone of 1790, and the aiuton of Charles Claggett of about the same time were first in a series of models, some with piano keyboard and horizontal friction cylinder or cone acting on upright bars and others with bars stroked by the player's fingers or bowed by a continuous bow.

Musical glasses are considerably older: the tuned metal cups or bowls of Asia (sometimes played in India as friction vessels) were transformed in Europe into tuned glasses and are first seen in the *Musica theoretica* (1492) of the Italian musical theorist Franchino Gafori. One hears of them intermittently thereafter until they come to the fore in the mid-18th century as concert instruments. The rims of glasses of graduated sizes containing enough water to tune them were rubbed by the player's moistened fingers. By the 1760s they had attracted the attention of the American scientist and philosopher Benjamin Franklin, who proceeded to convert them into a more efficient and, above all, a polyphonic (many-voiced) instrument, which he called armonica—now known as the glass harmonica. Its popularity was immediate. Mozart's *Adagio und Rondo* K 617 was written for it, as was his *Adagio für Harmonika* K 356, both performed in 1791. Efforts to combine it with a keyboard enjoyed only a passing vogue. Among the last to write for it was the French composer Hector Berlioz in his *Fantasia on The Tempest* of 1830; a decade later it was replaced by the growing family of free reeds.

Membranophones. By the Renaissance, Europe had a variety of drums performing specialized functions: frame drums and small tabors accompanied dance and song; larger tabors served as time beaters in small mixed ensembles; great cylinder drums with fifes were placed at the disposal of foot troops; large kettledrums and trumpets were restricted to cavalry and ceremonial music of the aristocracy. The music was at first improvised; later both outdoor carousel music and indoor polychoral sacred music were written for one or two pairs of instruments, sometimes in two contrasting ensembles or choirs—for example, Johann Heinrich Schmelzer's *Arie per il balletto a cavallo* (1667).

Kettle-drums

Kettledrums were introduced into the orchestra about 1675–90 by Jean-Baptiste Lully in *Thésée* and by Henry Purcell in his *Ode for St. Cecilia's Day.* With the development of new playing techniques, modified drumstick heads, and the possibility of notating their music (hitherto prohibited by the rules of secrecy imposed upon guild members), kettledrums, henceforth called timpani, triumphantly entered orchestra, opera, and church, soon becoming the most important percussion instrument in the orchestra. J.S. Bach included a timpani solo in his Cantata No. 214 (*Tönet, ihr Pauken!*) and again in his *Christmas Oratorio* (1735). Haydn also wrote significant parts for the instrument. It was Beethoven, however, who liberated the drums from merely rhythmic functions and their conventional tunings; he was also one of the first to write chords for the instrument.

The snare drum remained primarily a military instrument, although Handel used it in his *Musick for the Royal Fireworks* (1749) and Christoph Gluck wrote for it in his opera *Iphigénie en Tauride* (1779). The bass, or "Turkish," drum was rare in Europe until the craze for Janissary music in the later 18th century; it was found in Gluck's *Le Cadi dupé* (1761), Mozart's *Die Entführung aus dem Serail,* and Haydn's *Military Symphony.*

The northern frame drum, or tambourine, was given the status of a salon instrument by 18th-century French society, and, combined with harp or keyboard instrument, it could be heard at fashionable soirees.

Friction drums maintained an existence (and still do to this day) in various parts of Europe, where they were played at Christmas, during the carnival season, or to greet the New Year.

Developments after 1800. In general, until the early 19th century, the trend in Western musical culture had been to make diminishing use of nontonal percussion instruments. Those that succeeded in gaining access to the orchestra were used sparingly, often only as special effects or indications of local colour. By the mid-20th century, this trend had been reversed, especially in popular music, in which percussion instruments, both traditional and alien, play a basic part. Castanets, for example, either clicked together rhythmically or in sustained rolls, had been little more than dancers' instruments since the 16th century. Wagner was probably the first major composer to use them, in the Paris version of his opera *Tannhäuser* (1861); 14 years later Bizet employed them with great effect in his opera *Carmen.* Now, modern rhythm bands frequently include one or two single castanets or a pair attached to a long handle for ease in clicking.

On the other hand, tonal percussion instruments have assumed increasing importance. Those inherited from the Middle Ages, such as xylophones and Jew's harps, were expanded to the limit of their potential; others were imported and modified to meet local requirements. Influenced by the great popularity of the piano, keyboards were adapted to numerous 19th-century idiophones in an attempt to render hitherto monophonic (single-voiced) instruments polyphonic.

The 19th century. The 19th century saw a rise in the use of percussion instruments in orchestral music. For example, Berlioz called for 10 cymbals in his *Requiem* (1837), some struck together, others to be hit with various drumsticks. Tchaikovsky used syncopated cymbal crashes in his overture *Romeo and Juliet* (1870). The solo triangle appeared in Liszt's First Pianao Concerto(1849), and Wagner called for rolls or tremolos on the instrument in both *Die Walküre* (*The Valkyrie*) and *Die Meistersinger* (*The Mastersingers*). Saint-Saëns included a xylophone solo in his *Danse macabre* (1874). Among membranophones, the snare drum is given a solo in Rossini's overture to *La Gazza Ladra* (*The Thieving Magpie,* 1817), and Berlioz, Wagner, and Richard Strauss each made use of the tenor, or long, drum. The bass drum was employed by Beethoven in his Ninth Symphony (1824) and by Verdi, who asked for hard, loud blows in his *Requiem* (1874).

Several new instruments—or at least new versions—were

New instruments

introduced in the 19th century. The glockenspiel (from the German *Glockenspiel,* "bell chime") was originally a bell chime, as its name indicates. Its transformation into a metallophone was in response to the need for a portable instrument. For marching bands the bars were hung in a lyre-shaped frame; for symphony and opera orchestras—and today rhythm bands as well—a large, horizontal glockenspiel shaped like a xylophone is used. Graduated steel bars struck from a keyboard by piano hammers form the celesta, patented in 1886 by Auguste and Alphonse Mustel of Paris; Tchaikovsky used the celesta in his ballets *The Sleeping Beauty* (1890) and *The Nutcracker* (1892), and it is found in opera scores and light orchestral music as well. Late 18th-century experiments with graduated sets of tuning forks struck by hammers from a keyboard produced the 19th-century "tuning-fork pianos," the most noteworthy of which were different models of Victor Mustel of Paris from 1865 on. Tubular bells are European adaptations of Southeast Asian bamboo chimes. They started appearing as substitutes for traditional bells, which were both expensive and cumbersome, in the 19th century, first in the form of steel bars, then hollow bronze cylinders, and finally brass tubes struck with wooden mallets.

Mirlitons, with their ability of amplifying and colouring tone, had been known in Europe since at least the 16th century, but they did not gain popularity until the early 19th century. From 1883 on, a French toy maker named Bigot brought out a series called bigotphones, which were shaped like orchestral instruments. Popular in the mid-20th century was the tubular kazoo.

The importance of timpani in the orchestra became firmly established in the 19th century. Meyerbeer wrote a melodic solo for four timpani for his opera *Robert le Diable* (1831). Berlioz required 10 players on 16 drums in his *Requiem,* and Wagner used 2 players, each with a pair of drums, throughout his opera tetralogy *Der Ring des Nibelungen.* Russian composers often wrote for small kettledrums with high pitches. Pedal, or machine, drums, which allow players to make almost instantaneous pitch changes, were developed in the 1880s and were soon featured in the tone poems and operas of Richard Strauss and Vincent D'Indy's Second Symphony (1902).

Contemporary percussion

The 20th century. The exploitation of various and unusual tone colours and effects characterizes the use of percussion instruments in 20th-century music, classical and popular alike. Clappers, for example, have been used sparingly but to great effect in, among others, Richard Strauss's *Elektra* (1908), to simulate the cracking of a whip, and Mahler's Sixth Symphony (1904). Claves, of Cuban origin, consist of two cylindrical hardwood sticks and are found primarily in dance orchestras, but symphonic composers write for them as well (Edgard Varèse in *Ionisation* [1931] and Aaron Copland in his Third Symphony [1946]). Castanets are found in Richard Strauss's *Salome* (1905).

The xylophone appeared in Mahler's Sixth Symphony; it is also scored, in two different sizes, in Puccini's *Turandot* (1926). Alan Hovhaness called for a xylophone solo in his *Fantasy on Japanese Wood Prints* (1965). The marimba, a xylophone with metal resonating tubes suspended beneath its wooden bars, is featured in Darius Milhaud's *Concerto for Marimba and Vibraphone* (1947). The vibraphone is similar to a celesta but has motor-driven revolving vanes inside each resonator, giving it its unique pulsating tone. Since its development in the 1920s, it has found widespread use in jazz but is also heard increasingly in art music such as Alban Berg's *Lulu* (1934) and Michael Tippett's Third Symphony (1972). The glockenspiel is featured throughout the modern era, from Debussy's *La Mer* (1905) to Pierre Boulez's *Pli selon pli* (1962) and beyond. Tubular bells were employed effectively in Ernst von Dohnányi's *Variations on a Nursery Tune* (1914).

Rattles are used primarily in modern rhythm bands, but various types are found, for example, in Carl Orff's *Weihnachtsspiel* (1960) and Benjamin Britten's *The Prodigal Son* (1968). Scraped gourds are now part of the professional percussionist's equipment, and scrapers, in the form of blocks covered with sandpaper, are rubbed together in Morton Gould's *Latin-American Symphonette* (1941). Scrapers also survive today as carnival noisemakers.

Unusual playing techniques

Twentieth-century composers frequently call for instruments to be played in new and unusual ways. The gong, for example, is played on the rim with a triangle beater in Richard Strauss's *Die Frau ohne Schatten* (*The Woman Without a Shadow,* 1919), set in vibration by a violin bow in Krzysztof Penderecki's *Dimensions of Time and Silence* (1960), and lowered and raised into a tub of water after being struck in John Cage and Frank Harrison's *Double Music* (1941). Likewise, cymbals have been rubbed together in a circular motion in Bartók's *Second Rhapsody for Violin and Orchestra* (1944), played by drawing a cello bow over the edge in Arnold Schoenberg's *Five Orchestral Pieces* (1909), and placed on the heads of a pair of timpani in Arthur Bliss's *Meditations on a Theme of John Blow* (1955). In William Walton's *Façade* (1923) the triangle is used to strike a cymbal, while William Russell's *Fugue for Eight Percussion Instruments* (1933) requires three muffled triangles of different sizes. The tambourine is dropped on the floor in Stravinsky's *Petrushka* (1911), its jingles flicked in Walton's *Façade,* brushed in Constant Lambert's *The Rio Grande* (1927), and played without jingles in Manuel de Falla's *El retablo de maese Pedro* (1922).

Drumming in the 20th century in the West gained an important place outside its traditional preserves of orchestra and military band. Film and musical theatre scores are full of percussion, and their metamorphoses into symphonic suites by arrangers such as Robert Russell Bennett take optimum advantage of all percussion instruments. Both jazz ensembles, or combos, and experimental music have explored new fields. In the former, the drum, or trap, set—bass drum with foot-operated beater, snare drum, set of tom-toms (cylindrical drums graduated in size), and suspended cymbals—is treated as a solo instrument among its peers. The latter has been preoccupied with rhythmic stress and has exploited drum tones for their own sake. On a popular level, rhythm is stressed or punctuated, often by the clarity and opposing pitches of Latin-American drums. Consequently, both the role of the drum and playing techniques have become freer—in orchestral as well as popular music. The snare drum, for example, plays an important solo role in Ravel's *Boléro* (1928) and an unconventional improvisatory one in Carl Nielsen's Fifth Symphony (1922). Glissando passages on the timpani are found in Bartók's *Music for Strings, Percussion, and Celesta* (1936), and stepwise ascending and descending chromatic passages are used in Britten's *Nocturne* for tenor solo, seven obbligato instruments, and string orchestra (1958). Franco Donatoni's *Concerto for Strings, Brass, and Timpani* (1953) calls for the drum to be hit in the centre of the head, while other composers stipulate that it be struck on the head and rim simultaneously (a rim shot). Britten directed that the bass drum be hit with a snare-drum stick in *Peter Grimes* (1945), but soft wire brushes or other types of sticks may also be used, as in Harold Farberman's *Concerto for [Five] Timpani and Orchestra* (1962).

PERCUSSION INSTRUMENTS IN ASIA

Ritual, social, and musical uses of clappers

Idiophones. Still preserved today are actual clappers from ancient Egypt and from Sumer of about 3000 BC. Their use seems never to have died out. Copts still ritually strike clappers of a type that has probably been in existence since the 3rd or even 4th millennium BC. Modern Vietnam also retains clappers in its religious observances. On the Indian subcontinent circular wooden clappers are played by beggars and fakirs in some regions and are used as rhythm instruments in others. In East Asia they have a role in the theatre, as signal instruments, at funerals, or, as in the Ryukyu Islands, accompanying traditional dances. Castanets probably originated in ancient Phoenicia; they appear in Egypt in the 24th dynasty (*c.* 730–709 BC) and are typical dancers' instruments.

Cymbals are indigenous to Asia; ancient Assyria had a unique form, funnel-shaped with long necks serving as handles. Known in ancient Israel from about 1100 BC on, cymbals were the only permanent idiophones of the Temple orchestra. Egypt did not have true metal cymbals until the 24th dynasty. Today they remain in ritual use in northern India, Japan, Tibet, and Vietnam. They appeared

in the 5th century AD in India, where they are now also found at secular festivities. In China they play a prominent part in the theatre. Turkey, in contrast, has traditionally connected cymbals with military usage. In some parts of Southeast Asia their ancient metal-connected function of dispelling evil spirits still prevails.

Xylophones reach their highest development in Southeast Asia. They vary in form from the most primitive log type to the highly developed orchestral instruments found in Indonesia. Trough xylophones were depicted in Java in the 14th century but are not restricted to Southeast Asia; those of Japan, for instance, are rhythm rather than melody instruments, and in Myanmar (Burma) they are associated with royalty. Xylophones of the Indonesian gamelan, or percussion orchestra (and some mainland ensembles), have various complementary compasses.

Stone chimes (lithophones) of two types occur: oblong bars like xylophone keys resting horizontally, found in Vietnam only, and vertically suspended plaques. In China their generic name is *ch'ing;* there, single sculpted musical stones and also 16-stone chimes are suspended from ornate frames. Stones forming a chime, carved in a typical L-form and struck with a mallet on their larger portion, are very ancient; a chime of this form dating from the late Shang era (*c.* 1401–*c.* 1123 BC) was excavated at Anyang, in northeastern China. Both in China and in Korea, where the oldest chime goes back to the 14th century, the lithophone is a Confucian ritual instrument. Single stones and chimes are still in use in rural Annam (Vietnam).

Indonesia and Indochina have metallophones constructed like xylophones, of which they are indeed metal counterparts. But in China the *fang-hsiang* with its 16 bars is a metal imitation of the lithophone. Among important components of the gamelan is the *saron,* a trough metallophone depicted as early as about AD 800 on the Borobudur stupa (Buddhist monument), Java, and the frame metallophone *gender,* now usually supplied with tubular resonators, which has been known from the 12th century on. Introduced to China by a Turkic people in the 7th century, the horizontal type of metallophone reached Korea in the 12th century and is still occasionally played there. In Japan it is a Buddhist ritual instrument.

Slit-drums

The slit-drum is made by hollowing a log or wood block through a slit. Those of East Asia and Indonesia are of great antiquity and of a high degree of development. The Chinese *mu yü* (traditionally fish-shaped) is a Buddhist and Taoist ritual slit-drum. Its Korean and Japanese counterparts are likewise ritual time markers, while in Vietnam the slit-drum is both a temple and a watchmen's instrument. On Java slit-drums can be traced to the Hindu-Javanese period (1st–9th century AD). Small models are generally suspended vertically, whereas larger ones rest horizontally; some underscore dance rhythms, while others are signal instruments.

Southeast Asia is the home of tubular chimes; resonant, tuned bamboo tubes are united to form a chime in rural Annam and Java. In western Java up to 16 tubes are strung in ladder formation and suspended from a house or a tree and played with padded beaters.

Western Asia is believed to be the home of the gong, which reached China in the 6th century and Java by the 8th. Originally, it seems to have afforded protection against evil spirits, and even today the Iban people of Borneo beat gongs during a storm. Chinese gongs serve a whole gamut of purposes: as signal instruments of the army, as rhythm makers to accompany a song and, in the case of the bossless *lo,* as a Buddhist ritual instrument. In Japan the employment of the gong varies from temple to theatre to folk festival.

Gong chimes

In Indonesia and eastern Asia tuned gongs are united to form gong chimes. The Chinese upright *yung lo* is a Buddhist and Confucian cult chime and was formerly also played at court. The horizontal gong chimes of Indonesia (called *bonang* in Java) are outstanding components of Southeast Asian orchestras and have been known from the 10th or 11th century on. Frames of Thai gong chimes arch upward at both ends to form an upright semicircle. Ancient kettle gongs, products of Bronze Age culture, are found only in China, Indochina, and Indonesia. They are hung so that the striking surface is vertical and are struck in the centre of this surface (the head). Kettle gongs were cult instruments connected with rainmaking; those of the Dong Son culture area of northern Vietnam may be dated from the 5th to the 3rd centuries BC.

Bells of bronze dating from about 1000 BC have been excavated in India, from the 22nd dynasty (945–730) in Egypt, and from about 700 in Assyria. An intimate connection existed in ancient India between bell sound and mystic experience, and today a handbell is still rung in temple ceremonies in India and other areas of Buddhist influence. The Chinese differentiate between clapper bells (*ling*) and clapperless ones (*chung*); their temple bells, like those of Japan, are always of the *chung* type. Temple bells usually assume the form of chimes in China; one from the 6th century has 13 bells, but more modern chimes consist of 16 bells hung in two rows of a frame. In addition to metal bells of the high-culture domains, rural areas still use primitive wooden bells with single or multiple clappers.

The sistrum in its earliest form, that of a U, is seen in Sumer in the mid-3rd millennium BC, and a little later, about 2100/2000, a rectangular form appears in Horoztepe, Anatolia (modern Turkey). Egyptian sistrums are characterized by being closed at the top: the *sesheshet* was shaped like a temple, the *iba* like a closed horseshoe. Sacred to the Egyptian goddess Hathor, the *iba* was played only by women, and after Hathor's metamorphosis into Isis it remained sacred to Isis.

A sliding rattle called *angklung,* found only in Indonesia, consists of several tuned bamboo tubes with cut-back tongues, inserted into a frame; they slide back and forth when the frame is shaken.

Scraped idiophones are Confucian ritual instruments in East Asia. The "tiger" of China is a vessel scraper of wood with a series of notches cut along its back; known as early as the Chou dynasty (*c.* 1122–221 BC), it is scraped with a split bamboo stick. Split idiophones (made of hollow cane split between nodes) are slapped against the player's wrist or thigh in South China and Southeast Asia, producing a fixed-pitch buzz.

Jew's harps have idioglott tongues (cut from the same material as the frame) in Indonesia, while both idioglott and heteroglott (the tongue made separately and attached to the frame) forms occur in China and on the Indian subcontinent. More recent are those of metal having the outline of an onion. In the Philippines and some other areas Jew's harps are important adjuncts to courtship.

Musical cups

Musical cups, the forerunners of musical glasses, are depicted on the Borobudur stupa. The Indian *rastrarang* can be played either with small sticks by percussion or by rubbing wetted fingers along the rims—the cups do not contain water. But the *jaltarang,* also of India, makes use of water for fine tuning and for the playing of *gamakas* (ornaments) by carefully bringing the sticks into contact with the surface of the water. Similar musical cups are played in Japan in Buddhist temples and in the music of the Kabuki theatre.

Membranophones. Unlike the drums of Western musical tradition, those found in ancient (and parts of modern) Asia are primarily cult and ceremonial instruments. Most, if not all, Western drums are their descendants, and western Central Asia may well be their common homeland. Babylonia already had a variety of forms: cylinder, hourglass, goblet, and bowl-shaped, all of terra-cotta and all beaten with bare hands. Assyrians also carried in procession a large, conical drum played in the same manner.

Temple drums were of considerable proportions: huge frame drums existed from the 3rd millennium on in Mesopotamia, and the waist-high *lilissu* had a goblet form—a bowl on a stand—and may have been the ancestor to the kettledrum. All these were played by men, but the smaller frame drums appearing in Sumer about 2000 BC are depicted in the hands of women; a king's granddaughter was appointed player of the *balag di* in the Temple of the Moon at Ur around 2400 BC. Ever since, frame drums have been predominantly women's instruments. The Bible says that in ancient Israel "Miriam, the prophetess, the sister of Aaron, took a timbrel in her hand; and all the women went out after her with timbrels

and dancing." They are still played throughout the Middle East, in some areas in art music ensembles, in others only in popular and folk music.

Wherever the Muslim presence has made itself felt, large and small kettledrums are encountered. In Turkey classical monophonic singing is accompanied solely by a small kettledrum, played either in the centre of the head or close to the rim, depending upon whether clear or muffled beats are desired.

Association of drums with thunder

In many regions of the ancient and modern East drums were believed to create or imitate thunder. Sets of thunder drums are depicted on East Turkistan art objects from the 9th to the 11th century. In China, Lei Kung, duke of Thunder, is traditionally surrounded by numerous drums on which he creates thunder, and in Japan thundering drums were even automated by attaching a number of them to the outer circumference of a wheel that, when revolved, caused them to rattle—an early application of the rattle drum principle. As in Africa and America, cult drums of Asia have been associated with human sacrifice; in China, drums were consecrated in the 7th and 6th centuries BC by smearing them with the blood of a sacrificial human, usually a war captive.

Rattle drums, either containing in their cavities objects that rattle when the drum is twirled by a handle or with attached cords having knotted ends that strike the heads, can be traced back to the Shang dynasty (*c.* 1766–*c.* 1122 BC) and are now in use from Tibet and India to Japan. Still a cult drum in some areas—it is an attribute of Śiva (Shiva), the third member of the Hindu trinity—in others the rattle drum has degenerated to a mere toy. On the giant stupa of Borobuḍur, Java, an archetypal image of the known cosmos, are sculpted the musical instruments in use at the time of its erection (*c.* 800). These include cylinder, conical, hourglass, and pot drums—all Indian instruments. Yet, today's Indonesian orchestra, the gamelan, virtually ignores drums in favour of metallophones. Drumming is exclusively a man's business on some islands of the Malay archipelago, where drums are kept in the men's house, out of sight of women.

Drums played an important part in early court orchestras of China and Korea, judging by their surviving elements in *gagaku,* court orchestral music of Japan. Here, the leader beats time on a drum, either cylindrical or hourglass-shaped, having projecting heads, a characteristic feature of Japanese hooped drums. Larger barrel-shaped drums with nailed heads are suspended from elaborate frames. On the Indian subcontinent a variety of membranophones participate in art music ensembles or accompany dances, while small kettledrums are played pairwise in processions; large, single kettledrums are temple instruments or may be mounted in pairs on elephants' backs in outdoor ceremonies. Many smaller drums have laced and wedged heads, the skin being further tensed by an application of tuning paste. In Myanmar, Thailand, and south Nias Island (Indonesia) a number of tuned barrel drums of varying sizes are suspended in a low circular pen to form drum chimes; such a chime may consist of from 16 to 24 drums, all played by a single musician with his fingers and palms, occasionally with a drumstick. These chimes form part of the theatre orchestra and are even played in processions.

Drum chimes

In East and Southeast Asia a mirliton device is applied to many woodwinds in order to obtain a characteristic modification of tone quality. To this end an additional aperture is cut in the tube and covered with a thin membrane. A different application of this principle is encountered in India, where a pair of short, wooden mirliton "trumpets" are placed against the throat of a humming performer.

PERCUSSION INSTRUMENTS IN AFRICA AND AFRO-AMERICA

Idiophones. *North Africa.* Idiophones of Muslim Africa are mainly those of the Middle East or derivations thereof. Outsize hollow clappers shaped like a dumbbell sliced lengthwise are clicked by Moroccan singers, who hold a pair in each hand. An inverted bowl set afloat in a larger, water-filled bowl, is beaten with a single stick by the Saharan Tuareg as their substitute for the West African water gourd. Finger cymbals are worn pairwise on finger and thumb of each hand by dancers. Basically, however, the percussion of this area is executed by drums.

Black Africa. In contrast, Black Africa has an almost bewildering variety of idiophones. Clappers, generally of wood, are played from coast to coast. Simple percussion sticks are known in East and West Africa. Scrapers in both solid and vessel form are widespread.

Xylophones vary from the primitive pit xylophone, with a few wooden bars placed over a pit or trench, to the leg xylophone, with a couple of bars placed on the outstretched legs of a woman player, to the large instruments with independent framework and tuned keys graduated in size. African xylophones are usually provided with a gourd resonator suspended from each key, often containing a mirliton device that adds a buzzing quality to the tone. Ensemble playing of several xylophones, reported by 17th-century travelers, is still practiced. In some areas xylophones form small orchestras with several players to one larger instrument. Unmistakable similarities of form, playing technique, tuning, and even of the music performed confirm the African xylophone's Southeast Asian origin.

Xylophone ensembles

Slit-drums occur in the Western "Bend" (of the Niger River, in modern Mali) and the Congo basin. They may be cylindrical, boat-, wedge-, or crescent-shaped, and zoomorphic with a dorsal slit. Possibly related to the drummed tube zither, a cylindrical slit-drum with from two to five slits is encountered in West Africa; the Kissi people of Guinea strike not only the slats formed by the multiple slits but the ends of the slit-drum as well.

Bells occur in a large variety: metal and wooden, single or double, clapperless and with single or multiple clappers, played as rhythm or signal instruments. The apotropaic qualities of metal bells are recognized in Africa, where such bells may be associated with chieftainship. Double bells, usually of metal, share a common handle but differ in length or in diameter and, consequently, always in pitch. Metal double bells are devoid of clappers and are often made of sheet iron soldered down the side, whereas double bells of wood often have multiple clappers.

Water gourds—half gourds floated open side down in a pan of water and struck rhythmically with small sticks—are played in West Africa; in Benin their chief use is at funeral rites.

Rattles are the instruments par excellence of dancers, although they can also be worn on the leg simply to provide walking rhythm. Strung and gourd rattles are common, with the latter often serving in religious cults or magic rites in the Congo basin area. In West Africa the surface of a gourd is covered by a network of dried fruit seeds threaded on a cord; a player holds the gourd handle in one hand and shakes the plaited ends of the cords with the other. Sistrumlike forked sticks strung with threaded pairs of calabash fragments have an important part in fertility and initiation rites among the Mande of West Africa. The ancient horseshoe and rectangular forms of sistrum are still played in Ethiopia in the Monophysite Christian church.

The African linguaphone is known to the West as the sansa (zanza), by the Bantu name *mbira,* or, in English, by the misnomers "kaffir piano" and "thumb piano." It consists of a varying number of cane or metal tongues fitted to a wooden board or resonator so as to permit one end of the tongues to swing freely; their different lengths determine the pitch. Sansas show affinity of tuning with xylophones that cannot be considered accidental; thus they may be considered small, portable versions of the latter.

Afro-America. West African idiophones introduced into the Americas with the slave trade are still flourishing. Clappers originating among the Yoruba (a Nigerian people) are played in Cuba; the claves, or pair of cylindrical percussion sticks of Haiti and Cuba, are standard equipment in Western rhythm bands. The xylophone may already have entered America in pre-Columbian times. Known chiefly as the marimba, one of its African names, it has been accepted in Western musical culture. Bells frequently figure as voodoo cult instruments in Caribbean and Afro-Brazilian communities. In Cuba water gourds are played at funeral rites for Afro-Cubans.

Steel drums originated in Trinidad during World War II

Steel drums

and have become vehicles for popular music in the U.S. since. Actually a single "drum" forms a chime, as one head of an ordinary oil drum is divided into sections of different sizes by punched grooves, each section then being tuned to its own pitch. Today only a greater or lesser rim, depending upon the range required, is left but originally the oil drum was left intact.

Rattles play an important part in African cults of the New World, both gourd rattles with internal and external percussion and a distinct variety consisting of two metal cones joined at their widest part. (The maraca gourd rattle is probably indigenous to South America.)

Scrapers are highly popular. The notched gourd with natural handle, called guiro, is another Afro-American instrument taken over by the West. Notched turtle carapaces are scraped in the Caribbean. The jawbone of a horse, mule, or donkey, with its teeth left in, is played in both North and South America and in the Caribbean; its use among coastal Negroes of Peru goes back to the 18th century. In the United States it is still encountered in Louisiana and the Carolinas.

Sansas in the Caribbean and in South America bear such names as *marimbula* (Cuba) and *marimbao* (Brazil), clearly indicating their origin.

Membranophones. *North Africa.* Drumming tradition in the Muslim north centres on smaller, portable drums, such as frame, goblet, and small kettledrums. Frame drums are made in a number of forms: circular with single membrane, square, even diamond-shaped (ancient Egypt had circular, square, and rectangular ones). Although the human voice is the preponderant instrument in Islāmic religious music, the frame drum plays an important role as vocal accompaniment. It also lends rhythm for dancing and is the basic percussion instrument of Muslim art-music ensembles. In Morocco groups of women may sing to the accompaniment of a frame drum supplied with jingles, a spike fiddle (one in which the handle traverses the body and emerges at the lower end to form a spike), small cymbals, and a pair of kettledrums, each playing her own instrument.

Black Africa. Black Africa makes perhaps wider use of its membranophones than does any other culture. Numerous variant forms of drums and lacings make classification difficult; indeed, a study of types remains to be established. Some drums are played as musical instruments, others transmit messages ("talking" drums), some are restricted to cult and funerals and others—partly desacralized—to royalty, while still others participate in everyday life. Ethiopia admits drums to the church, while West African cult drums may not be seen by the uninitiated. Drums are beaten with bare hands or with rectangled or knobbed sticks. Footed drums (*i.e.*, with a base prolonged to form "feet") attain a height of 10 feet (3 metres) in the Loango area of western Central Africa (coastal areas of modern Congo, Cabinda province of Angola, and Zaire) and must be tilted to bring the head within the performer's reach. The playing head of hourglass drums may be struck with one hand and with a stick alternately. Kettledrums are royal, ritual, or ceremonial, and unlike their North African counterparts they are of wood, often with sculpted shells. Their traditional pairing with trumpets reaches as far as south of the Congo.

"Talking" drums

That portion of West Africa known as the Bend is the area of talking drums, by means of which messages are conveyed for up to 20 miles, to be relayed by another drummer. Languages of this area are characterized by pronounced high and low pitch tones (tone languages), a quality exploited when two drums—a lower-pitched, or male, drum and a higher-pitched, or female, one—transmit low and high tones respectively. Accent, number, and pitch of the syllables are transmittable. Among the Yoruba a talking drum set consists of four hourglass drums and a kettledrum; the leather lacings of the former are gripped by its player, enabling him to change the pitch as he exerts more or less pressure on them; the chief drum of the set is capable of an octave range and, in addition to tones, produces also the typical Yoruba glides by manipulation of the lacings.

East African drum chimes, of Asian heritage, are tuned to specific pitches; these instruments attained royal status in Uganda, where the largest chime consists of 15 drums requiring 6 musicians to play them.

Friction drums of the lower Congo area were once exclusively cult instruments but are now becoming desacralized. Whereas in Central Africa they are played only by men, women of the South African Pedi play them at female initiation rites.

African mirlitons can be most imaginative: standard material is a spider's egg membrane, and this may be added to apertures pierced in the bottom of xylophone resonators or applied to one end of an independent cane tube that is inserted into a nostril, as among the Fang (Fan) of Gabon.

Afro-America. West Africans reconstructed their native drums in the New World, preponderantly as cult instruments. Small sets of two or, more often, three drums of graded sizes form an integral part of Afro-American rituals and, in the Caribbean, also of voodoo dances. Only the skins of sacrificial animals may be used for membranes among Afro-Bahians in Brazil, who baptize their new drums, preferably with "holy" water obtained from a Roman Catholic church. Drums in Haiti are sacred objects and may even represent the deity itself: as such they receive libations. One type of bongo drum—there exist at least four of these—has been adopted by Western rhythm bands, as has the conga.

PERCUSSION INSTRUMENTS IN AMERICA

Idiophones. A wide assortment of idiophones is available to American Indians, but many of these are restricted to nonmusical uses. Concussion sticks, for instance, serve as game calls in North America, while concussion stones are invariably ritual: they are clashed to make thunder. Small, conical bells of metal and multiclapper bells of wood were known in ancient Peru.

Slit-drums have been played in Central and South America since pre-Columbian times, but their occurrence in South America is now rare. Characteristic of the well-known *teponaztli* is the form of its slits, cut to form an H with tongues of different thicknesses, thus allowing it to emit two sounds. Formerly, Zapotec warriors of Ixtepeji, Mex., went into battle carrying an idol and singing to the accompaniment of the *teponaztli*, while Indians of 16th-century Hispaniola danced to their slit-drums.

Strung rattles

Strung rattles are worn as leggings to emphasize a dancer's movements, but when the strung material consists of a dead enemy's teeth, as among the Brazilian Mundurucú, the rattle becomes a source of magic strength to the wearer; elsewhere, strung deer or caribou hooves attract game during the hunt. Vessel rattles of gourd and pottery imitations of gourds have been in use since Aztec times. Cult instruments in prehistoric America, they are still used by medicine men during their incantations. Hollow, seed-filled staffs were ceremonial rattles of Aztec and Maya, and descendants of these instruments are still played in North America.

Scrapers are seen on the 8th- or 9th-century frescoes of the temple at Bonampak in Chiapas state, Mexico, played in a procession. Today among the Pima Indians of Arizona, scrapers play an important part in rainmaking ceremonies. Elsewhere in North America they serve as time markers. Scraped sticks of animal or human bone or of antler, with a series of notches along one side, were sounded at Aztec sacrificial or memorial ceremonies. In modern times they have been played in North America by medicine men. Split idiophones were employed in western coastal areas of North America chiefly for ceremonial purposes; some tribes slapped them against their chests, others against their palms. Finally, a friction-instrument vessel of Central and South America, the rubbed tortoise carapace, is a ritual instrument and taboo to the noninitiated; the instrument is rubbed with the fingers, not scraped.

Membranophones. Pre-Columbian drums of Central America appear to have been played without sticks, regardless of their size, and to have been devoid of lacings, whether they were small pottery drums, such as those excavated in Costa Rica, or the large footed drums of Mexico. Slender pottery drums of the Guatemala highlands, open top and bottom, can be dated to the late Classical Period

(*c.* 700–1000). Skeletons of wooden cylinder drums, very shallow, have been found in Peru.

The North American shallow drums are "medicine" (magic) and dance drums, having a heavy hide head struck by a hard beater and emitting a loud, staccato sound. Larger models are suspended and struck simultaneously by up to 10 drummers seated in a surrounding circle. The "dream-dance" drum, a tub-shaped shallow drum, is elaborately decorated and has a bell suspended in its interior; it is credited with great medicine power.

Cylinder drums made of a hollowed log were traditionally war and dance drums of tribes of the southwestern United States and are now sold in tourist shops. Pottery drums, either potbellied, bowl-shaped, or footed, were formerly common among the eastern and southern tribes of the United States; the potbellied type remains in use among the Pueblo Indians of the Southwest.

Frame drums

American Indian frame drums are usually circular; square shapes are rare, but rectangular frame drums are found in California, Mexico, and Bolivia and octagonal ones among the Cherokee of the southeastern United States. All were war drums, regardless of whether they had one or two membranes. By adding a rattling device, a frame drum is converted into a medicine drum. The Inuit frame drum, a shaman's instrument, is distributed over Greenland, northern Siberia, North America, and among the Lapps of northern Scandinavia; it differs from other frame drums in that it has a fixed handle and is struck on the hoop, not on the membrane.

Friction drums are rare; in Venezuela one is formed from a small barrel over which a piece of leather is stretched, with central perforation to admit a friction stick.

PERCUSSION INSTRUMENTS IN THE PACIFIC

Idiophones. The different cultures of this wide area where singing and dancing form so prominent a part of the musical life include a number of primitive idiophones, some of which are played with considerable sophistication. Concussion sticks are clashed by an Aboriginal Australian singer to lend emphasis. The Maori breathe words of a song onto a carved stick held between their teeth while tapping it with a second stick. In Hawaii concussion stones were held pairwise by dancers who clicked them together like castanets. In Papua New Guinea primitive log xylophones are played, consisting of two banana stems or other logs placed on the ground with a few keys placed across them.

A percussion gourd of New Guinea has an hourglass form, open at both ends; when plunged in and out of water, it is said to emit the sounds "uh-ah-uh-ah." Split-bamboo percussion tubes, doubling as rattles, are indigenous to the same area, while the percussion board *o-le-polotu* of Samoan and Tongan chiefs accompanies solo songs. Slit-drums

Slit-drums can be huge. Made from a tree trunk, living slit-drums in Vanuatu (the New Hebrides) are carved with the faces of ancestors, and in New Guinea roofed drum houses are built over large, horizontal slit-drums to protect them from the weather. The Maori, one of the relatively few peoples who have no membrane drums, use their slit-drums as signal instruments. Related to these is a percussion tube of Fiji, partly hollowed and tapering at the ends and struck with two sticks on the side opposite the slit.

Idioglott Jew's harps of bamboo are the major tonal idiophones of the area; here the tongue is vibrated either by the player's finger or by jerking it with a cord. A friction vessel of New Ireland (in Papua New Guinea) consists of a rounded and hollowed block of wood, its upper portion carved into three tongues of different lengths and hence emitting as many pitches. Already rare nowadays and taboo to women and children, it is played at death commemoration rites by a male performer who rubs well-oiled hands over the tongues.

Membranophones. Two forms of drum are distributed over this huge area. Elongated hourglass drums, usually with wooden handles of a piece with the drum shell, often beautifully carved and ranging up to 6 feet (1.8 metres) in height, are commonly in the hands of dancers and singers and are said to symbolize the transition from earth to heaven. Among the Wapenamundu of New Guinea they lack handies and are war drums. Such hourglass drums are not found in Polynesia. The other form is a conical, footed drum made of a tree trunk, reaching great dimension. Those of Polynesia are sometimes 8 feet (2.4 metres) high and have elaborately carved pedestals. They are usually made of breadfruit tree wood or hollowed coconut palm, with a single, sharkskin head. Throughout the area drums are beaten with bare hands.

Whirled friction drums are met with in Hawaii, where a large nut or a calabash is furnished with a friction cord and swung through the air. (S.Ma./E.A.Bo.)

Stringed instruments

All stringed instruments, or chordophones, produce sound by the vibration of strings, which may be made of vegetable fibre, metal, animal gut, or plastic. In nearly all stringed instruments the sound of the vibrating string is amplified by the use of a resonating chamber or soundboard. The string may be struck, plucked, or rubbed (bowed); in each case the effect is to displace the string from its normal position of rest and to cause it to vibrate in complex patterns.

Since most stringed instruments are made from wood or other easily perishable materials, their history before written documentation is almost unknown, and contemporary knowledge of "early" instruments is limited to the ancient cultures of East and South Asia, the Mediterranean, and Mesopotamia; but even for these places historians must depend largely on iconographic sources rather than surviving specimens.

Stringed instruments seem to have spread rapidly from one society to another across the length and breadth of Eurasia by means of great population shifts, invasions and counterinvasions, trade, and, presumably, through sheer cultural curiosity. In the Middle Ages the Crusades stimulated Europe in the adoption of a whole set of new instruments; similarly, the Chinese accepted many new instruments from their Central Asian invaders. Indeed, the only world area that did not echo to the sound of strings was pre-Columbian America.

No system of classification can adequately categorize the interactions of natural material, craftsmanship, and man's exuberant imagination that produced an endless variety of stringed instruments. The most widely accepted system of classification is that developed by Hornbostel and Sachs, a method based on the type of material that is set into vibration to produce the original sound. Thus, stringed instruments are identified as chordophones—that is to say, instruments in which the sound is produced by the vibration of chords, or strings. This main category is then further divided into four subtypes—lutes, zithers, lyres, and harps—according to the manner in which the strings are positioned in relation to the body of the instrument. Within these categories, the descriptive nomenclature of an instrument is given in terms of parts of the human body: for example, the belly (front), back, sides, and neck. Instruments are not necessarily related only to others in the same classification. Transformations continually occur, and "hybrids," according to the Sachs-Hornbostel system, may in fact represent altogether viable subtypes of their own. Classification

THE PRODUCTION OF SOUND

The ear, because of its own structure, adds to and subtracts from the outside sound. It is, for instance, relatively insensitive to low-frequency sound pressure but is extremely sensitive to fine degrees of pitch change. At the same time it can accept a great number of pitch and tuning systems. On a worldwide basis, there is a large and varied number of tonal systems. The oldest known of these in the West is the so-called Pythagorean system; others include mean-tone tuning, just intonation, and the even-tempered system, methods of tuning calculation that vary slightly in the exact size they assign to the intervals within an octave. All of these systems represent theoretical mathematical concepts to some degree, and their origins must be sought in arcane numerological systems rather than in practical musicianship. Thus, "tuning" and

"playing in tune" do not necessarily refer to the same thing; players and tuners make constant adjustments to any basic mathematically determined framework according to their judgment and experience. In other words, even though a given "scientific" tuning system outlines scales and modes, the instrumentalist who plays an instrument with great pitch flexibility (the violin, for instance) spends much time in the spaces between the notes assigned in the given scale. The Japanese zither (koto), for example, can be tuned according to a number of fixed systems; nevertheless, its player produces many microtonal variations on these fixed pitches by manipulation of the strings. Even in such a technological society as that of the modern West, the well-tempered scale is honoured more in the breach than in the observance: a piano tuner would not think of tuning altogether according to its dictates and uses a so-called stretched tuning, in which he imperceptibly sharpens (raises) pitches as he ascends, thus making the highest notes relatively sharper than the lowest ones. Investigation has disclosed that string players tend to play in the Pythagorean rather than the well-tempered system.

Inconsistencies, then, are inherent in all tuning systems; makers of fretted lutes (the guitar or the Greek lute, *laghouta,* for example) operate according to a combination of ear and rule of thumb when they insert frets (note-position markers—*e.g.,* of gut or wire) in the fingerboard. Such instruments are fretted according to the "rule of the eighteenth," in which the first fret is placed at one-eighteenth of the distance from the top to the bottom of the string, the second, one-eighteenth of the distance from the first fret to the bottom, and so on. Even if this method produced an acoustically perfect scale (which it does not), the player would not be able to reproduce this exactly, for as he presses the string to the fingerboard, the string is stretched and is thus slightly lengthened. That is why the act of stopping a string at its exact centre gives a note slightly sharper than the expected octave above the open string. Despite all of this, the search for an acoustically perfect tuning system goes on.

Though constructional methods differ widely from one area and instrument to another, there are a limited number of basic problems to be overcome by the maker of stringed instruments. The very principle that makes it possible for chordophones to sound is string tension; at the same time, tension is destructive to the instrument since it tends literally to pull it apart. So the body of an instrument must be made of strong material; it must be reinforced, and at the same time it must not be so rigid that it cannot easily resonate—*i.e.,* produce a supplementary vibration intensifying that of the string. The challenge of reconciling these opposite needs is the central one for the chordophone maker. Climate, too, has a marked effect on musical instruments: humidity expands a wooden instrument, and dryness contracts it. Of these factors, dryness is the most harmful, since the contraction of the wood actually pulls the instrument apart. Much energy has been expended over the centuries in investigations of various varnishes, shellacs, glues, and sealers. Many makers prefer to make their instruments in dry conditions, for the expansion caused by humidity is unlikely to prove as harmful as the contraction caused by dryness.

Effect of climate on instruments

However common the practice may have been in the past, wooden instruments are not now usually gouged out of one piece of wood (though the Japanese lute, *biwa,* portions of the koto, and often the Puerto Rican lute, *cuatro,* are thus fashioned); it is too painstaking and time-consuming for the maker. Instead, the instrument is built up of many pieces of wood glued together; the shaping of curved pieces is accomplished by gouging and planing (as in the belly of the violin) or by heating and pressing in a frame (the sides of the violin or guitar). Soundboards, the most important part of the resonance system of stringed instruments, are carefully planed to close tolerances. Mass-production methods are unsuitable for the production of high-quality chordophones because no two pieces of wood are precisely alike in their acoustical qualities; each piece of wood requires special judgment and treatment. Ideally, therefore, stringed instruments of the highest quality must be individually made. Piano manufacture is a partial exception to this rule, but even in a piano factory, individual treatment and craftsmanship are allowed full sway. The modern piano is a product of several different factories. The cast-iron frames are made by specialized foundries, and the steel strings, the keyboards, and the actions by specialized firms. Each of these processes requires experienced craftsmen; and the work of assembly, polishing, tuning, and tone regulation calls for hours of individual attention to each instrument.

The construction and maintenance of stringed instruments has been complicated over the centuries by a continual rise in standard pitch, requiring strings to be tightened. Older instruments (such as a Stradivarius violin) have been subjected to additional physical strain and therefore needed heavier bass-bars (braces under the belly).

As already stated, the three possible methods of sound production on a stringed instrument are plucking, striking, and bowing. A string vibrates in a complex way: the entire string vibrates in one segment (producing the fundamental pitch), and various segments at the same time vibrate independently to produce overtones. The resulting sound is weak indeed unless the instrument is provided with a resonator to amplify the sound. The shape of the resonator varies greatly. It has been influenced by the materials, tools, and technology available in the society, the symbolic meaning of the shape, and the sound desired by the culture. The last factor seems to be governed by the first three: that is to say, the prescribed shape of the resonator affects the overtone structure of the instrument, producing a certain timbre, which the society in question then defines as attractive-sounding.

Importance of the shape of the resonator

One of the clearest illustrations of the basic importance of the shape of the resonator to a musical instrument is the African mouth bow (a musical bow in which the player inserts the bow in his or her mouth). By varying the size and shape of the oral cavity while striking or plucking the single, unfingered string, the player produces a clearly perceptible, if quiet, melody that exists only because the changes in the mouth emphasize various overtones. On stringed instruments with permanently fixed resonators, the size, dimensions, shape of apertures, thickness, and bracing of the resonating surfaces largely determine which overtones will be emphasized and, thus, what the instrument will sound like. On a good violin, for example, the resonances of the body of air enclosed in the body of the instrument and of the belly should be close in pitch to the two strings A and D, thus amplifying and colouring these pitches and their overtones. The sound quality of a stringed instrument is also influenced by the thickness and material of the strings; primarily, however, it is the size and shape of the resonating body and especially the material, density, and thickness of the soundboard that determine the sound of an instrument. A well-known Spanish guitar maker, in a successful attempt to prove the importance of the belly of the guitar, once constructed an instrument—an excellent one—from the acoustically dead material papier-mâché, except for a carefully chosen and wrought wooden soundboard. Makers, then, devote a large part of their skill and knowledge to the choice of material for the soundboard; the maker of wood-bellied instruments prefers old wood because it is dry and well seasoned. Thus, some guitar makers find the soundboards of discarded pianos unusually suitable for their purposes; makers of the classical Chinese zither, *ch'in,* preferred old coffins or well-seasoned wood from an old tree.

The timbre of a struck or plucked stringed instrument is also affected by the manner of setting the string into motion. A string plucked with a sharp point (the player's fingernail or a plastic plectrum) emphasizes the higher overtones, thus creating a "bright" tone quality. By contrast, a soft pad, such as that on a piano hammer, emphasizes the fundamental pitch. The relative hardness of the hammer on the piano is thus of critical importance to the sound of the instrument, and the final process in piano manufacture is voicing. A skilled worker adjusts the timbre of the instrument by the simple expedient of pricking the felt hammers with needles until he achieves a unified quality throughout the range of the instrument. The tone of an instrument is also markedly affected by

the place where the string is struck. The permanently fixed striking place on keyboard instruments has to be chosen with a combination of concern for the timbre and the mechanical requirements of the instrument. On all other stringed instruments the player varies the tone quality by choosing to pluck, strike, or bow at various places along the length of the string.

Another way in which musicians and musical instrument makers influence the sound of their instruments is by the use of sympathetically vibrating strings. On the piano, for example, when the so-called damper pedal is raised, thus leaving all the strings free to vibrate, the act of striking one note causes all closely related pitches to vibrate in sympathy, thus modifying the loudness and tone of the struck note. This effect (which is encountered also on the zither and harp) is not a central feature of these instruments, but there are numerous Eurasian chordophones on which the principle is of fundamental importance. The North Indian plucked instruments, sarod and sitar, each possess about a dozen sympathetic strings tuned according to the notes of the mode being played. The Indian fiddle, *sāraṅgī,* has from 35 to 40 sympathetic strings; the Norwegian Hardanger fiddle (*Hardingfele*) has 4 sympathetic strings, the viola d'amore 6 or more. Sympathetic strings are generally made of thin brass or steel, and their vibration reinforces the upper harmonics, thus producing a bright, silvery sound.

Sympathetic strings

TYPES OF INSTRUMENTS

Lutes. Probably the most widely distributed type of stringed instrument in the world is the lute (the word is used here to designate the family and not solely the lute of Renaissance Europe). The characteristic structure consists of an enclosed sound chamber, or resonator, with strings passing over all or part of it, and a neck along which the strings are stretched. The player moves his fingers up and down the neck, thus shortening the strings and producing various pitches.

In the lute the part of the resonating chamber over which the strings pass is called the belly, and the other side of the resonator is called the back. The portion between the back and belly is the side, or rib. A lute may be plucked with the fingers or a plectrum or may be bowed, but the means of sound production do not affect the essential morphological identity of plucked, struck, and bowed lutes.

Lutes may be subdivided into those with skin and those with wood bellies; in most Eurasian cultures examples of both types exist side by side. In Japan the wood-bellied lute is the *biwa,* the skin-bellied one the samisen; in the Middle East the wood-bellied one is the *'ūd* and the skin-bellied, the *tār;* in the United States it is the guitar and the banjo, respectively. The two different varieties of lute are distinct in sound and structure; and methods of construction, timbre, history, and symbolic associations differ markedly. A second subdivision concerns the shape of the instrument; for instance, the lute proper has a round back, the guitar a flat one. These two basic constructional principles (the shape of the resonator and whether the belly is constructed from wood or skin) constantly interact, producing all sorts of combinations.

The string vibrations of the lute are transferred to the resonating chamber by the bridge, which holds the strings above the lute's belly; the resonator magnifies the vibrations and transmits them to the air. Makers lavish great attention on the choice and fashioning of material for the belly: if it is of wood, it must be selected and aged with much care and planed to a prescribed thickness; if it is of skin, it must be made only from certain materials. (The belly of the Japanese samisen is preferably made from the skin of a female cat; the wooden belly of the Puerto Rican *cuatro* is best constructed from wood from a female *jagrumo* tree that has been well seasoned and, if possible, taken from an old house.) In the late 20th century, synthetic materials have frequently replaced skin bellies.

Lute strings

Lute strings have traditionally been made of animal intestines (gut) or metal or silk, though nylon has now replaced these older materials all over the world. Whatever the material, each string must be of equal thickness throughout its length. Some lutes have only a single string, but the great majority have three, four, or more. Very often there are sets, or courses, of two strings to a pitch, so that an instrument that produces four pitches with open strings actually has eight strings arranged in pairs.

In the tunings of lutes, though fourths and fifths (intervals the size of four and five tones of a Western seven-note scale, as C to F and C to G) predominate in many places, any given instrument is likely to be tuned differently from one location, piece, or player to another. Functionally more important is the question of whether a lute is fretted or unfretted. It is clearly easy to change from one pitch to another on an unfretted instrument by sliding the finger along the string, but it is also possible to do this on an instrument with extremely high frets (Japanese *biwa,* Indian vina) by pressing—hence stretching—the string into the cavity between two frets. Instruments with low frets (the guitar, banjo, European lute, viola da gamba) are found mainly in the West, where a limited and clearly defined tonal system is in use and where significant microtonal changes in pitch are not necessary. Even here, however, players manage to produce microtonal inflections, slides, and vibrations on fretted instruments.

The fiddle can be distinguished from other lutes only by the manner in which it is played—with a horsehair bow. The practice of rubbing the strings with this implement is of uncertain age and origin, but it seems to have appeared almost simultaneously (9th–10th centuries AD) in China, Java, the Arab world, Byzantium, and Europe. As with the other lutes, there is a fundamental division between skin- and wood-bellied instruments. (The former are far more common on the fiddle than the latter, which occur mainly in Europe.) Musically more significant, however, is the division between the stick fiddle, in which the player's finger does not actually press the string to a fingerboard (but rather slides up and down the string itself), and the fiddle with a fingerboard (for example, the violin). On fiddles without fingerboard (including the Chinese *erh-hu,* the Javanese and Arab *rabāb,* various African fiddles, and the North Indian *sāraṅgī*), the player's left hand is able to move with extreme flexibility up and down the string, thus making the subtlest kind of inflection possible.

As with other lutes, fiddles may have only one string (the Tuareg *imzhad*) or as many as 40 (the *sāraṅgī*); on the latter, sympathetic strings are not directly touched or sounded by the player but vibrate sympathetically when other strings are set into motion, thus giving a fuller resonance. Examples, in addition to the *sāraṅgī,* include the Norwegian Hardanger fiddle, the Swedish *nyckelharpa,* and the viola d'amore.

The fiddle bow

The fiddle bow itself generally is constructed so that the player can tighten or loosen the hair at will; on most stringed instruments the player is able to make immediate changes by manipulating his hand on the bow hair while playing, thus producing various tone qualities. The modern Tourte bow of the violin has a screw mechanism that cannot be changed while playing. Most bows are actually bow-shaped, but the Tourte bow is made in a compound curve to which considerable tension can be applied, making it possible to apply much pressure to the strings.

The bowing principle has been applied to nonlutes from time to time: the old Icelandic *fidla* was a bowed zither; the Scandinavian *talharpa* was a bowed lyre.

Zithers. Instruments of the zither family, in which the strings lie parallel to and are of the same length as the string bearer (often also the resonator), are widely distributed in Eurasia, the Americas, and Africa. There are two important subdivisions of this category. The so-called long-zither family is found only in East Asia; its characteristic resonating chamber is slightly convex, as much as 6 feet (180 centimetres) long, and about 1 foot (30 centimetres) wide; there is a varying number of strings frequently provided with movable bridges. These instruments, of which the best-known example is the koto, seem to devolve ultimately from tube zithers made directly from lengths of bamboo. The bamboo prototypes are said to be idiochordic because their strings, part of the bamboo itself, are worked loose from the tough surface of the tube, to which they remain attached at either end. The maker then inserts small bridges at the extremes of the strings.

(Various modifications and transformations of this principle exist, such as the bamboo-tube *valiha* of Madagascar and Malaysia, in which wire strings replace the idiochordic ones). All long-bodied, curved-surfaced Asian zithers of the koto type may owe something to this idiochordic principle. In Eastern tradition the most ancient zither is the seven-stringed *ch'in,* which seems to have originated in the Shang dynasty (*c.* 1400 BC). The Japanese *wagon* and koto, the Korean *kayagum,* and the Chinese *cheng* fit into this general category. All these ancient instruments are rich in symbolic associations.

The flat zither

The other important subdivision of the zither family is the flat zither; in Africa it is made either from a hollowed plank over which strings are fastened (board zither) or from individual narrow canes lashed together, each having one idiochordic string (raft zither). The box zither, which seems to be native to the Middle East, is a rectangular or more often trapezoid-shaped hollow box the strings of which are either struck with light hammers or plucked. Examples of the former are the Persian *santūr* and its modern Chinese derivative, the *yang ch'in* ("foreign zither"), the cimbalom of east-central Europe, and the piano (which is a sort of cimbalom with keyboard). The most prominent plucked box zither is the Arab *qānūn* and its various derivatives, including the harpsichord (a plucked zither controlled by a keyboard). In Europe a variety of plucked zithers developed having a fretted fingerboard under one or a few of the strings. In the United States, popular plucked box zithers include the hammered dulcimer, which is widely used in folk music, and the autoharp, which is equipped with damper bars that prevent unwanted strings from sounding, making it relatively easy to play chords.

Struck zithers are occasionally termed dulcimers, and unfretted plucked ones psalteries, after European instruments using those names.

Lyres. The lyre family, though it was of great importance in the ancient centres of Babylonia, Egypt, and Greece, is now found only in a few areas of East Africa. A lyre is made from an oval, round, or rectangular sound chamber (usually skin-bellied); from this resonator two arms protrude; they are joined at the top by a crosspiece; the strings extend from this crosspiece over the belly, with which they are connected by a bridge. These strings are not normally stopped but are allowed to vibrate throughout their entire length when plucked by the performer.

The *beganna* and the *krar*

In Ethiopia, where the lyre remains in extensive use, there are two distinctive types, as there were in ancient Greece. The 10-string *beganna* (which corresponds to the ancient Greek kithara) is a large, heavy, rectangular instrument that is considered by the Christian Ethiopians to be a God-given instrument that came to them from King David; it is used, of course, for sacred music. The smaller lyre, *krar* (the ancient Greek *lyra*), has a bowl-shaped resonator and is emphatically secular in its use and connotations; indeed, Ethiopians think of it as the instrument of Satan. The construction of this five- or six-stringed instrument illustrates the sort of change that is of wide occurrence in contemporary instrument making everywhere, for though the traditional *krar* was made from wood, the resonator of the present-day instrument is made of an easily available metal pan. The *krar* can be played in two ways: in the first (called muting) the left hand mutes the unwanted strings while the right hand strums with a plectrum; in the second, the fingers of the left hand pluck while the right hand plucks a drone on tonic strings tuned to the tonic, or focal note, of the melody.

The lyres of medieval western Europe (4th–12th centuries) had from five to seven strings and, to judge from iconographic evidence, were played in a way that closely resembled the muting technique of Ethiopia. Later northern European lyres were sometimes played with a bow; their shapes are considerably varied, but both the rectangular kithara-like shape and the rounded *lyra* shape apparently existed.

Harps. The harp family exhibits an extraordinary variety of constructions, but in all harps the strings are of unequal lengths and are fastened at either end to a frame that lies in the same plane as the strings. The least complex, and prototypical, harp type of instrument is the musical bow, shaped very much like a hunter's bow. (The musical bow is sometimes classified as a zither rather than a harp.) The bow's single string is tapped or struck, and the pitch can be varied by varying the tension of the string or by using the player's mouth as a resonator and varying its size and shape, thus emphasizing different harmonics. It is a favourite instrument in equatorial Africa.

The arched, or bow-shaped, harp, known in Egypt as early as 3000–4000 BC, is a multistringed version of this musical bow; its player kneels or stands, supporting the harp on the shoulder. Harps of this type may be found in West and Central Africa, where they are often provided with elaborate anthropomorphic carvings and skin-covered resonators. The bow harp, then, is a traditional African form that has been in use in that continent for at least 5,000 years.

On an angle harp the bowlike support is replaced with two crosspieces at right angles to one another; the strings are stretched between these at an angle of 45°. This type seems to have originated in Assyria, though occasionally it is found in Egypt and Greece.

The frame harp

The closed, or frame, harp is characteristic of both medieval and modern Europe; the shape of its frame is more or less triangular, the frame being strengthened by a pillar that encloses the strings in a kind of tripartite structure. It is to this category that the modern orchestral harp of Europe and the old Irish and Scottish harps belong. In all of these instruments the crosspiece held nearest the player is a hollow resonating chamber. The so-called Brian Boru harp (14th century), now at Trinity College, Dublin, is 32 inches (81 centimetres) high, with 36 brass strings; the sound box is carved from a single piece of willow, and the harp was plucked by the fingernails.

THE MUSIC OF STRINGED INSTRUMENTS

Solo uses. Music for a solo instrument is often, though not always, used to accompany dancing or is derived from dance music. In Europe and America, the violin is widely used to play dance music; for instance, the Norwegian Hardanger fiddle player performs rhythmically complex polyphonic music to accompany the *halling, gangar,* or *springar.* In Scotland, Ireland, and rural North America, the violin is favoured for accompanying country dances. It is known that a single fiddler played for dancing among the upper classes in medieval Europe and also probably among the common people, with whom the fiddle was popular. In all areas, the fiddler has an additional repertoire not for dancing, which shows off his compositional and improvisational ability as well as his virtuosity. A skillful medieval fiddler constantly improvised new pieces. It is no coincidence that the violin solo sonatas and partitas of J.S. Bach, like their country cousins, are polyphonic compositions having a liberal sprinkling of stylized dance movements.

A second genre of solo piece is the descriptive composition. In such diverse places as Ireland, West Africa, and the United States are found fiddle pieces picturing the hunt, in which the player delights in the depiction of such realistic sounds as the baying of the hounds, the sound of hooves, and the groans of the exhausted animal. In China there is a genre of highly realistic descriptive compositions for *p'i-p'a*—including some that depict famous battles from start to finish. Among numerous descriptive pieces in Renaissance and Baroque Europe, a well-known example is a sonata for viola da gamba, by the French virtuoso gamba player Marin Marais (1656–1728), that graphically and in detail describes a gallstone operation in the days before anesthetics.

Solo music of the Middle Ages and Renaissance

In the European Middle Ages and Renaissance, an important type of composition for solo stringed instruments was the transcription of polyphonic songs; in the medieval period fiddle and hurdy-gurdy players frequently rendered elaborated versions of well-known strophic songs. In northern Europe, songs intended to accompany dance could also be played on the fiddle, and in Spain the *vihuela de arco* filled a similar function. In the Renaissance, a string player was expected to have the ability to perform highly elaborated versions of preexistent melodies on the

viol, lute, or keyboard: and many manuals provided the player with exercises designed to teach him to elaborate the basic melody in a stylistically correct manner. Similar techniques continued to be practiced during the Baroque period and even into the 19th century.

For accompaniment. All over the world, stringed instruments have as one of their central functions the accompaniment of bards, who sing tales of heroes and otherwise reflect the preoccupations of their societies. The example of Homer and his lyre is of course the best known, and the 19th-century European art song for solo voice and piano also belongs to this genre. Other examples, include the harpers of Celtic Ireland and Scotland, who devoted their skills to the accompaniment of learned bards. The *azmari* of Ethiopia sings lengthy historical epics and strophic love songs to his own accompaniment on the fiddle or lyre. In Japan, blind *biwa* players chant a narrative style of music known as *katarimono;* here the *biwa* is used only between verses for interludes and commentaries. A similar technique is in use among the minstrels of North Africa: the lute, *gunbri,* is played only between verses of the story, as a descriptive comment.

Ensembles. Musical ensembles everywhere have their own internal social structure, mirroring that of their society at large in the degree of authoritarianism, type of leadership, amount of freedom available to the individual players, and so on. The audience for a given ensemble also tends to be socially stratified. Large, authoritatively ruled ensembles tend to be found in societies that have a complex bureaucratic and pyramidal social order. Such groups are most typically to be found clustered around the royal or princely courts of China, Japan, Korea, Java, Bali, and North Africa and in the court-derived music of Europe and America. In all of these instances a more or less fixed and archaic repertoire remains in use. In Japan, Korea, and, to an extent, Southeast Asia, the court music has derived from an archaic (and no longer extant) court music of China. The two types of stringed instruments in use in Japanese court music are the zithers, koto and *wagon,* and the lute, *biwa.* The koto has 13 strings and the *biwa* 4.

The gamelan orchestras of Indonesia employ but two chordophones in ensembles, which are otherwise dominated by struck metallophones, or metal instruments, such as tuned gong sets and xylophone-like instruments with metal bars. The bowed *rebab* probably entered the orchestra from the Middle East, where it was called *rabāb,* ancestor of the European rebec, when Java was converted from the Hindu religion to Islām. It plays in sliding fashion around the fixed pitches of the orchestra; its player is thought of by Javanese as the "rajah" of the gamelan, with the drummer as his "prime minister."

In Islāmic countries and in the West, stringed instruments predominate numerically in the orchestra; the classical ensembles of the Maghrib, which mainly perform the ancient Andalusian suites, typically consist of about one dozen musicians. The instrumentalists include a number of violin or viola players, a *rabāb* player, lute players, drummers, and sometimes flutists, cellists, and a pianist. All of the string players play the melody together but not in unison, for they are expected to vary it individually with ornaments and improvised passages. A true unison, therefore, is neither expected nor desirable. The ensemble is normally led by an *'ūd* (lute) player who indicates the pitch, mode, mood, the changes of tempo, and so on.

Orchestral stringed instruments

The greater number of stringed instruments in use in Western and North African orchestras are bowed; Western orchestras, however, are distinctive in that these bowed chordophones exist and are played in families of graduated size (violin, viola, cello, bass), and this phenomenon derives from the extent to which Western musicians have been preoccupied with harmony and multipart composition. In the development of the Western orchestra two great—but gradual—changes have occurred over the centuries: first, stringed instruments have increased dramatically in number in the orchestra, and, second, higher and higher notes and hence finger positions have been demanded of string players. Socially and musically, the role of the player in an early 18th-century symphony (in which there would be no more than two or three players to each part) is very different from the anonymous function allowed the violinist in a symphony by Berlioz, say, or Mahler. The symphonic orchestra seems to represent the merger of two functionally and aesthetically different groups that medieval Europe probably derived from Arab civilization. One of these, used for outdoor ceremonial music, consisted originally of shawms (oboes), drums, and trumpets; the other, for indoor (chamber) use, was made up of stringed instruments, quiet percussion instruments, and flutes. The modern orchestra preserves vestiges of these two ensembles in its seating arrangements, orchestration, and leadership.

The Western concept of chamber music is nowadays thought of as being entirely distinct from orchestral music; in the 17th and early 18th centuries, however, the distinction would have been difficult to draw, since there was no clear difference either in the music, the size, or the sociological position of the two types of ensembles. The symphonic orchestra arose because of middle-class demand for public concerts and from the desire of composers after the French Revolution to provide democratic music for the masses; thus, mass audiences demanded large orchestras, and the striking multiplication of instrumentalists affected the strings above all others.

Modern Japan cherishes a number of traditional chamber-music ensembles; of these, the commonest one consists of the koto, the samisen, and the *shakuhachi* (flute). The *jiuta* is a common form played by this group; here, the koto plays the principal melody, and the samisen and *shakuhachi* simultaneously produce a variant of it. The Japanese picturesquely describe this ensemble by saying that the koto is the bone, the samisen the flesh, and the *shakuhachi* the skin.

Basic elements of Indian ensembles

The basic ensemble in South Indian music consists of a drone instrument (usually the tamboura), a tuned drum (mridanga), a violin, and a singer. The group is often augmented to include a number of other instruments, but the basic elements must be present. The violinist is an accompanist to the singer; he must be able to play in unison with him in fixed pieces and to follow him in immensely complicated improvisational sections, maintaining all the while the correct raga (melodic mode) and tala (rhythmic mode). An analogous group in North India might include the sitar or sarod as solo instrument, with the accompaniment of the drums, tabla, and a drone. Often the fiddle, *sārangī* (with 3 main strings and 35–40 sympathetic ones), accompanies a singer.

Rather similar principles apply in the eastern Mediterranean: a chamber-music ensemble must include instruments—usually strings—to play the melody and to improvise in the introductory sections known as *taqsīm* and percussion instruments to deal with the rhythmic modes, known as *īqā'āt.* To these, in modern Greek music, the element of harmony has been added so that a solo instrument (clarinet or violin) plays the highly ornamented melody and another instrument (guitar, or *laghouta*) plays the chordal background and maintains the reiterated rhythmic pattern. Similar ensembles are found in the Americas and in Africa.

In Puerto Rican traditional music, a guitar plays the harmony, the five double-stringed lute (*cuatro*) plays the melody with the singer, and the scraper (guiro) and drums (*timbales*) produce the rhythmic part. Among the Berbers of North Africa, groups of itinerant professional musicians typically play one or two *gunbrī* (lutes), a one-stringed fiddle (rendering a highly adorned melody), and percussion. In Senegal, lutes similar to the *gunbrī* are played by the musicians known as griots, often in ensembles of three or four flutes, drums, and rattles. The bluegrass style of Appalachian North America largely conforms to this Mediterranean and African pattern; the ensemble typically includes only bowed and plucked strings and singers.

Rock groups also adhere to these general principles: they also represent a blend of African and European traditions. The typical rock ensembles use plucked electric stringed instruments, electric keyboard instruments, voice, and drums. The electric guitar plays the melody, and the electric bass renders the bass part. In various North and South American blends of Mediterranean, African, European,

and indigenous tradition, the African element includes the percussion instruments and the skin-bellied lute (banjo); the Mediterranean element includes the wood-bellied guitar and *cuatro.* The bass parts are derived from Europe, the scraper from the American Indians, and the singing style from various of the four traditions.

SOCIAL AND CULTURAL ASSOCIATIONS

Throughout the world, particular instruments are associated with particular functions, social levels, areas, ages, and sexes. Certain instruments preserve the same function all over the world: singer-poets recount tales of heroes, recite the genealogies of the great, and preserve and disseminate the precious traditions of a given society—everywhere accompanying themselves on a stringed instrument. An early example would be the blind Homer, who, presumably accompanied by his lyre, sang of gods and heroes. Similar traditions still survive in Greece and the Balkans, but the instrument of the modern "singer of tales" is the fiddle. In Ethiopia, where so many traditions are reminiscent of Greece, the *azmari* accompany themselves with a lyre or fiddle. In North and West Africa griots sing and play skin-bellied lutes called *gunbrī* or *halam;* in Morocco they play and sing alone in the squares of the towns for coppers; in Senegal (where they perform in groups) they are employed by the wealthy. The Japanese *biwa* (often played by blind bards) was used to accompany epic narratives, the texts of which usually concern the adventures and battles of the samurai, and to accompany Buddhist chanting. In medieval Europe, minstrels, self-accompanied on the *vielle* (fiddle), sang of the heroism of such as Charlemagne.

Very often, stringed instruments are identified with a certain social class, either in the sense that the player himself occupies a particular caste position or in that the instrument is the prerogative of a particular rank in society.

Social standing of string players

A well-known example is that of the Irish and Scottish harp of the periods during which the Celtic kingdoms flourished; harpers, who were highly respected members of society, were employed in the households of only the very wealthy and the high nobility. By the same token, harpers were regarded with great suspicion by English officials in Ireland, for they were suspected of spreading sedition. In sharp contrast is the attitude of respectable members of medieval Arab society toward lute players; their status was low indeed (certain judges even held that the lute was an unlawful possession which could be destroyed at will). Paradoxically, the *'ūd* player's skill and imagination was highly valued by the courts. These attitudes are old indeed in the Mediterranean; Aristotle regarded professional kithara players as low-caste and of questionable morals. In his view (and this is still prevalent in the West) the highborn should learn to play as an accomplishment but not professionally. In the 17th century, members of the English upper class were swept with a craze for playing consort music for ensembles of various sizes of viola da gamba ("leg viols," held, cello-fashion, between the knees). It was a common—and much valued—accomplishment to be able to play a part in a viol consort, and, as Samuel Pepys recorded in his diary, servants were often chosen because of their ability as violists.

The violin family in Europe has had two very different social connotations. In the string quartet and orchestra the instrument has been associated with the entertainment of the upper class and the bourgeoisie, and this represents the continuity of the medieval tradition under which the fiddle was highly regarded by the upper class. Alfonso X the Wise, king of León and Castile, was one of many rulers who supported a group of fiddlers at his court.

In opposition to this, the violin has long had great popularity among the folk. In almost every country in Europe and the Americas the rural fiddler has provided the music for dances and entertainments. This country fiddler is distinguished from his urban colleague by his nonstandardized technique, playing position, and tunings and by his learning process, which is totally aural. His virtuosity may be of a high order. The pleasures of the common folk have long been associated with the fiddle, though the medieval fiddler usually played the bagipes, sang, juggled, and told jokes as well.

The role of musical instruments in religious and healing practice is complex: at one time or another Judaism, Islām, and Christianity have each been hostile to the use of instruments in places of worship. The Church Fathers made frequent allegorical and symbolic reference to instruments, and it is common to find depictions of angels, cherubs, or of King David playing on the very instruments that were not permitted to sound in Christian worship. The Hindu attitude toward stringed instruments is very different. Though Vedic chanting is the oldest known music of India, the Rigveda nevertheless mentions the use of such chordophones as the *karkari* and a number of vinas.

Caste and symbolic associations of the *ch'in*

The Chinese scholars' zither, *ch'in,* had definite caste and symbolic associations. No scholar would have been without one, for it restrained licentiousness and purified the heart; it compelled man to return to his divine origin and restrain his passions. Thus, the *ch'in* could not be played when drunk or after sexual intercourse; it could not be played for a courtesan, a merchant, or a barbarian. The *ch'in* was often played by Buddhist monks; complex cosmological and symbolic meanings existed for every aspect of its shape, constructional material, tone, and playing technique. The *ch'in,* therefore, was involved with healing, religion, and philosophy; and of these three, its therapeutic function was perhaps the most pervasive. This instrument harmonizes the blood circulation and regulates breathing; it leads to health and long life. It cures melancholy and can, it is claimed, even make a devoted player immortal.

The function of stringed instruments in the healing process is often an indirect one: a healing specialist may sing powerful songs to the accompaniment of a lute (the *gunbrī* of the North African Gnāwa) or a fiddle (Central Asia). Beyond this relatively prosaic association, stringed instruments have symbolic meanings that transcend their technological, sound-producing function. The horse-headed fiddle of the Mongols is directly a part of the Mongol system of belief in the horse as a symbol of fecundity and rebirth; the winged horse that the shaman is believed to ride in his quest for enlightenment and healing power is equivalent symbolically to the fiddle.

This close connection of stringed instruments with ideas of birth and rebirth explains why so often a particular instrument is typically played, or even listened to, by members of one sex only; in certain instances instrumentalists, whether they were Greek kitharodists or Arab *'ūd* players, were slaves with a low moral reputation. The playing of many stringed instruments by women has been either a low-caste occupation or an accomplishment to be savoured in the confines of the home. In India during the Vedic period there seem to have been stringed instruments (such as the *kāṇḍa-vīṇā*) that were played only by women; and Chinese tradition has it that the long zither, *cheng,* was invented by a woman. In the Western continents, instrument makers seem usually to be men, since in most societies the manipulation of woodworking tools has been a male occupation. In medieval Europe, minstrels made their own instruments, as they do in Puerto Rico today. Since the making and playing of instruments in such places have until recently been mainly in male hands, women have not had available to them this particular link to musical instruments through manufacture.

CRAFTSMANSHIP IN STRINGED INSTRUMENTS

There is no reason to suppose that the shape of an instrument is governed only by acoustic requirements; it seems often to be the other way around: the symbolically appropriate shape preferred by a given culture produces a particular tone quality, which then becomes the desirable one. Available materials, manufacturing techniques, and complex historical, symbolic, and artistic considerations guide the craftsman who creates musical instruments. Transformations occur as old meanings are lost: the scroll surmounting the pegbox of the violin may well be a faint visual echo of the horse's-head carving that surmounts the fiddle in its ancestral lands in Central Asia. Craftsmen are well aware that the soundboard of an instrument is responsible for the best part of its resonance; they are aware that other portions can be considerably altered without making much change in the sound quality. Instrument

makers have long delighted in producing modifications of existing designs and in experimenting with new materials. In all this they are limited only by the essential technological requirement of a chordophone—ability to withstand the constant strain imposed by the tension of the strings coupled with sufficient resonation.

A limited number of basic woodworking techniques are used almost the world over in the production of stringed instruments. In lute construction the entire sound box (and sometimes the neck as well) can be hewn from one block of wood. Instruments that often are made in this fashion are the Japanese *biwa,* the North African *gunbrī,* and the Puerto Rican *cuatro.* Existing side by side with this technique is another, in which the lute is made out of a kind of composite box in which any angular or curved portions are fashioned by heating and bending the wood (common examples include the violin and the guitar). Again, the resonator can be made of preexistent natural materials, as in the case of the Malagasy *valiha* zither (bamboo), the South Indian vina (gourd), or the lyre said to be invented by Hermes (tortoiseshell).

Though occasionally (as in the case of many harpsichords and virginals) instruments with pictures painted on them are encountered, this decorative technique is most unusual—probably because it requires a separate craftsman—and most instrument makers prefer to show their skill by the choice of woods, by complex inlays, and by carving.

The anthropomorphic harp

Anthropomorphic and zoomorphic shapes surmount many ancient harps and lyres. The anthropomorphic harp of ancient Egypt and modern Africa represents an example of this visually symbolic approach to instrument making, which has been described as producing "sounding statues." In Europe anthropomorphic and zoomorphic carving exists side by side. Notable examples are the Irish Brian Boru harp, which exhibits a profuse variety of animal shapes; the Norwegian Hardanger fiddle, surmounted with a dragon's head; and the viola d'amore, which often is surmounted with the head of a blindfolded woman. The Balkan fiddle, *gusla,* and the Central Asian horse fiddle are usually crowned with a carved horse's head, and the South Indian vina features a carving of a dragon. These shapes are not mere decoration or fancy; they represent important symbols in the society from which the instruments come.

In East Asia the craftsman's emphasis is on the beauty of wood, excellence of finishing, and apparent simplicity of construction. Occasionally, on instruments such as the *ch'in,* one finds pictures painted or calligraphy inscribed. The proper material is extremely important: a *ch'in,* for example, should be made of wood taken from an old tree that had nestled next to a bubbling stream. Phoenix-bird symbolism of rebirth is abundant in the nomenclature of East Asian instruments, and this fact serves to point up a profoundly important truth about musical instruments everywhere: they are intimately connected in folktale, myth, and legend to local symbols of rebirth. Thus, legend relates that Hermes made the first lyre from a turtle carapace; similarly, the first Arab lute was modeled after the body of a beloved male child; the Finnish culture hero Väinämöinen made the first zither, kantele, from the body of a giant pike; the Celts made their first legendary harp from whalebones. In each case, the symbolically significant creature is "reborn" as an instrument which "sings" as well as appears in a shape reminiscent of the creature modeled.

THE DEVELOPMENT OF STRINGED INSTRUMENTS

Little or no evidence is available concerning the chordophones of prehistoric times: the earliest iconographic evidence and the oldest surviving specimens come from Mesopotamia and Egypt, and evidence concerning instruments earlier than these can be gleaned only from myth and legend.

The harp. The harp clearly evolves from the musical bow, which must have been in existence prior to the establishment of Mesopotamian and Egyptian civilizations. Since the musical bow is identical in shape with the simple hunter's bow, it has been assumed that the instrument derives from the hunter's implement. There is, however, no evidence for this; quite the opposite: the musical bow is very often played by women, who do not usually hunt, and, further, there is absolutely no way of knowing whether or not man hunted with a bow-shaped implement before he made musical sound with a bow. The three early harps found in the burial chambers at Ur were bow-shaped instruments with 12 to 15 strings; nearly identical instruments were played in Egypt at roughly the same time. Iconographic evidence suggests that in both Egypt and Mesopotamia the harp, often played by women, was used in secular, erotic entertainments, although it had sacred uses as well.

Although the harp family is known to exist in Myanmar and to have been in use in China and India, it is not characteristic of these areas; it is, rather, musically important in equatorial regions of Africa, in Europe, and, since European incursions, in the Americas. In modern Africa it clearly is related to the Egyptian harps, and again it is associated with women.

The harp has maintained and increased its importance in Europe. It is omnipresent in folktales and legends; it is the national symbol of Ireland. The Celtic harp must have been in use as early as the 10th century, and fragments of one were found in the 7th-century Sutton Hoo burial ship unearthed at Suffolk, Eng. In Gaul, Ireland, Wales, and Scotland the harp was an important and favoured symbol; it was said that there were but three things necessary to a comfortable household—a virtuous wife, a chair cushion, and a harp. By the end of the 18th century the harp had almost gone out of use in the Celtic realms, but by then the large orchestral harp had made its appearance in other places in Europe.

The Celtic harp

This basic instrument (with the addition of a set of pedals for instantaneously altering the pitch of a note) is found—often still played by a woman—in the modern symphony orchestra; but the older European harp tradition flourishes best in Mexico and South America, where the harp is a component of various folk ensembles.

The lyre. Greek legend credits the invention of the lyre to Hermes, who had stolen Apollo's cows and, in order to atone for his transgression, presented the god with the lyre, which he had accidentally discovered when he had brushed against a turtle carapace that lay on the ground and, as he did so, heard its sinews begin to vibrate. The tale is interesting for two reasons: first, the turtle shell was, in fact, frequently used as the resonator of the Greek *lyra,* and, second, the tale makes an explicit relationship between the lyre and cattle. Similarly, in Mesopotamia the lyre was surmounted with a carved bull's head, and in modern East Africa the lyre is most frequently encountered in cattle cultures.

A famous lyre from Ur (now at the University Museum, Philadelphia) is one of nine dug up at the burial ground; these and similar instruments seem to have been used both to accompany bardic recitations and for religious purposes. The "harp" that the Hebrews hung in the tree in their Babylonian captivity was actually a lyre, as was the instrument used by Homer (*phorminx*). In view of the importance of the bull in the worship ceremonies of Crete and Mycenae, it is not surprising to find lyres among the stringed instruments of these peoples. In Celtic society depictions of lyres are found on the coins of pre-Christian Gaul. These instruments, which were U-shaped, may have come to western Europe from southwestern Asia with groups of Indo-European peoples who spread across Europe. Other types of lyres were found in Europe, too, and it is possible that these variously shaped but still related instruments might be analogous to the various Indo-European languages in that they are basically closely related but quite different in detail.

In medieval Germany and Scandinavia long, narrow lyres with four to seven strings were played, and similar lyres (the Finnish *jouhikantele,* the Swedish *talharpa,* the Welsh *crwth*) were played with a bow in parts of Europe until the early 20th century. Today the lyre flourishes only in Ethiopia, in The Sudan, among the fishermen of the Persian Gulf, and in restricted areas of East Africa.

The zither. Several different types of instruments are

classified as zithers; they are used today in all continents. The long zithers of China, Japan, and Korea are venerable indeed. Their curved surface and long, narrow shape betray their affinity with the prototypical idiochordic bamboo zithers of the Pacific, Southeast Asia, and southeastern Africa. The importance of bamboo to music in Asia is literally legendary; in Java, music is thought to have been first produced by the accidental admission of air into a bamboo tube. In China, the source of East Asian civilization, musical instruments are classified according to their constructional material; one of the eight substances in the system is bamboo, which the Chinese relate to the direction East, the season Spring, and the phenomenon Mountain. The Chinese zither *cheng* includes the radical meaning "bamboo" in its ideograph. The ideographs of the older zithers, *ch'in* and *se,* are more difficult to interpret; but the narrow, curved shapes of the instruments themselves betray their affinity with the ancient principle. Zithers of this type are known to have existed in the Shang period (*c.* 1766–*c.* 1122 BC); the *cheng,* with either 13 or 16 strings, came into use during the Ch'in period (221–206 BC). By the 18th century, interest in this instrument had waned in China, but at an early date it was introduced to Japan, where, as the 13-string koto, it flourishes today. The koto, like the *cheng,* is played frequently by women.

Bamboo zithers

A relative newcomer to the spectrum of Chinese zithers is the *yang ch'in* (foreign zither), which reached China from Persia a number of centuries ago; it is the only representative of the box zither in East Asia. The history of this type of chordophone is obscure indeed, but two instruments of this general shape that may be very old are the African raft and board zithers. The raft zither is constructed on the idiochordic principle, but it uses a number of canes about half an inch in diameter; each of these has one string raised out of its own surface, and all of the canes are then lashed together. The board zither is made from a hollowed-out board over which a number of strings are attached. This latter instrument is found only in restricted areas of East Africa; it is possible that its principle of construction was carried to the Middle East by traders. Medieval Arab authors (including Ibn Khaldūn) mention the plucked trapezoidal zither, *qānūn* (derived from Greek *kanōn,* "rule"). Nowadays, the instrument has a range of three chromatic octaves with three strings to each pitch, and a complex system of levers by which its many strings may be finely and quickly retuned to the various Arab scales. Closely related is the Persian-derived *santūr,* another trapezoidal zither that is struck by two light hammers. Versions of this zither are found in China (*yang ch'in*), Greece (*santouri*), and eastern Europe (cimbalom). These trapezoidal zithers are the prototypes for the later keyboard instruments of western Europe: the *qānūn,* which is played with two plectrums, became, with the addition of a keyboard, the harpsichord; the cimbalom, with the addition of a keyboard, became the piano. In the Middle Ages, the keyboard was attached to a number of instruments, including the lute, the hurdy-gurdy, and the various Scandinavian keyed fiddles, of which the Swedish *nyckelharpa* survives. The experiment was truly successful, however, only on the clavichord, harpsichord, and later the piano; on the fiddle, it always remained of peripheral importance.

The lute. The first surviving evidence of the existence of the lute comes from Mesopotamia and Egypt. One of the earliest Babylonian delineations (*c.* 2500 BC) shows a shepherd with a long-necked, small-bodied lute; this instrument, which was doubtless skin-bellied, had a rounded back that might well have been made from a turtle carapace (as in modern North Africa) or a gourd (as in Puerto Rico). A similar instrument is also found in Egypt, and from specimens surviving from ancient times it is known that the stick forming the neck passed through the body of the instrument, ending at the sound hole, where it served as a fastener for the ends of the strings. This instrument, like the harp, survives in West Africa and in North Africa (as the *gunbrī* or *halam*).

Earliest known lutes

The Greeks of old seem to have made rather sparing use of the lute, but it was commonly encountered in Rome. Though the skin-bellied lute predominated in the ancient Mediterranean, the wood-bellied lute has been more typical of Europe; indeed (with the exception of the African-derived banjo), all currently used European lutes and fiddles have wood bellies. The model for the European lute was the classical Arab lute, *al-'ūd* ("the wood"), which has been the most important instrument of classical Arab music for 1,000 years. The instrument, with its characteristically curved back, probably entered Europe through a number of different gateways, including Sicily, Andalusia, and Palestine with the crusaders. Though European and Arab lutes are very similar in general construction, the Arab lute is not fretted as is the European lute, and the European lute little by little acquired additional courses of strings during the Renaissance, when it became a standard instrument for solo playing and the accompaniment of singers. The many courses of strings caused numerous problems: "When a lute-player is 80 years old," wrote the 18th-century German theorist Johann Mattheson sarcastically, "he has spent 60 years tuning his instruments."

The many lutelike instruments of modern India (tambura, vina, sitar, and sarod) are, technically speaking, lute-zithers, since their fingerboards are hollow; in appearance and playing technique, however, they are indistinguishable from lutes. They seem to represent a special, and quite recent, subfamily of chordophones.

In East Asia the lute family exists only in a comparatively recent manifestation, but both in wood-bellied form (Chinese *p'i-p'a,* Japanese *biwa*) and skin-bellied version (Chinese *san-hsien,* Japanese samisen). In Japan, these instruments existed in the year 752, and the Imperial Treasury at Nara preserves three *biwas* used at a great concert held in that year. The *biwa–p'i-p'a* family can be traced ultimately to Persia, where, as the *barbat,* it influenced the music of Afghanistan and Turkestan on its way to China and Japan. The skin-bellied lute, *san-hsien,* can be traced in China only to the 13th century; from there it was taken to the Ryukyu Islands and thence to Japan (mid-16th century), where it still plays an important musical role as the samisen.

Lutes of East Asia

Bowed instruments. The principle of bowing is nearly always applied to stringed instruments of the lute class, though one occasionally finds it used with zithers or lyres. It is difficult, if not impossible, to make a clear-cut distinction between plucking with a plectrum and bowing, since plucking sometimes involves rubbing the string. But bowing, defined as the use of the almost universally encountered horsehair bow, can be traced as far back as the Islāmic civilization of the 10th century. The stroked *rabāb* evidently possessed a long neck and up to four strings. There is no iconographic evidence of such instruments before the 13th century in Islām itself, though an illustration (*c.* 930) from Christian Spain delineates a bowed instrument with three strings. In Byzantium, too, the bowed *lira* (lute) existed by this time, and it seems likely that the principle of bowing originated among the horse cultures of Central Asia, whence it spread quickly through Islām and the East, so that by 1000 it had almost simultaneously reached China, Java, North Africa, the Middle East and Balkans, and Europe. Modern scholarship has shown that a word meaning "horse" is given to the bridge of the fiddle throughout Eurasia, from Japan (*koma*) to western Norway (*hest*). In China the fiddle is acknowledged to have come from the "barbarians" of Central Asia; in those days it was in China an instrument of the people; later, at the time of Kublai Khan, it began to be used in court music. In Africa, the fiddle seems to have entered the continent with Islām.

In Europe the bow appears first in Spain and shortly thereafter in Italy, and it is suspected that it entered through Muslim Spain and Sicily, though it is possible that other fiddles entered Europe through the Balkans, Hungary, and Scandinavia. Even in early illustrations, evidence is found of the uniquely European method of holding the fiddle against the shoulder. At the same time, other European fiddles were held vertically, the manner in which fiddles are held everywhere else in the world. Early European fiddles were made (by their players) in only two parts: the belly was a thin piece of spruce or fir wood, and the back was hollowed out of one piece of

The bowed instrument in Europe

hardwood. These medieval fiddles divide into two types, one of which has a clearly discernible neck; the other possesses a neck that merges imperceptibly into the body; this second type, exemplified by the rebec, is equivalent to the North African *rabâb* and the Byzantine-Greek *lira*. As the centuries passed, Europe continued to have two distinct types of fiddles: one, relatively square-shaped, held in the arms, became known as the viola da braccio ("arm viol") family and evolved into the violin; the other, with sloping shoulders and held between the knees, was the viola da gamba ("leg viol") group. The gambas, which were important and elegant instruments during the Renaissance, eventually lost ground to the louder (and originally less aristocratic) braccio-violin family.

Electronic technology. In the second half of the 20th century, electronic technology has made remarkable changes in the structure and function of many stringed instruments by making amplification and tonal change possible. The best known and most pervasive example is the electric guitar, which, strictly speaking, may be considered a chordophone but is often classified as an electrophone. The electric guitar may be hollow-bodied like a traditional guitar or solid-bodied, but in either case amplification of the strings is provided by a "pickup" (or contact microphone) that creates artificial resonance through its connection to amplifiers and loudspeakers. Pickups are often attached to violins, lutes, and other instruments, as well as to guitars, making these instruments usable in noisy environments and vast amphitheatres. Musicians who use such instruments (especially electric guitars) have developed feedback and other techniques that can alter the timbre beyond recognition. (T.Gr.)

THE VIOLIN FAMILY

The violin family at present comprises the violin, viola, violoncello, and double bass; it forms the backbone of the modern symphony orchestra. In addition, the violin and viola are widely used in the music of South India and North Africa, in modern Greek and Arab music, in European and American folk music, and by Romany musicians. The term violin, a diminutive of viola (itself an abbreviation of viola da braccio), is linked etymologically to words ranging from the Icelandic *fidla* to the Provençal *viula*.

Bowed chordophones seem to have originated in Central Asia and spread rapidly throughout Eurasia in perhaps the 10th century. Though many different applications of the bowing principle existed in medieval and Renaissance Europe, one direct ancestor of the violin may have been the *polnische Geige* (Polish fiddle), mentioned as early as 1545 by Agricola, and later by Praetorius.

The immediate precursor of the violin is the *lira da braccio*, an elaborate instrument of the Renaissance, whose form foreshadows the physical essentials of the violin body: the arched modeling of the belly and back and the shallow ribs. This shallow arched form probably encouraged or suggested another important detail: the use of a short vertical stick to prop the front and back apart and prevent the collapse of the belly arch under pressure of the strings. This device, the sound post, is peculiar to the violin family, although it was later used on the viola da gamba family (known as the viols). It is the acoustic effect of the sound post that imparts to the violin its lively response and generous singing tone, for it couples and coordinates the vibrations of the body as a whole, under the influence of the strings.

The sound post

Although the generic name for the family is the Italian *viola* (whence violino, "small viola"; violone, "large viola"; violoncello, "small violone"), the treble instrument very soon became its most important member, from which the others took their main characteristics. Unlike the treble viols, whose tone was reticent and impersonal, the violin was always recognized both for its superior cantabile and for its inherent sprightliness and smart attack, especially in Italy, its birthplace, where the earliest makers, Gasparo da Salò, Andrea Amati, and Giovanni Paolo Maggini, had settled its average proportions before the end of the 16th century. Thus the violin arrived at exactly the right time to lend impetus and conviction to the innovations of the Florentine school of composers, whose preoccupation with the expressive qualities of the solo voice marked a breakaway from the older polyphony. To this movement, the violin formed the perfect instrumental counterpart.

Two other features contributed to the character of the violin, the first being the tuning of the strings in fifths and their numerical limitation to four. This wide regular tuning was ideal in furnishing a uniform diatonic fingering technique, reducing the amount of string-crossing the bow has to do, generally freeing the bridge from too many strings and permitting better clearance on each string for bowing. The second additional feature is the unfretted fingerboard, in which the violin followed the *lira da braccio*. No doubt frets, if they were ever used, were removed from the arm viols because they impeded the use of the hand in supporting the instrument and in fingering. It is also true that the direct stopping of the strings by the fleshy part of the fingertips produces a tone quality that, although slightly damped, is more assertive and flexible than the tone obtained from the use of frets, as on the viols.

The violin family came to be used in a way that was entirely new in instrumental music—*i.e.*, as a massed "choir" in which the several parts were doubled at unison by instruments of like kind. This string ensemble, so different in its effect from the chamber music of the preceding "golden age," owes its first organization, if not its invention, to the French at the court of Louis XIV, whose *vingt-quatre violons du Roi* was the model for Europe of the embryo orchestra-to-be.

Morphology. All members of the violin family are basically similar in structure, nomenclature, and playing method. The shape of members of this family represents an extremely efficient method for the production and amplification of tone, as well as flexibility and convenience for the player. Instruments of the violin family are, however, difficult to play, requiring many arduous years of practice for their mastery. They are made, following builders' experience and convention, of several different woods that have been dried and aged with the greatest care. The creator of a successful instrument in this family must be a master craftsman in wood selection, carving, shaping, and assembly. The nomenclature of these instruments is basically anthropomorphic, with the playing surface being termed the belly, the opposite side the back, and the sides the ribs. Names of some parts, however, seem to hint at the origins of bowed instruments among the horse cultures of Central Asia—*e.g.*, tailpiece, saddle, and tailpin.

Structure of the violin body

All members of the violin family have a body that consists of a belly of spruce or pine and a back of sycamore, maple, or a similar hardwood, spaced apart by shallow ribs of the same material. The arching of the belly and back is both transverse and longitudinal, creating a central bulge, flattening off in all directions to the edges. In most cases the bulge changes from convexity to concavity as it approaches the edges, which are given a slight upward curl. The arching is worked from solid wood of suitable thickness, which is dug out on its undersurface to a curve that follows the general contour of the outward modeling but not exactly, for the finished thickness is graduated in all directions, being thinnest in the margins of the outline just inside the ribs. The adjustment of these thicknesses is one of the prime skills in the craft of violin making. The wood used in both back and belly is usually, though not always, cut "on the quarter"—*i.e.*, in wedge-shaped segmental planks from the centre to the outside of the log. To form a plate, two wedges are glued "back to back" with the thin edges outward. This not only provides the basis for the modeling but also ensures that the annular rings of the tree are evenly disposed about the centre line of the plate, the oldest growth being on the outside edges.

The familiar outline of the violin body is visually satisfying, perhaps because its balance and proportion are largely functional. Its master makers have evolved a form based on an artistic unity of opposed curves that allows free play to individual nuance with scarcely any measurable deviation from the norm. The rounded, outward-curving sections of the body, called the upper and lower bouts, are separated by the indented waist, or middle bout, which provides clearance for the bow on the outer strings.

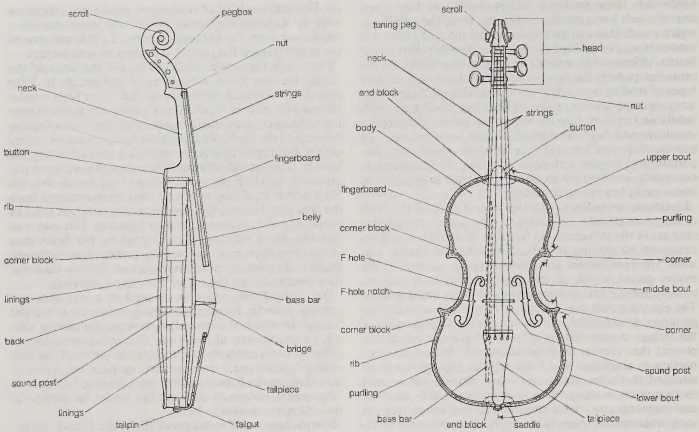


Figure 1: Cross section and front view of a violin.
From R. Donington, *The Instruments of Music*. © R. Donington 1970; Methuen & Co Ltd

The middle bout meets the upper and lower to form outturned corners, where the ribs are brought together and glued firmly to corner blocks within the instrument. Other blocks, called end blocks, are mounted top and bottom centre to provide firm bearings for the neck and the tailpin, which between them have to resist the tension of the strings. The ribs are slightly inset from the outline of the belly and back, so that the edge overhangs all around. The internal corners between the ribs and the plates are strengthened by a narrow fillet of pine, called the linings, which runs between the blocks. Despite the very considerable stresses to which it is subject, the violin body is held together by simple flush glued joints, which can in emergency be opened up, without damaging the instrument, for repairs.

The arched belly or soundboard of the violin and its relatives is supported in a curiously unorthodox and individual way, quite different from the regular barring of instruments with flat soundboards. The sound post has already been mentioned. It is a loose stick of pine, carefully cut to size, that is wedged between the plates of the finished instrument under, but a little behind, the top-string side of the bridge. It is not fixed: its position is critical and must be adjusted with great care for the best tonal result. This adjustment is made through the sound holes in the belly. The other side of the bridge is supported by a bar glued under the belly and running lengthways along the grain of the wood. This bar, called the bass bar, is deepest under the bridge, but tapers to nothing at either end, since it fits into the internal curvature of the belly. Externally, the plates are finished off at the edges with a narrow inlay of laminated woods, the purfling, which follows the outline close to the edges. This, the only decoration normally permitted, has the function of preventing incipient splits from running.

The bass bar

The neck and head are cut from a solid block of sycamore wood. The lower end is formed into a shoulder that abuts against the ribs at the top of the body and, in fact, passes through them into a shallow mortise cut in the end block within. The back end of this shoulder is covered by a projection of the wood at the top of the back, known as the button. The pegbox carries the four tuning pegs, two on each side. It is slotted to the front to receive the strings. The pegs are tapered and pass through two holes in the cheeks of the head. At the top of the head is the scroll, again a typical embellishment of the violin, its austere purity of line and curve being both the challenge and the sign manual of the master craftsman. The front face of the neck is flat, and to this is glued the curved fingerboard, which projects beyond the shoulder and over the belly toward the bridge. At the top of the neck is the nut, which is grooved to take the strings, keeping them correctly spaced apart and slightly raised over the fingerboard. The neck is raked back at an angle with the plane of the belly, so that the fingerboard rises with the strings toward the bridge. The bridge is high and arched because of the bowing technique. It is formed with two feet that are carefully cut to fit the transverse arch of the belly and is given a conventional perforated or fretted design, which is said to aid its free vibration. In section it is wedge-shaped, tapering to the thin, notched edge over which the strings pass. It is not a fixture but is kept in position only by the pressure of the strings. Its correct position is between the sound holes and just above the lower corners of the middle bout. The sound holes are of italic *f* form, sweeping outward and downward from the waist to the lower corners. A line joining the crosses of the *f*s marks the approximate position of the bridge. The lower ends of the strings are held by the long tailpiece below the bridge, whose function is to reduce the length of unused string behind the bridge and to keep the strings pulling radially inward on its top edge. The lower end of the tailpiece is anchored by a loop of gut to an ebony button (the tailpin) set in a hole in the lower end block. The saddle takes the pull of the tailgut off the edge of the belly.

The sound holes

Tuning. The violin itself is normally tuned in fifths (g, d′, a′, e″), although other tuning systems (called scordatura) have been used for special musical purposes; the viola is tuned one-fifth lower than the violin (c, g, d′, a′); and the violoncello exactly one octave below the viola (C, G, d, a). The double bass, which has had many different tunings and various numbers of strings over the years, is now tuned in fourths (E, A, D, G).

Playing positions. The violin and viola are played in the horizontal position—*i.e.* "under the chin." The cello (customary abbreviation of violoncello) and double bass both stand vertically on the floor, the first resting on a long steel rod called the end pin, with the player holding the instrument between his knees while seated. For the double bass the player stands or rests on a high stool. As is done with every other necked stringed instrument, the player's left hand fingers the instrument, the bow being

held in the right. The highest string is to the right, viewing the instrument from the front, the lowest to the left.

In contemporary usage, the violin and viola are held between the chin and the collarbone with the aid of a chin rest, thus leaving both hands free for manipulation of the instrument. In earlier styles and in folk music, the violin was held so that it sloped downward, almost resting on the chest.

Violin. During its history the violin has been subject to modifications that have progressively adapted it to its evolving musical functions. In general, the older types have been more deeply arched in the plates, and the more modern, following the innovations of Antonio Stradivari (1644–1737), have been shallower, which has affected the overall tonal characteristics. The stresses to which the instrument is subjected under working conditions have increased not only because of the rise in pitch from the 17th century onward but also because of certain changes in physical design from about the beginning of the 19th century. Before that time the height of the bridge and its arching were lower, the neck thicker and wider, and the bass bar shallower and shorter. These, with the type of bow then in use and the lower pitch, produced the small, delicate tone that served composers up to the time of Mozart. With the advent of larger auditoriums and the development of the violin virtuoso, however, greater power was demanded, and this demand was met by raising the height of the bridge, lengthening and slimming the neck slightly and setting it back at a greater angle, and putting in a stronger bass bar. The sum effect of these alterations was to develop the optimum sonority of which the instrument was capable, and the long experience of makers and players has shown that the Stradivari type with its shallower arching has stood up best to this metamorphosis. All fine violins now in use have been thus modified to bring them into line with modern technique and modern conditions.

19th-century design modifications

Viola. This instrument is similar to the violin in every essential, but, owing to its larger size, it has never been completely standardized in its main dimensions, since, whatever these are, they are bound to tax the human frame and fingers when the instrument is played. A compromise has to be effected between what is the ideal size for the best tonal results and what is practicable to the player in handling. Too large an instrument is simply unplayable; too small an instrument is weakest where it is most wanted—on the lower strings. The problem has never been solved to complete satisfaction, but a characteristic viola tone has been produced that is darker, more weighty, and more sombre than the violin.

Violas have been made at various times with a body length (the most convenient measure of their maneuverability) of 15 to 18 inches (38 to 46 centimetres); probably the majority of the most manageable and successful instruments are midway between these extremes. However desirable it may appear in theory, too big a body, whether in length or depth, is not only difficult to play because of its size but also tends to develop a "tubby," aggressive, unmanageable tone that lacks the blending qualities of the traditional instrument.

Violoncello, or cello. The true bass of the violin, and the member of the family most nearly approaching it in character, is the violoncello. In build it differs somewhat, the ribs being proportionately much deeper and the much higher bridge standing on legs rather than feet. The neck is raked back at a sharper angle to allow for the height of the bridge. The instrument is held between the knees while it rests on an end pin, which is telescoped through the tailpin and can be clamped in any position to adjust the height of the instrument above the floor. This playing position leaves both arms exceptionally free; in particular, the left-hand technique is more fluid and covers a wider range than in any other stringed instrument. This is strikingly shown by the ease with which a good cellist commands the brilliant solo register of the top (A) string, high above the normal tessitura of the instrument.

Double bass. The double bass has numerous features that set it apart from other members of the violin family. For example, it only rarely serves as a solo instrument. In the symphony orchestra, it often serves simply to double the cello part one octave lower, and it is not even included in such standard musical ensembles as the string quartet. Furthermore, even though double basses have been in use for as long as the violin, they are not yet completely standardized in number of strings, tuning, shape, or body size.

The bass is sometimes made with the blunt corners, sloping shoulders, and flat back associated with the viola da gamba family, and in fact the instrument is commonly known as the bass viol. But true double bass violins, with arched back and outturned corners, have existed since the early 17th century and are still in use. The unusual tuning in fourths, which is almost universal on the bass, was adopted because the great length of the strings (42½ inches, or 108 centimetres) makes the whole-tone interval in the fingering so large that it can be covered only by the span of the first and fourth fingers. The closer tuning therefore brings the technique of fingering more into line with what is possible on the smaller instruments, namely a scalewise (diatonic) fingering that reduces hand movements to a minimum. The normal tuning, E_1, A_1, D_1, G, means that the bass cannot descend an octave below the cello's bottom string, and it is for this reason that a low fifth string is sometimes added, tuned to B_0 or C_1. The latter note occurs in symphonic works from the Classical period onward—for example, in Richard Strauss's *Also Sprach Zarathustra* (1896; *Thus Spoke Zarathustra*)—and is being more specifically demanded by modern composers.

Bass tuning

Another method of obtaining C_1 is to fit an attachment mechanism that lengthens the existing E string (which is carried up to the top of the head on an extension bar) when these low notes are wanted. This has the advantage that it preserves the normal four strings and their normal tuning for all ordinary purposes and imposes no extra load on the bridge, as does the fifth string.

On the double bass the pegs are replaced by a "machine head," such as is commonly used on guitars and other plucked instruments, each tuning peg being fitted with a worm-and-wheel screw adjuster. The pegs themselves are made of solid brass. The "tailgut" of the smaller instruments is also replaced by metal, usually a thick copper wire but preferably a stranded steel cable. An extending end pin, similar to the pin used on the cello, is now in universal use. On most basses the ribs are not of equal depth all around but are cut away at the top so that the back slants toward the shoulder of the neck in its upper part. This enables the player to bring the neck and upper portion of the body closer to him and makes for ease of handling. The normal size of the bass, around 6 feet (1.8 metres) high, is about as large as the average person can manage for modern technical requirements. This size has been known since the early 17th century, but larger and smaller basses have been made at all times, and in the late 20th century the small electronic bass has become common in popular bands and orchestras.

Other violins. J.S. Bach, along with other composers, occasionally wrote for the small, high-pitched instrument known as the violino piccolo; now and then his works also require the viola d'amore (a fretless hybrid shaped like a viol but sized and played like a viola with sympathetic strings) or the elusive violoncello piccolo (a small cello). These instruments have been in disuse for many years, except for historical reconstructions of earlier music.

The violin and cello are obtainable in several sizes suitable for young children, who, as they grow, move progressively from quarter- to half- to full-size instruments. This practice has been encouraged particularly by adherents of the Japanese Suzuki method of string instruction who have exported their philosophy, methods, and instruments to all quarters of the globe.

The bow. The violin bow consists of a strong, light, flexible wooden stick, sprung so that a ribbon of horsehairs can be stretched between its ends. Before playing, the hair is drawn across a solid cake of resin and rubs off a small quantity in powder form; this supplies the frictional element that is necessary to make the string vibrate. Proper design is as important in a violin bow as in the violin itself, for it must give the player a feeling of complete control over the tone he is producing and must respond to every nuance of pressure and attack imposed upon it.

Until the late 18th century, the bow stick was either straight or (as on a hunting bow) bent outward from the horsehair, which was under comparatively low tension. This type of bow, which was used during the Baroque and Classical periods, was short and had a light head and a narrow ribbon of horsehair.

The modern bow, which is really the culmination of a long line of evolution, was perfected late in the 18th century by Francois Tourte of Paris. Its chief point of departure is that the curve of the bowstick is concave rather than convex, thus putting the horsehair under considerable pressure (necessary for modern bowing technique). The light tapering stick now is made of brazilwood (Pernambuco wood) with a hatchet-shaped head formed at the thinner end. At the other end is a movable frog, which has a threaded eye projecting into a mortise or groove cut in the stick and runs on a screw that can be turned at the lower end of the stick. The hank of hair is stretched between the head and frog, and its tension is adjusted by the screw. The hair is retained as a flat ribbon by passing through a specially shaped ferrule and a shallow channel in the frog before it is wedged into a socket farther along. The hair is usually concealed in the channel by a small sliding panel made of mother-of-pearl. The hair is similarly wedged in the head, the front of which is faced with ivory or silver to protect it from damage. When the screw is slackened off and the hair is loosened, the stick curves toward the hair. When the hair is tightened, the stick straightens out, or rather the curve flattens somewhat. It is the correct setting of this curve, which is put into the stick by bending under dry heat, and the exact shaping of the tapering section of the stick that give a good bow its desired qualities.

The Tourte bow

The larger instruments have followed the violin in bow design, adapting it to their special purposes by adjustments of dimension and weight. For a long time the double bass lagged behind, and during the first half of the 19th century this instrument was still being played with a broad, heavy version of the earlier outcurved bow. This was supplanted in France, and in other countries under French influence, by the violin-type bow and in Austria and German-speaking countries generally, a little later, by the Simandl bow, named after a contemporary professor of the Vienna Academy. This bow is really an adaptation of the older type but with an incurved stick, wide frog, and narrow head. (E.Hy./T.Gr.)

Keyboard instruments

Keyboard instruments include all musical instruments on which different notes can be sounded by pressing a series of push buttons or parallel levers. This large group of instruments has assumed great importance because the keyboard enables a performer to play many notes at once as well as in close succession. This versatility enables the modern pianist or organist to play, in transcription, any work of Western music, whether it involves chordal harmonies, independent contrapuntal parts, or only a single melody. The capabilities of keyboard instruments have influenced the composition of music for other media, because virtually every major composer from William Byrd (*c.* 1543–1623) to Igor Stravinsky (1882–1971) and beyond has been at least an accomplished keyboard performer, if not a renowned virtuoso. The evolution of an idiomatic keyboard compositional style has been linked to technological and theoretical developments within Western urban culture; keyboard instruments are not normally associated with folk music, and only during the 20th century has their use spread widely outside the Western world.

In its broadest sense, the term keyboard instrument may be applied to any instrument equipped with a keyboard and thus may be used to refer to accordions, percussion instruments such as the celesta and the carillon, and many electronic instruments—for example, the Moog synthesizer and the Ondes Martenot. In a narrower sense, such as is employed in this discussion, the term is restricted to instruments in which sound is produced from strings, whether by plucking, striking, or rubbing, or from pipes or reeds.

DEVELOPMENT OF THE KEYBOARD

Evolution from early forms. Long before the appearance of the first stringed keyboard instruments in the 14th century, the keyboard was developed and applied to the organ. A keyboard of the kind familiar today—a series of parallel levers hinged or pivoted so that they can be pushed down by the fingers—first appeared on the hydraulus, an organ probably invented in Alexandria in the late 3rd century BC. This type of keyboard seems to have disappeared after the fall of the Roman Empire, and the organs of the early Middle Ages generally had sliders that were pulled out to sound different notes; some may have had keys that turned like the key for a lock. Keys of the last type were certainly used on the organistrum, a large medieval hurdy-gurdy operated by two players: one turned a crank rotating a wheel that rubbed against one or more strings to make them sound, while the other produced different notes by turning the key-shaped levers that stopped the strings at various points (much as guitar strings are stopped against the fingerboard).

Some small portable organs had push buttons instead of keys as late as the 1440s, but a keyboard resembling the modern type existed in the 14th century, although the arrangement of naturals and sharps (corresponding to the white and black keys on the modern piano) was only gradually standardized. The arrangement of the keys depended in part on the music played and partly on the current state of musical theory. Thus, early keyboards are reported with only a single raised key in each octave (B♭), and there were organs that had both B and B♭ as "natural" keys, with C♯, D♯, F♯, and G♯ as raised keys. The colours of the keys—white for naturals and black for sharps—became standardized much later, about 1800, depending on fashion or on the relative cost of such materials as bone, ivory, or boxwood for the "white" keys and stained hardwood or ebony for the "black" keys. Flemish instruments had bone naturals and oak sharps by 1580; French and German instruments had ebony or fruitwood naturals and bone or ivory sharps until the 1790s.

Key arrangements and colours

Special key arrangements. *The short octave.* Even after the present arrangement of five raised keys and seven natural keys per octave had become standard in the 15th century, two exceptions existed. The first of these—the "short octave"—concerned only the lowest octave at the bass end of the keyboard. In the short octave, not all keys actually sounded notes of the expected pitch; their

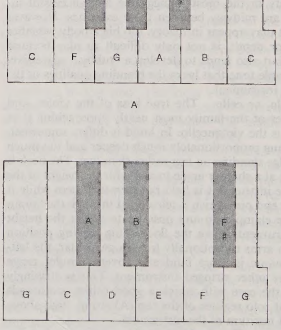


Figure 2: *Special key arrangements.*
Short octave (A) beginning on C and (B) beginning on G (see text).

respective strings were tuned to lower notes. In the earlier form (Figure 2A), the keyboard apparently started on E, but the string for this key was tuned to the C below. The apparent F♯ was tuned to D and the G♯ to E, so that the notes of the entire octave from C to c were encompassed within an apparent key span of only E to c. With this arrangement C♯, E♭, F♯, and G♯ were not available in the bass octave, but these notes were rarely required in the bass in music of this period. When the missing F♯ and G♯ later became necessary, short-octave keyboards were made with these keys divided into two parts, the fronts sounding D and E and the back parts sounding F♯ and G♯. Later still, a second short octave was developed (Figure 2B) in which the keyboard apparently began on low B. This key actually sounded the G below, and the apparent C♯ and E♭ were tuned to A and B (or B♭). Eventually, as musical styles changed, the two retuned sharps were divided in this arrangement as well, providing C♯ (or sometimes B♭) and E♭ at the back of these keys while retaining A and B at the front.

Divided sharps. The second type of exceptional keyboard arrangement was originally required by the so-called meantone tuning system generally used in the 16th–18th centuries. Meantone tuning provided significantly purer tuning for a relatively small number of tonalities than does equal temperament, the system now in use (in which all tonalities are somewhat out of tune; see MUSIC, THE ART OF: *Music and sound: Tuning and temperament*), but only at the expense of restricting the usefulness of the remaining tonalities. This characteristic arose because in meantone tuning each of the raised keys could be used in only one way: for example, if the key between D and E was tuned to E♭, it could not be used as D♯ without retuning. One solution was to build keyboards with the raised keys divided, the front half of the key sounding the appropriate sharp while the back half sounded the equivalent flat. The keys most commonly divided were A♭/G♯, E♭/D♯, and B♭/A♯. Instruments with up to three divided keys in each octave were commonly made in the 16th and 17th centuries, especially in Italy. Since the 1590s still more complicated keyboards have been built, permitting even more refined tunings; some in the 19th century had more than 50 keys per octave. Instruments have also been made with the octave divided into 24 rather than 12 equal parts to permit playing music utilizing quarter-tone intervals.

Impact of tuning systems

Keyboard size and range. Although some early organs had very wide keys that could be played only with the fists, stringed keyboard instruments seem always to have had natural keys no more than an inch wide, yielding an octave span of 7 inches (17.8 centimetres). The octave span on the modern piano is about $6\frac{1}{2}$ inches (16.5 centimetres), much the same as on Flemish and Italian harpsichords of the 16th–18th centuries, whereas that of English keyboards was generally $6\frac{3}{4}$ inches (16.2 centimetres). On most French and German instruments of the 18th century, the octave span was even narrower ($6\frac{1}{4}$ inches [15.9 centimetres]), permitting the playing of tenths—such as C to the second E above—by a hand of average size.

The range of the keyboard gradually expanded from a single octave for some early organs to $2\frac{1}{2}$ or 3 octaves in the 15th century and 4 or $4\frac{1}{2}$ octaves in the 16th century. By the early 18th century, except in Italy and Spain, a range of five octaves was common: from the F below low C to the F above high C (F_1 to f'''). This range began to be expanded only at the very end of the century, usually upward toward c'''' (C above high C) but occasionally downward to C, (C below low C). A few pianos with a range of six octaves (from C, to c'''') were built before 1800, and Beethoven's *Hammerclavier Sonata,* Opus 106 (completed 1818), requires $6\frac{1}{2}$ octaves from C, to f''''. A seven-octave range was reached before 1830, and the usual modern piano keyboard consisting of 88 keys provides the only slightly greater range of seven octaves and a third, from $A_{,,}$ to c''''.

THE CLAVICHORD

The earliest known reference to a stringed keyboard instrument dates from 1360, when an instrument called the *eschiquier* was mentioned in account books of John II the Good, king of France. The *eschiquier* was described in 1388 as "resembling an organ that sounds by means of strings." There exists no more complete description of the *eschiquier,* however, and it is not known whether the instrument was a variety of clavichord, in which the strings are struck by blades of metal that must remain in contact with them as long as they are to sound; a harpsichord, in which the strings are plucked; or a type of keyboard-equipped dulcimer, in which—as in the piano—the strings are struck by small hammers that immediately rebound from them. All three types of instruments were described and illustrated about 1440 by Henri Arnaut of Zwolle, personal physician of Philip the Good, duke of Burgundy.

Despite the uncertainty regarding the *eschiquier,* it seems probable that the clavichord was the earliest stringed instrument having keys that could be pushed down by the fingers. The term "clavichord" first appears in a German document from 1404, and the instrument is recognizable in a German altar carving from 1425. Its principle of operation resembles that of the medieval organistrum, and it is apparently closely related to the monochord, an instrument consisting of a shallow closed box over which one or two strings were stretched and supported by movable bridges. The monochord was in continuous use by theorists from ancient Greece onward as a device for explaining and measuring musical intervals. The kinship of the clavichord to the monochord was so close that, as late as the 16th century, clavichords were often called *monocordia.*

Principle of operation. The clavichord is rectangular in shape, and its strings run from left to right across the keys, which are placed along one of the longer sides of the rectangle. The soundboard of the instrument is at the right-hand end of the case, and the vibrations of the strings are communicated to it by a bridge on which the strings rest. The soundboard amplifies the sound of the strings by permitting them to set a large mass of air into vibration rather than the very small mass of air that contacts the string itself. (This is the same principle that makes a tuning fork sound louder when its stem is pressed against a tabletop.)

Shape and layout

The clavichord's operation is extremely simple. A brass blade rather like the end of a screwdriver is driven into the top surface of each key near the back of the key (Figure 3); a smaller piece of wood, whalebone, or horn is driven into the back end of the key. (This piece fits into a fixed slot behind the key and prevents the key from moving from side to side as it moves up and down.) When the front end of the key is pushed down by the finger, the back end rises, and the brass blade, called a tangent, strikes the strings (which in most clavichords are arranged in pairs), causing them to vibrate. To the left of the tangent a strip of cloth is woven between the strings. When the key is struck, only the portion of the strings to the right of the tangent—*i.e.,* between the tangent and the bridge—sounds; the cloth prevents the string section to the left of the tangent from sounding. As soon as the key is released, the tangent falls away from the strings, which are then entirely silenced by the cloth. Because the sounding portion of each string is the segment between tangent and bridge, the tangent serves not only to set the strings in vibration but also to determine their sounding length. Thus, a series of tangents striking a given pair of strings at different points will produce a series of different notes, and all the earliest clavichords were designed to take advantage of this fact. Arnaut of Zwolle's clavichord used only 9 or 10 pairs of strings to produce all the 37 notes of its 3-octave keyboard, and the clavichord represented in

From N. Bessaraboff, *Ancient European Musical Instruments* (1941), Harvard University Press

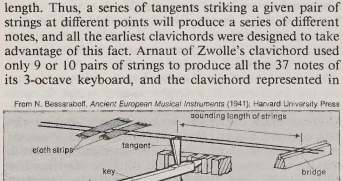


Figure 3: Clavichord action (see text).

an Italian intarsia (picture in wood inlay) of about 1480 (Palazzo Ducale, Urbino) used only 17 pairs of strings to produce 47 notes in a 4-octave range.

Making a single pair of strings serve several keys had two important disadvantages. Because each pair of strings can sound only one note at a time, it is impossible to play any two notes sounded from the same strings simultaneously, making it impossible to play certain chords. Furthermore, an unpleasant clanking sound is likely to result if the performer attempts legato playing of successive notes sounded from the same strings, making it necessary to play in a semidetached fashion.

As early as the time of Arnaut of Zwolle, the first of these disadvantages was minimized by allowing no more than four keys to sound from the same pair of strings and by carefully choosing the points at which such groups of four keys were placed, so that only dissonant chords would be unplayable. The second problem could be solved only when a maximum of two keys were served by the same strings, so that each natural key shared its strings only with the sharp or flat next to it. G, for example, was paired with G♯, and in the music of the period the two notes were seldom needed at the same time or in immediate succession. Of course, if one wanted to use the G♯ key as an A♭, the problem would reassert itself; but, as long as meantone tuning was in use, the G♯ could not serve as A♭ in any case.

Eventually, however, it was felt necessary to be able to play in all tonalities without restrictions either of style of playing or in the use of dissonant chords, and clavichords began to be built with one pair of strings for each key.

Fretted and unfretted clavichords

Such clavichords are called "unfretted," in contrast to those having several keys for each pair of strings, which are called "fretted." Although the unfretted clavichord was known as early as 1693, the oldest extant example, built by Hieronymus Albrecht Hass of Hamburg (Ger.), dates from 1742. Fretted clavichords were being made well into the 1780s; they had fewer strings to go out of tune, and the smaller number of strings permitted all the keys to be shorter and more equal in length, giving the instrument a superior touch. In addition, the smaller number of strings imposed a smaller downward force on the soundboard, resulting in a brighter, clearer tone.

Tone quality. The greatest disadvantage of the clavichord is its extremely soft tone. Because it arises directly from the way in which the sound of the instrument is produced, this disadvantage cannot readily be overcome. It is impossible to impart very much energy to a string by striking it at one end (it is for this reason that a guitarist makes less sound when he strikes the strings against the fingerboard with his left hand than when he plucks them with his right, even though the pitches produced are the same). In compensation, the clavichordist alone of all keyboard-instrument players has control over a note once it has been struck. As long as a note is sounding, he has contact with the string through the tangent and key, and by changing his pressure on the key he can vary the pitch of the note, produce a controlled vibrato, or even create the illusion of prolonging or swelling the tone. Although the maximum loudness of which a clavichord is capable is not great, its softest pianissimo is very soft indeed, and the clavichordist controls an infinite number of gradations in loudness between these two extremes. As a result of this touch sensitivity, the clavichord was highly valued as a teaching and practice instrument. In addition, its relative cheapness made it the normal domestic keyboard instrument in Germany, Iberia, and Scandinavia.

The quiet tone of the clavichord made it impractical to use the instrument in ensemble music, except for providing a discreet accompaniment for a flutist or a singer. Although much of the solo keyboard music of the 16th–18th centuries can be played on the clavichord, it cannot be stated that much of it before the latter part of the 18th century was especially composed with the clavichord in mind. At that time, however, the clavichord experienced a great revival in Germany, and music composed with its singing tone and unique capabilities of dynamic shading and vibrato was written for it by such masters as Carl Philip Emanuel Bach (1714–88).

Clavichords in the 19th century

Clavichords continued to be made in Germany and Scandinavia well into the 19th century, long after the piano was popular. Indeed, many instrument makers built both clavichords and pianos (and harpsichords as well). The continued demand for the older instruments may have been a consequence—among other things—of musicians' recognition of the three instruments' differing capabilities.

The clavichord owes its modest modern revival in the United Kingdom and America largely to the efforts of Arnold Dolmetsch, who began building clavichords and performing on them in public in the 1890s. Both his style of playing the clavichord and the design of his instruments were influential for a long period. Today, however, increasing numbers of clavichord makers and players are exploring earlier forms of the instrument.

THE HARPSICHORD

Principle of operation. *Plucking mechanism.* The sound of the wing-shaped harpsichord and its smaller rectangular, triangular, or polygonal relatives, the spinet and virginal, is produced by plucking their strings. The plucking mechanism, called a jack (Figure 4), rests on the key and consists of a narrow slip of wood with two slots cut into its top. The larger slot holds a pivoted tongue from which protrudes the quill, plastic, or leather plectrum that does the actual plucking; the smaller slot holds a piece of cloth that rests on the string and silences it when the key is not depressed. When the harpsichordist pushes down on a key, the back end rises, lifting the jack and forcing the plectrum past the string, plucking it. When he releases the key, the jack falls, and when the plectrum touches the string on the way down, it forces the pivoted tongue backward so that the plectrum can pass the string again without plucking it. Once the plectrum has passed beneath the string, a light spring made of bristle or metal pushes the tongue forward again. Finally, when the key is completely at rest, the cloth damper touches the string, silencing it. A wooden bar, padded on its underside, is placed over the jacks. The purpose of this bar is to prevent the jacks from flying out of the instrument and to limit the depth to which the keys can be depressed.

Although slight variations in loudness and timbre, or

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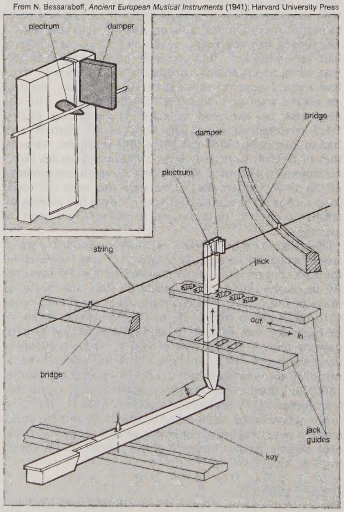


Figure 4: Harpsichord action (see text).

Variations in loudness and timbre

tone colour, can be obtained by differences in the firmness with which the harpsichordist depresses the keys, no sustained crescendos are obtainable by the action of the fingers alone. For this reason, most harpsichords made since about 1550 have had at least two strings and two jacks for each key. Each can be engaged or disengaged at will by a slight shift of the uppermost of two slotted guides through which the jacks pass. Moving the guide in one direction brings its entire row of jacks close enough to the strings for the plectra to pluck them; moving the guide in the opposite direction takes the jacks far enough from the strings so that the plectra cannot reach them. Two rows of jacks can provide three different levels of loudness or three differing tone colours, depending on whether the performer uses each row separately or both together.

Two-manual instruments. Even given two rows of jacks, it would not ordinarily be possible to produce the rapid changes in loudness required for pieces in echo style, for example, or to play loudly with one hand while providing a soft accompaniment with the other. To accomplish this, it is necessary to have two keyboards or "manuals," one of which operates a single row of jacks while the other operates two or more. It then becomes possible to play loudly on one keyboard and softly on the other, either simultaneously or in rapid alternation. Two-manual harpsichords of this kind were invented at some point before 1620 in Flanders and gradually became known throughout the rest of Europe during the 17th century. These instruments commonly had three sets of strings, two unison sets at normal pitch (called eight-foot pitch because the low C at this pitch is produced by an organ pipe eight feet long) and a third set of shorter strings tuned an octave higher, or at four-foot pitch; this shorter set passed over its own bridge and was fastened to pins driven through the soundboard into a rail fixed to its underside. There were three rows of jacks (Figure 5). The front row plucked one set of unison strings and was made in such a way that it would be moved by the keys of both the upper and the lower keyboards. Both the middle and back rows operated from the lower manual only; the second row plucked the second set of unison strings, and the back row plucked the octave strings. For most purposes a one-manual harpsichord sufficed: each row of jacks provided a continuously changing tone colour from one end of the keyboard to the other, permitting individual lines in the music to be articulated clearly. For this reason, as well as because of their lower price, the old harpsichord makers built far more single-manual instruments than doubles, and many more singles survive today.

Couplers. There is, however, one type of music that can only be played on a two-manual instrument. Called in French the *pièce croisée,* this kind of music involves separate lines that cross and recross in the same range, frequently employing the same note either simultaneously or in close succession. The parts in such pieces cannot be distinguished when played on a single manual, and they cannot even be played on two manuals if the manuals are not completely independent. (For example, if a note is already being held on the lower manual, it cannot be restruck on the upper manual when the lower manual lifts the upper-manual jacks.) The solution to this problem was found in France in the 1640s. Instead of providing the upper-manual jacks with an extension that reached down to the keys of the lower manual, they were made to rest entirely on the upper-manual keys; the lower-manual keys were then fitted with small upright pieces of wood called coupler dogs, which reached upward toward the underside of the upper-manual keys. The upper manual was constructed to slide forward and back by about ¼ inch. When it was pushed into the instrument, the coupler dogs were positioned below the back ends of upper-manual keys. As a result, when any lower-manual key was pushed down and its back end rose, the coupler dog would push up on the underside of the corresponding upper-manual key, lifting its jack as well. When one wished to uncouple the two keyboards in order to play *pièces croisées,* one could do so by pulling the upper manual outward. The coupler dogs then passed slightly beyond the ends of the upper-manual keys, so that they were not lifted when the lower-manual keys were depressed.

Music played on the two-manual instrument

Two-manual harpsichords of this kind permit players to exploit the difference in the tone colours produced by the two rows, or "registers," of unison jacks. This difference depends on the distance along the string at which it is plucked. The closer the plucking point is to the end of a string, the brighter is the sound; the farther away from the end that a string is plucked, the fuller and rounder the tone becomes, until one approaches the centre; plucking near the centre of a string produces a sweet, flutey, but somewhat hollow sound. In order to emphasize the difference in tone colours produced by the two rows of unison jacks, French harpsichord builders put the row of octave jacks between them, thereby increasing the distance between the two unison plucking points and the difference in tone of the two unison registers.

Special effects. A set of jacks plucking very close to the end of the string yields a very brassy, nasal sound. This type of register, called a lute stop, was first used in Germany in the 16th century and later spread to Flanders and to England, where it was added to the normal three registers on two-manual instruments. It did not have its own set of strings but, rather, plucked those of one of the existing unison registers. In England the lute stop plucked the same set of strings as the set of jacks operated by both keyboards; but, because the lute-stop jacks rested only on the upper-manual keys, they could also be used to provide a completely independent register on the upper manual. It was thus possible to play *pièces croisées* by taking off the unison register controlled by both manuals, using the lute stop for the upper manual and leaving the lower manual with its own unison register. Many harpsichords of all countries were also equipped with a buff stop (sometimes also called a lute stop), a device that presses pieces of soft leather against one of the sets of unison strings, producing a muted, pizzicato tone.

Lute and buff stops

In Germany in the 18th century, harpsichords were made with still more strings and jacks for each key. Some had three unison strings in addition to an octave string; some had two unisons, an octave, and a suboctave (or 16-foot) register; and some even had a 2-foot register, with very short strings tuned two octaves above the unisons. Harpsichords with three keyboards were apparently built throughout the 17th and 18th centuries, although only one authentic three-manual harpsichord is known today.

It should be emphasized, however, that the harpsichord of the 16th–18th centuries normally had only one or two keyboards and only two or three sets of strings and jacks per note. In the 16th and early 17th centuries, one-manual instruments usually had only two registers (either two unisons or a unison and an octave) with or without a buff stop; in the second half of the 17th century a second unison register became common, increasing the number

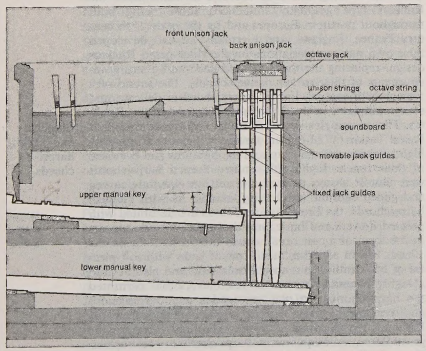


Figure 5: Flemish two-manual harpsichord action (see text).

of jacks and strings to three per note. Two-manual instruments, likewise, had no more than three sets of strings (two unisons and an octave) and three sets of jacks throughout the 17th century. In the 18th century, a fourth row of jacks was sometimes added. In Britain and Flanders, this row was the close-plucking lute stop; in France, if a fourth row was added, it was placed behind the other three and equipped with plectra of soft buff leather that provided a gentle, flutey tone, which was highly prized in the rather decadent period of the harpsichord's decline. Until the last half of the 18th century, it was usually possible to change registers only by moving knobs at the side of the instrument or above the keyboards, which could be done only when one hand or the other was not playing. This fact and the surviving written evidence suggests that the harpsichordists of earlier times changed registers relatively infrequently, avoiding monotony of sound by relying on variations of touch and the changes of texture and pitch level written into the music.

History. The harpsichord may have evolved from devices invented by medical astrologers for the purpose of investigating the effects of cosmic musical harmonies on the human body. The wing-shaped instrument was described by Arnaut of Zwolle in the mid-15th century and was apparently known throughout Europe by the end of the century, although no 15th-century examples have survived. The harpsichords depicted in sculptures, paintings, and miniatures of the period all appear to be shorter and to have thicker cases than the earliest surviving 16th-century examples, all of which are Italian and are constructed of very thin cypress.

Earliest surviving harpsichords

Italy. The thin-cased style of harpsichord construction appears to have been developed in Italy about 1500, and it rapidly influenced the design of harpsichords throughout the rest of Europe. The strings of the Italian harpsichords were rather short, with the strings for c‴ (C above middle C) generally being about 10 inches (25 centimetres) long on instruments tuned to what is today considered normal pitch. On some Italian harpsichords, however, the strings for c‴ are about 14 inches (36 centimetres) long; it is thought that these were tuned to a pitch a fourth below that of the shorter-strung ones, the key for C sounding what today would be the G below. The comparatively short strings imposed a relatively low tension on the case of the Italian harpsichord, allowing it to hold up with so light a structure.

In general, Italian harpsichords had only one keyboard with two rows of jacks and two strings tuned in unison or unison and octave. The fragile Italian instruments were normally housed in thick outer cases of softwood, which were either painted or covered with stamped leather. The cases, in turn, rested on separate legs or elaborate stands. The tone of these lightly constructed instruments is surprisingly loud and penetrating, making them ideal as accompanying instruments in an orchestra and suiting them perfectly to the rattling scale passages typical of Italian harpsichord music.

Flanders. As the new Italian design spread northward, first into Germany and then to Flanders, France, and England, it was modified to the extent that the 16th- and 17th-century northern European instruments had somewhat longer strings (11½ to 12½ inches [29 to 32 centimetres] for c‴) and thicker cases (3/16 to ¼ inch [5 to 6 millimetres] in contrast to the ⅛ inch [3 millimetres] found on Italian instruments). In the 1560s in Flanders, however, this type of instrument was replaced by still another design, which ultimately dominated all northern European harpsichord making. These instruments had long strings (about 14 inches for c‴ at normal pitch) and thick cases with substantial internal bracing to withstand the greater tension imposed by the greater string length. Because the longer strings made it unfeasible to double the string length for each octave below middle C, harpsichords of the newer Flemish design have less gracefully curved bentsides and wider tails than either Italian harpsichords or the intermediate instruments built elsewhere north of the Alps.

The name most often associated with Flemish harpsichord building is that of the Ruckers family, which for four generations (from about 1580 to 1680) dominated Flemish harpsichord making and whose instruments were exported to all parts of Europe—one was even shipped as far as Peru. At first sight, Ruckers harpsichords appear crude compared to their Italian counterparts, and their thick softwood cases give the impression of being clumsily cobbled together on the inside. Nonetheless, the tone of unaltered or properly restored examples is extraordinarily good, and it is easy to see why Ruckers instruments were so highly prized that a lively business in making forgeries of them flourished in the 18th century.

Harpsichord building of the Ruckers family

In addition to a wide variety of virginals (discussed below), the Ruckers family made several different harpsichord models. The most popular was apparently six feet long, having a four-octave keyboard from C to c‴, with a short octave in the bass; one unison and one octave register; and, occasionally, a buff stop on the unison. They were typically painted in imitation of marble on the outside and decorated on the inside with block-printed paper on which a Latin motto was painted. The soundboard was usually decorated with paintings of flowers, leaves, and birds. (This decoration should be contrasted with that of Italian harpsichords, which, except for their finely profiled moldings and lavish outer cases, were generally unadorned.) Flemish harpsichords were set directly on fairly massive stands, examples of which may be seen in the numerous Dutch paintings of musical groups of the period. Similar harpsichords were made in smaller sizes tuned a fifth or an octave above normal pitch (the key c′ sounding either g′ or c″). By the mid-17th century, some single-manual instruments had a range of 4½ octaves from F_1 or G_1 to c‴.

The Ruckers family appears to have been the first to make two-manual harpsichords. These were of two types: in one (which may have been the earlier type and was not built after about 1650), both keyboards were served by a single set of unison and octave strings and were not meant to be played at the same time. Instead, the keyboards were so arranged that c‴ on the upper keyboard was placed over f‴ on the lower keyboard, which meant that playing a piece on the lower keyboard automatically transposed it to a pitch a fourth below that of the upper keyboard. Whether this arrangement was used to facilitate routine transpositions or whether it was intended to provide in a single instrument the same resources as those available from both an Italian instrument with a 10-inch c‴ and one with a 14-inch c‴ is still a subject for controversy. The second type of two-manual harpsichord built by the Ruckers family was basically the type one finds today, with keyboards aligned over one another and intended to provide contrasts in loudness. Because the only set of upper-manual jacks was also played directly from the lower manual, it was not possible to play *pièces croisées.*

France. During the 17th century, instruments of the Ruckers type gradually influenced those being built throughout northern Europe; and by the early 18th century France, England, and Germany all had developed their own national variations on the thick-cased Ruckers design, replacing the thinner-cased and shorter-strung instruments of their earlier native schools. The sound of a typical 18th-century French harpsichord is delicate and sweet compared to the more astringent sound of a Ruckers. Those examples by the Blanchet family and their heir Pascal Taskin (1723–93) are noted for their extraordinarily high level of craftsmanship and the lightness and evenness of their touch. Eighteenth-century French harpsichords were almost always painted and rest on elaborate carved and gilded cabriole (curved-leg) stands. As with Flemish harpsichords, the French soundboards are decorated with painted flowers and birds, and the maker's mark appears in the form of a cast ornament in the sound hole. In the 1760s, Taskin added a fourth row of jacks with soft plectra of buff leather as a special solo stop and also devised a highly ingenious system of knee levers that permitted the harpsichordist to play crescendos and decrescendos and to change registers without taking his hands from the keyboard. By the time of these inventions, however, the great Baroque composers of harpsichord music, such as François Couperin, J.S. Bach, Jean-Philippe Rameau, and

Blanchet and Taskin harpsichords

Domenico Scarlatti, were dead, and these devices have no relevance to the historically accurate performance of harpsichord music of the Baroque era or earlier.

Great Britain. In Britain the making of harpsichords in the 18th century was dominated by two London families, the Kirkmans and the Shudis. Both families made instruments for several generations and eventually moved on from harpsichord building to piano building. Their harpsichords are very similar, and the two-manual instruments all have a close-plucking lute stop in addition to the usual two unisons and octave. They are invariably veneered in walnut or mahogany and rest on simple stands, usually with straight or tapered legs. The tone of a Kirkman or Shudi harpsichord is both more robust and more brilliant than that of a French or Flemish instrument, making it a superb instrument for filling in the harmonies in orchestral music as well as for the performance of the solo harpsichord literature.

Germany. Two German schools appear to have existed in the 18th century. One in the southern part of the country has left very few surviving instruments, which is unfortunate because these are the kind probably played by J.S. Bach. As far as is known, the southern German instruments were fairly plain, veneered ones, having only three registers and a rather darker tone than either French or Flemish instruments. The second German school was centred in the city of Hamburg and is best represented by the work of the Hass family. The Hass instruments are among the most elaborate ever made, in both decoration and complexity. They are the only 18th-century harpsichords with 16-foot and 2-foot registers, and some have lute stops as well. Their tone does not, unfortunately, live up to the quality of their craftsmanship or the ingenuity of their design, seeming overly brilliant and too thick in all the surviving examples that have been restored to playing condition.

Hass family instruments

Decline of the harpsichord. Although many of the finest surviving harpsichords date from after 1750, few composers of the first rank were writing for the instrument by that time. Furthermore, the emergence of a newer, lighter style of music and an increased interest in crescendo and decrescendo effects led to the addition of various new devices foreign to the essential nature of the instrument. These include the knee- and foot-operated contrivances for the rapid changing of registers or for producing crescendos and decrescendos. Such devices represent the harpsichord builders' response to the same musical needs that eventually caused the harpsichord's replacement by the piano; but they were created before the real rise in the piano's popularity and must not be thought of as attempts to stave off the competition of the newer instrument.

As with the clavichord, builders continued to make harpsichords side by side with pianos. In England, Shudi's son-in-law, John Broadwood (see below), continued to make harpsichords until after 1800 (although in decreasing quantity), producing at the same time an ever-increasing number of pianos. There is even a small but interesting group of compositions by British, German, and French composers calling for both instruments.

Modern revival. The harpsichord had all but vanished except as a curiosity or in rare historical concerts when the modern revival began in the 1890s with the building of new harpsichords by the piano firms of Érard and Pleyel in Paris. Almost immediately, the full brunt of 19th-century piano technology was applied to the manufacture of the revived instruments, and they became increasingly massively strung and framed as time passed. Pedals for changing registers were included from the beginning, and Pleyel first added the 16-foot stop in 1911. The Pleyel's sound, as preserved in the recordings of the Polish virtuoso Wanda Landowska and her numerous pupils, typified the harpsichord for most music lovers until the 1950s, and it is for a heavy, metal-framed instrument of this type, with pedals for changing registers and a 16-foot stop, that most 20th-century harpsichord music has been composed.

Pleyel instruments

In 1905 modern harpsichord building was begun in Germany, initially taking the new Pleyel and Érard instruments as inspiration. Subsequent German building produced a highly characteristic instrument somewhat reminiscent of the harpsichords of the 18th-century Hamburg school in sound. Taking as their model an improperly restored instrument falsely said to have belonged to Bach, these instruments generally had the unhistorical stop arrangement of one 8-foot and the 4-foot on the upper manual, with the second 8-foot and a 16-foot on the lower manual.

Arnold Dolmetsch, who began the modern revival of the clavichord, also built harpsichords, working in Paris and Boston as well as in England. He deserves to be considered the "godfather" not only of the present British school of harpsichord making but also of the flourishing American school, most of whose members are, however, building a very different and far more historically based instrument than any that Dolmetsch made after about 1910.

The virginal, spinet, and clavicytherium. The virginal, spinet, and clavicytherium are all varieties of harpsichord that differ from it primarily in size, shape, and musical resources. Virginals and spinets usually have only a single set of strings and a single row of jacks. The clavicytherium is basically a harpsichord set upright so that its soundboard is vertical. The earliest known mention of the clavicytherium dates from about 1460; the oldest extant example (Royal College of Music, London) was probably made in Ulm, Ger., about 1480. Instruments of this form were made from the 15th through the 18th centuries. In general, their mechanism has to be fairly complicated because the jacks must move horizontally rather than vertically and cannot therefore return to their rest position solely by the action of gravity. As a consequence of this complexity of its mechanism, the touch of the clavicytherium tends to be heavy, although the instrument takes up less floor space, and the vertical soundboard projects sound outward far more effectively than the horizontal soundboard of the conventional harpsichord.

The virginal and spinet are small varieties of harpsichord, but the precise usage of the terms differs. Some writers reserve the term virginal for rectangular instruments and call all small triangular or polygonal instruments spinets. Others apply the term virginal to all plucked stringed keyboard instruments whose strings run more or less from left to right across the keys (a usage followed in this article), reserving the term spinet for instruments in which the strings run obliquely away from the player. The terminological question is complicated by the fact that the word virginal in 16th- and 17th-century England referred to all plucked stringed keyboard instruments, including harpsichords and spinets as well as those today termed virginals. The term *épinette* ("spinet") had a similarly broad usage in France.

Italian builders of the 16th and 17th centuries made virginals and spinets employing a thin-cased construction similar to that of their harpsichords, and, like Italian harpsichords, these smaller instruments were kept in stout outer cases. The typical Italian virginal was either rectangular or polygonal in shape, with its keyboard projecting from the front of the case, and many of the surviving examples are sumptuously decorated with inlay or intarsia. Most Italian spinets are constructed as an irregular quadrilateral, but in the 17th century a new form was developed that more closely resembles a small harpsichord in having a bentside at the player's right and a long straight back slanting away from him. The new form was copied throughout Europe and became the standard domestic keyboard instrument in England in the late 17th century.

In Flanders, early virginals were polygonal and resembled Italian ones except that their keyboards were inset rather than projecting. In the 1560s, at the same time as the thick-cased harpsichord is believed to have emerged, thick-cased rectangular virginals made their appearance. By the end of the 16th century, two distinct types existed. They can readily be distinguished by the position of their keyboards: off-centre either to the left or to the right in one of the long sides of the rectangular case. Virginals with the keyboard at the right were far more common. They produce a characteristic flutey tone because the placement of the keyboard causes the strings to be plucked near their centre for most of the instrument's range. In virginals with the keyboard at the left, the strings are plucked off-centre except in the extreme treble, and the tone changes

Types of Flemish virginals

gradually from reedy in the bass, through full in the middle register, to flutey in the treble, much as on a harpsichord. Flemish builders produced virginals of both types in several sizes, the smaller ones being tuned to higher than normal pitches. They also made "double" virginals, consisting of a large virginal at normal pitch and a smaller one tuned an octave higher, which could be stored in a recess next to the keyboard of the larger instrument. The two virginals could be coupled together by placing the smaller instrument on top of the larger one.

The virginals made in England were of the left-keyboard type. Those made elsewhere in Europe (some having the keyboard centred) were also built with strings plucking off-centre.

THE PIANO

Principle of operation. Although the basic principles of the piano's operation are simple, the refinements required in developing the powerful yet sensitive modern piano make it also the most complex of all mechanical instruments except the organ. The strings of the piano are struck by a felt-covered hammer that must rebound from the strings instantaneously or it will dampen their vibrations in the very act of initiating them. The hammer must thus be allowed to fly freely toward the strings. For the pianist to retain maximum control of loudness, the distance of the hammer's free flight must be as small as possible; but, if the distance is too small, the hammer will bounce back and forth between the strings and the part of the mechanism that pushed it, producing a stuttering sound whenever the keys are struck firmly. As a consequence, all truly simple piano mechanisms—those in which, say, a rigid rod at the back of the key simply pushes the hammer upward until the key is stopped by a rail and the hammer flies free—must be adjusted to provide a large distance for free flight and can therefore give the pianist only limited dynamic range and control.

History. *Invention.* Piano mechanisms as unsophisticated as that described above continued to be devised and built throughout the 18th century. Nevertheless, the first successful piano—made in Italy by Bartolomeo Cristofori—solved the problems inherent in such simple mechanisms, as well as nearly every other problem facing piano builders until well into the 19th century. Cristofori reportedly experimented with a "harpsichord with hammers" in 1698. By 1700 one of these instruments, together with six of his harpsichords and spinets, was included in an inventory of instruments belonging to the Medici family in Florence. In 1711 the instrument was described in detail in the Venetian *Giornale de' letterati d'Italia* by Scipione Maffei, who called Cristofori's invention *gravicembalo col piano e forte* ("harpsichord with soft and loud")—whence the present names pianoforte and piano.

Cristofori's pianos

In the three surviving examples of Cristofori's pianos, which date from the 1720s, the mechanism, or "action," differs somewhat from that described and pictured by Maffei; however, rather than merely representing an earlier phase of Cristofori's work, Maffei's diagram may be in error. In the surviving instruments a pivoted piece of wood is set into the key (Figure 6). The pivoted piece (which in a modern piano would be called a jack and should not be confused with the jack in a harpsichord) lifts an intermediate lever when the key is depressed. The lever, in turn, pushes upward on the hammer shaft near its pivot in a rail fixed above the keys. When the key is pressed completely down, the jack tilts and disengages itself from the intermediate lever, which then falls back, permitting the hammer to fall most of the way back to its rest position, even while the key is still depressed. This feature, called an escapement, is the heart of Cristofori's invention; it makes possible a short free flight for the hammer, after which the hammer falls so far away from the string that it cannot rebound against it, even when the keys are struck firmly. Cristofori provided a check (a pad rising from the back of the key) to catch and hold the falling hammer. At the end of the key he included a separate slip of wood, resembling a harpsichord jack, to carry the dampers that silence the string when the key is at rest.

Utilizing an intermediate lever to act on the hammer

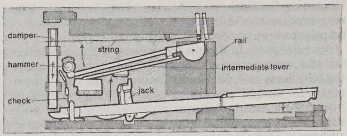


Figure 6: Cristofori's piano action (see text).
From R.E.M. Harding, *The Piano-Forte* (1933); published by Cambridge University Press

near one end of its shaft provides an enormous velocity advantage, and the hammer flies upward toward the string much faster than the front end of the key descends under the pianist's finger, adding to the crispness and sensitivity of Cristofori's action. In addition to his innovative mechanism, Cristofori also introduced a unique double-wall case construction that isolated the soundboard from the pull of the strings. The sound of his instruments is strongly reminiscent of the harpsichord. The dynamic range is surprisingly wide, but it should be emphasized that the instrument's loudest sounds are softer than those of a firmly quilled Italian harpsichord and do not begin to approach the loudness of a modern piano.

German and Austrian pianos. As a piano builder Cristofori had few immediate successors in Italy, but word of his invention became known in Germany through a translation of Maffei's account published in 1725. Before 1720 there had been independent attempts in France as well as in Germany to devise hammer mechanisms, although none was comparable to Cristofori's in sophistication or practicality. In the 1730s Gottfried Silbermann, of Freiberg in eastern Germany, a builder of organs, harpsichords, and clavichords, began constructing pianos patterned on Cristofori's. The surviving ones, probably from the 1740s, appear to have been directly copied from an instrument imported into Germany rather than derived from Maffei's description, but the ones he made earlier (and of which Bach is said to have disapproved in 1736) may have owed their failure to an attempt to follow Maffei's diagram exactly. By 1747 Silbermann had sold several of his pianos to King Frederick II the Great of Prussia, and one of these is reported to have met with Bach's approval in 1747.

Gottfried Silbermann's instruments

Subsequent German piano building did not follow the path charted by Silbermann. Instead, various German builders attempted to devise actions that were simpler than Cristofori's, generally adapting them to the clavichord-shaped instruments now called "square" pianos. In the most characteristic German actions, the hammers point toward, rather than away from, the player, and, instead of being hinged to a rail passing over all the keys, they are attached individually to their respective keys. As the front of the key is depressed, the back rises, carrying the hammer with it. A projecting beak at the rear of the hammer shank catches on a fixed rail above the back of the keys, so that the hammers are flipped upward as the keys are stopped by a second rail set just above them. This action had no escapement, and (on the evidence of a letter of 1777 from Mozart to his father) many German instruments of the 1770s still lacked this highly important feature.

Johann Andreas Stein of Augsburg in southern Germany is generally credited with devising the first German action to include an escapement. As a replacement for the fixed rail that caught the projecting beaks at the rear of the hammer shanks, Stein provided an individually hinged and sprung catch for each key (Figure 7). As the back of the key reaches its highest point, this catch (the escapement) tilts backward on its hinge and releases the beak at the back of the hammer shank. The hammer is then free to fall

From R.E.M. Harding, *The Piano-Forte* (1933); published by Cambridge University Press

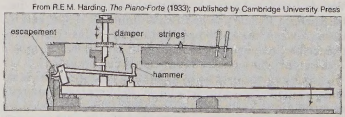


Figure 7: The German action (see text).

back to rest position even when the key is still depressed. This action is often called "Viennese," because it was used by all the important 18th- and early 19th-century piano makers in Vienna, including Stein's daughter and son-in-law, Nannette and Johann Andreas Streicher; Anton Walter, Mozart's favourite piano builder; and Conrad Graf, maker of Beethoven's last piano. It was used in German-speaking countries until the late 19th century, when it was replaced by mechanisms derived from a Cristofori-based action developed in England.

Although the tone of a piano by Stein or Walter is not loud, it is very sweet, with a singing treble and a clear tenor and bass that blend superbly with the sound of stringed instruments. The touch is extremely light and shallow: the force required to depress a key is only one-fourth that required on a modern piano, and the key need only be depressed half as far. In their sensitivity to the finest differences in touch and their singing tone, the Viennese pianos suggest the responsiveness of a clavichord, although producing a louder sound.

Special effects

Austrian and German pianos of the early 19th century often feature an array of pedals. Only one of Cristofori's surviving pianos has any special effects: levers on the underside of the instrument permit the player to shift the action sideways so that the hammers strike only one of the two strings provided for each note. By the time Silbermann built his pianos for Frederick the Great, a second special effect had been introduced—a mechanism to lift the dampers from the strings so that they could vibrate freely whether or not the keys were depressed. (These two effects, the sideways sliding of the action—to produce a softer sound and different tone colour—and the lifting of the dampers—to produce a louder, more sustained sound and another variation in tone colour—are the only ones found on all modern grand pianos.) Silbermann's pianos had hand levers for raising the treble and bass dampers separately and an additional hand lever for muting the strings. Stein's pianos normally had two knee levers for raising the treble and bass dampers and a third knee lever that interposed a strip of cloth between the hammers and the strings to produce a velvety pianissimo. Later instruments might have five or more pedals that, for example, pressed a roll of parchment against the bass strings to produce a buzzing sound or rang small bells and banged on the underside of the soundboard in imitation of the cymbals and drums of the then-fashionable "Turkish" music.

The English action. In the late 1750s a number of German piano builders emigrated to Britain, and one, Johann Christoph Zumpe, invented an extremely simple action for the square pianos he began building in the mid-1760s. Zumpe's action goes back to the Cristofori-Silbermann system in which the hammers point away from the player and are hinged to a rail over the keys. A metal rod tipped with a padded button is driven into the back of the key (Figure 8). When the key is depressed, the rod pushes the hammer upward; the key is stopped by a padded rail over its back end, and the hammer then flies freely. Despite the lack of an escapement, Zumpe's square pianos were an enormous commercial success and were copied in France, the Low Countries, and Scandinavia.

Zumpe had worked for the harpsichord builder Burkat Shudi when he first came to England, and around 1770 three other workmen in Shudi's shop, John Broadwood, Robert Stodart, and Americus Backers, devised for grand pianos an adaptation of Zumpe's action that included an escapement. This important development made London a major centre of piano building and created a characteristic English piano of fuller and louder sound than the Viennese piano but with a heavier, deeper touch and a

From R.E.M. Harding, *The Piano-Forte* (1933); published by Cambridge University Press

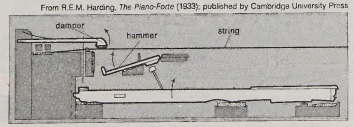


Figure 8: Zumpe's square-piano action (see text).

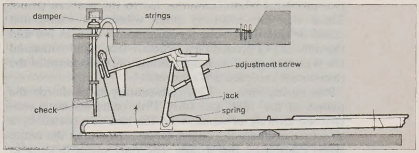


Figure 9: The English action (see text).

From R.E.M. Harding, *The Piano-Forte* (1933); published by Cambridge University Press

consequent inability to play repeated notes as rapidly. In the English grand-piano action (Figure 9), the fixed rod of Zumpe's square-piano action was replaced by a pivoted jack, similar to that in Cristofori's action. The upper end of the jack fits into a notch at the base of the hammer shank, slipping out of the notch as the back of the key reaches its highest point; the hammer then flies free, strikes the string, and falls back to be caught by a hammer check even when the front of the key is still held down. The tone of a typical 18th-century English grand piano is surprisingly reminiscent of the tone of an English harpsichord, suggesting that the English piano makers were, like Cristofori, seeking to make an expressive harpsichord, unlike the German builders who, in effect, appear to have been trying to build a louder clavichord.

Unlike their Austrian and German counterparts, English pianos had two or, at most, three pedals. One of the two ordinary pedals shifted the keyboard sideways so that the hammers struck two or only one of the three strings provided for each note. The second pedal raised all the dampers. It was sometimes replaced by two pedals—one for the treble dampers, the other for the bass dampers—or, occasionally, by a single damper pedal divided into two parts that could be depressed separately or together with one foot, as on the piano presented by Broadwood to Beethoven in 1817.

Although the pianos of the late 18th and early 19th centuries were perfected instruments ideally suited to the music of their period, the increasing popularity of public concerts in large halls and concerti with large orchestras stimulated attempts by piano builders to produce an instrument of greater brilliance and loudness. Their efforts gradually created today's vastly different piano. In recent years, the special merits of the earlier instruments (sometimes called "fortepianos" to distinguish them from modern pianos) have come to be appreciated, and several builders have begun to make replicas of them.

Other early forms. As previously mentioned, many 18th-century pianos were "squares," built in a form resembling the clavichord. More compact and less expensive than wing-shaped grands, the square piano continued through much of the 19th century to be the most common form of piano in the home. But as square pianos became larger and larger, these advantages diminished, and the square piano was eventually replaced by the upright. In the 18th and early 19th centuries, upright pianos (*i.e.*, pianos with vertical strings and soundboard) took three different forms. In the "pyramid piano" the strings slanted upward from left to right, and the case above the keyboard took the form of a tall isosceles triangle. Or a grand piano was essentially set on end with its pointed tail in the air, producing the asymmetrical "giraffe piano." Placing shelves in the upper part of the case to the right of the strings yielded the tall rectangular "cabinet piano." Because the lower end of the strings, which ran nearly vertically, was about at the level of the keyboard, all such instruments were very tall. Although there were attempts to construct lower instruments by, in effect, positioning a square piano on its side, the American builder John Isaac Hawkins made the first truly successful low uprights in 1800 by placing the lower end of the strings near floor level. Robert Wornum in England built similar small uprights in 1811, and in 1842 he devised for them his "tape check" action, the direct forerunner of the modern upright action.

Pyramid, giraffe, and cabinet pianos

Development of the modern piano. In the early 19th century, piano makers were principally concerned with

two problems whose solutions led to the modern piano. These were the relatively small volume of sound that could be produced from the thin strings then in use and the difficulty of producing a structure that could withstand the tension even of such light strings once the range of the instrument exceeded 5½ octaves.

Bracing and frame. Like 18th-century harpsichords, the pianos of the 18th and early 19th centuries were constructed entirely of wood, with the case (supported by a structure of internal wooden braces) sustaining the entire stress exerted by the strings. The only metal bracing in such instruments appears in the form of flat or arched pieces bridging the gap through which the hammers rise to strike the strings. These braces eventually proved insufficient when the walls of the case itself and the pinblock (the long piece of wood into which all the tuning pins were driven) were incapable of withstanding the increasing tensions placed upon them. For this reason, ever-increasing quantities of metal bracing came into use, first in the form of individual bars running parallel to the strings from the side of the case to the pinblock but finally in the form of a single massive casting that took the entire tension of the strings upon itself. The one-piece cast-iron frame was first applied to square pianos by Alpheus Babcock of Boston in 1825, and in 1843 another Bostonian, Jonas Chickering, patented a one-piece frame for grands. With the adoption of such frames, the tension exerted by each string (about 24 pounds [11 kilograms] for an English piano of 1800) rose to an average of approximately 170 pounds (77 kilograms) in modern instruments, the frame bearing a total tension of 18 tons.

Babcock and Chickering pianos

Overstringing. The strings in early pianos, like those in harpsichords or clavichords, ran parallel to one another, causing the grand pianos of the 18th and early 19th centuries to retain much of the graceful shape of the harpsichord. In the 1830s it was realized that the bass strings could be made longer and their tone improved if they were made to fan out over the treble strings. This idea was first applied to square pianos, but in 1855 Steinway & Sons built a grand piano with a complete cast-iron frame embodying this "overstrung" plan, in which the strings of the treble and the middle registers fan out over most of the soundboard and the bass strings cross over them, forming a separate fan at a higher level. Because the bass strings fan out, the tail of the modern grand piano is far wider than that of the earlier "straight-strung" instruments.

Modifications in the action. The gradual strengthening of the piano's structure to permit the use of heavier strings eventually gave rise to hitherto unforeseen problems. The thicker strings could yield the louder sound of which they were capable only if they were struck by heavier hammers; any increase in the weight of the hammer, however, required a manyfold increase in the force required to depress the keys. This difficulty was present to a minor extent even in the 18th-century English grand-piano action, and the touch on these instruments was both deeper and heavier than on Viennese pianos. Moreover, the deeper touch meant that it took longer for a key to return to rest position so that a note could be restruck. Consequently, English pianos were not capable of the rapid repetition of Viennese instruments. This problem became quite severe as the hammers grew heavier and as musicians wished increasingly to use tremolo effects in imitation of orchestral music.

What was necessary was an action that would permit a note to be restruck before the key returned to rest position. The first successful action of this type was devised by the Frenchman Sébastien Érard, who as a young man had built a harpsichord with a particularly elaborate system of pedals and knee levers and in 1810 devised the system of pedals still in use on the harp. Érard's first "repetition" or "double-escapement" action was patented in 1808, and an improved version that is the basis of the modern action was patented in 1821.

The double-escapement action of Érard

A further consequence of the use of thicker strings was that, if the sound of the instrument were not to become unduly harsh, the hammers had to be softer than those used on 18th-century instruments—light slips of wood covered with a few layers of thin leather. Felt-covered hammers were patented in 1826 by the Parisian builder Jean-Henri Pape, who also contributed a number of other ingenious and important improvements, but the use of felt instead of leather did not become universal until after 1855.

With the adoption of the one-piece cast-iron frame, overstringing, and felt hammers, the piano achieved its modern form in all but a few details. One was the invention in 1862 by Claude Montal of Paris of a pedal that kept the dampers off the strings only for notes already held down. Individual notes could thus be sustained without the overall blurring caused by raising all the dampers by the ordinary damper pedal. On three-pedal pianos, this device is included as the middle pedal, with the damper ("loud") pedal at the right and the action-shifting (una corda, or "soft") pedal at the left.

Types of modern piano. Since the abandonment of the square piano, only upright and grand pianos are regularly manufactured. The grands range in length from a minimum of about 5 feet (150 centimetres) for a "baby" grand to a maximum of about 9 feet (270 centimetres) for a "concert" grand, although both shorter and longer instruments have been constructed. Among upright pianos, the models over 4 feet (120 centimetres) tall—which frequently had an excellent tone because of their relatively long bass strings—have largely been superseded by the lower models, the "console" (about 40 inches [100 centimetres high) and the "spinet" (about 36 inches [90 centimetres] high). Because the spinet's case rises such a small distance above the keyboard, it usually has "drop" action, most of which lies below the level of the keys.

Console and spinet models

Modern piano actions. In 1636 Marin Mersenne, the author of the treatise *Harmonie universelle,* quoted a remark that the harpsichord of his time contained 1,500 different parts. The modern piano contains 12,000, most of which are found in the action. The modern grand piano action (Figure 10) is a simplified version of Érard's double-escapement action of 1821, and, although different manufacturers' actions differ in detail, they all work in much the same way. When the key is depressed, its back end rises, lifting the wippen. The wippen raises a pivoted L-shaped jack that pushes the hammer upward by means of a small roller attached to the underside of the hammer shank. The hammer flies free when the back of the L-shaped jack touches the adjustable regulating button. At the same time, the upper end of the repetition lever—through which the upright arm of the jack passes—rises until it is stopped by the drop screw. When the hammer rebounds from the string, the roller falls back until it is stopped by the intermediate lever, enabling the tip of the jack to return to position beneath the roller, even if the key is still partially depressed. The jack is then ready to raise the hammer again should the player restrike the key before it returns to rest position. In the meantime, the hammer is prevented from bouncing back up toward the strings by the padded hammer check, and the damper is raised above the strings by a separate lever lifted by the extreme end of the key.

Player pianos. The history of automatically playing stringed keyboard instruments dates at least to the 16th century. The inventory of musical instruments owned by

From E. Q. Norton, *Tuning and Care of the Pianoforte*

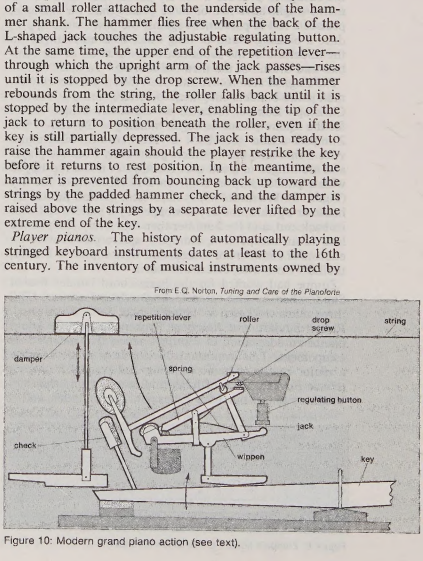


Figure 10: Modern grand piano action (see text).

King Henry VIII at his death in 1547 included "an instrument that goethe with a whele without playing upon," and three spinets equipped with a pinned barrel like that of a music box or barrel organ survive from the workshop of the Augsburg builder Samuel Bidermann (1540–1622). The most common type of player piano operates by means of a roll of punched paper that controls a pneumatic system for depressing the keys. Its heyday was the 1930s, and it was largely rendered obsolete by the increasing popularity of the phonograph and the radio. In the 1980s, electromagnetic player-piano actions equipped with laser sensors and computer controls were developed, allowing a pianist to record and immediately play back or edit his performance. Such sophisticated player pianos are especially useful in recording and teaching studios.

RELATED STRINGED KEYBOARD INSTRUMENTS

Stringed keyboard instruments have sometimes been altered slightly for various reasons. For example, as early as the 16th century harpsichords were occasionally strung with gut rather than with metal wire in order to imitate the sound of a lute. Such gut-strung harpsichords, one of which was owned by J.S. Bach, were called in German *Lautenwerck.* The 18th-century tangent piano dispensed with pivoted hammers and instead had loose slips of wood or metal supported vertically in a rack above the backs of the keys; as a bar abruptly halted the motion of a key, its slip, or tangent, continued to rise to strike the strings and rebound. While inexpensive to make and easy to maintain, this simple mechanism allowed the player relatively little control of loudness and articulation.

Stringed keyboard instruments have as their principal defects an inability, first, to sustain a tone indefinitely and, secondly, to alter the tone's loudness once a key has been depressed. Various attempts have been made to build stringed instruments sounded by other means than plucking or striking—including vibrating the strings by blowing a current of air past them, as in the *piano éolien* of 1837. The most successful of these other instruments adopted the principle of the hurdy-gurdy—*i.e.,* vibrating the strings by friction.

An instrument of this kind appears in several diagrams in the notebooks of Leonardo da Vinci (1452–1519). Some apparently highly successful ones (none of which, unfortunately, has survived) were made by the Nürnberg builder Hans Haiden, who described them at length in pamphlets published in 1605 and 1610. These instruments had a series of rosined wheels that rubbed the strings when they were drawn against them by the action of the keys. According to Haiden, the instrument, which he called a *Geigenwerck,* was capable of recreating the sound of an ensemble of viols and produced sounds of different loudness, depending on the force with which the keys were depressed.

Haiden's *Geigenwerck*

In 1772 a device called a celestina was patented by Adam Walker of London; it employed a continuous horsehair ribbon (kept in motion by a treadle) to rub the strings of a harpsichord. Thomas Jefferson, who ordered a harpsichord equipped with a celestina in 1786, commented that it was suitable for use in slow movements and as an accompaniment to the voice. Similar devices, some using rosined rollers, were applied to pianos by various ingenious inventors throughout the 19th century.

(E.M.R./I.a.L.)

THE ORGAN

An organ is a keyboard instrument in which sound is produced by pipes or reeds to which wind is supplied through a mechanism under the control of the organist. Pipe organs of the kind commonly encountered in Christian churches since the late Middle Ages are among the largest, most complicated, and most expensive musical instruments; they are products of sophisticated craftsmanship blended with artistry.

Reed organs such as the foot-pumped harmonium and melodeon, types developed and mass-produced during the 19th century, are simpler and cheaper to construct than pipe organs. They were widely used domestically and in small churches before becoming virtually obsolete by the mid-20th century, when electronic substitutes became commercially available. These electronic substitutes are versatile and relatively compact, though not necessarily inexpensive, and are chiefly useful in situations where tonal beauty, sensitivity, and imposing visual presence are not essential—for example, in popular music ensembles or homes. For more demanding purposes, electronic organs have given way in the late 20th century to even more versatile and portable synthesizers (see below *Electronic instruments*).

The enormous and varied pipe organ repertoire is especially rich in solo music intended for performance in churches, either during the liturgy or before and after services. The organ's most familiar ensemble role is accompanying choral and congregational singing, a function in which the organist may also conduct the singers. Organ recitals, a favourite form of public entertainment before the advent of radio and recordings, most often take place in churches but also occur in municipal auditoriums, concert halls, and other secular buildings where organs have been installed.

Perhaps most important among such venues in the early 20th century were theatres where organs were used to accompany silent films. Theatre organs, while not generally very large, were highly innovative in tonal and mechanical design and made use of technological improvements that were slow to find their way into more conservative church organs. Among the special effects produced by theatre organs are colourful sounds made by percussion devices that act independently from the pipes.

Parts, mechanism, and production of sound. Conventional pipe organs consist of four main parts: (1) the keyboard or keyboards and other controls that collectively are called the console, (2) the pipes that produce the tone, (3) the mechanism, or action, and (4) the wind generator. Ideally, the pipes, action, and supporting framework are encased in a free-standing structure, or case, that protects the delicate interior parts and blends and projects the sound through generous openings into the surrounding space. Traditionally, rows of dummy or real pipes and carved woodwork in attractive arrangements partially screen the openings in the case. Because organ pipes are not uncommonly up to 32 feet long, organ cases can be very large and form a significant architectural component of the space.

Importance of organ placement

The proper placement of an organ is acoustically crucial, and for most organ music a resonant room with three seconds or more of reverberation time is desirable. Organs having pipes that are installed in deep chambers adjoining the room occupied by the listeners, or placed in an acoustically "dead" environment, are likely to lack musical vitality. Fully exposed pipes without encasement, seen in many mid-20th-century organs, may produce a raw, unfocused sound.

The simplest type of organ has one keyboard, or manual, and one pipe to each key. The pipes, supported vertically by a rack, stand in a row, or rank, on an airtight chest that is supplied with wind from bellows or a rotary blower. While rotary blowers driven by electric motors are highly efficient and tireless, the turbulence and inflexible pressure of their air flow can adversely affect the tone of the pipes. Many organ builders and players, especially of smaller instruments, therefore prefer hand-pumped bellows, which are responsive to musical demands if close coordination exists between the player and the pumper.

Under each pipe is a valve, or pallet, connected by a system of cranks and levers to its respective key. A reservoir, loaded by weights or springs to maintain sufficient wind pressure, is ordinarily interposed between the wind generator and the wind-chest. This reservoir has a safety valve that operates to relieve excessive pressure when the reservoir becomes full.

The pitch of each note is determined by the length of its pipe; the longest pipe emits the deepest note, the shortest pipe the highest note. If two comparable pipes sound an octave apart, the effective length of the higher-pitched pipe is exactly half that of the lower-pitched.

Since the tone of a pipe sounding on a constant pressure of wind is immutable, both as to quality and loudness,

the expressive potential of an organ with only one pipe to each key is limited. All but the smallest portable organs, therefore, have at least three ranks, or sets, of pipes, and large church and auditorium organs may have 100 or more ranks. The pallet controlled from each key admits wind to all the pipes belonging to that key; but, in order that the organist may be able to use any of the ranks of pipes, alone or in combination, an intermediate mechanism is provided by which he may stop off any rank or ranks. From this function the control by whose operation the ranks are stopped off has come to be known in English as a stop, a term also used loosely for each rank of pipes.

Stop and key mechanisms. The operative part of the stop mechanism lies between the pallet and the foot holes of the pipes. It normally consists of a strip of wood or plastic running the full length of each rank of pipes. In it is drilled a series of holes, one of which registers exactly with the foot hole of each pipe. The perforated strip, or slider, is placed in a close-fitting guide in which it may be moved longitudinally. When it is moved a short distance, so that its holes no longer register with the pipes, wind is cut off to that rank, even when the organist opens the pallets by means of the keys. Wind-chests in which the stops operate in this way are called slider chests. Other ways of working the stops will be referred to later; but the simple, reliable slider chest was in almost universal use before the 20th century. The slider is connected to the console by a system of levers and cranks, and it terminates in a knob that the organist pulls outward to bring the stop into play or pushes in to silence it. The name of the particular rank governed by the stop is usually engraved on the knob or appears on a label next to it. An organ's tonal specifications are customarily defined by a list of the names of its ranks and their respective pitches.

The slider chest

Often the organist needs to play two or more inter-

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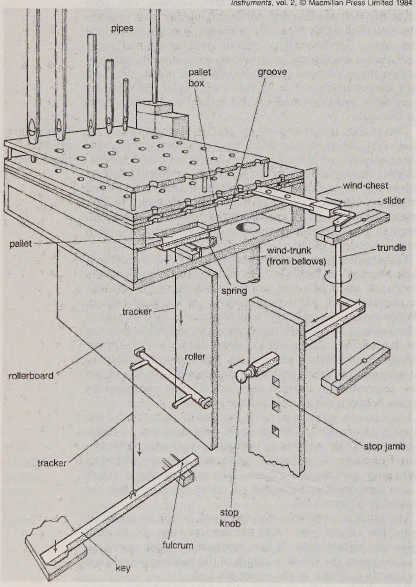


Figure 11: Stop and key mechanisms of a single-manual organ with tracker action (see text).

weaving, contrasted melodic lines, to give prominence to a melody against a quieter accompaniment, or to play loud and soft passages in rapid succession. None of these effects can be achieved on an organ with one manual, as so far described. For this reason, organs of more than about seven or eight stops usually have two manuals, each controlling its separate wind-chest and stops. Each manual department is self-contained, so that the organ is really a composite instrument. By prearranging the stops on the manuals, the organist may perform in any of the three ways mentioned above. The organist, therefore, may vary the sounds produced in one or both of two ways: by changing the stops on the manuals being played or by leaving the stops as they are and changing from one manual to another.

Since the 18th century organists have had yet a third way of controlling the volume of sound. The pipes of one or more manuals may be enclosed in a box, one side of which consists of hinged and movable shutters (similar to Venetian blinds) that are connected to a pedal at the console. By opening and closing the shutters, the sound from the stops of the manual concerned is made louder or softer. Such enclosures are called swell boxes. In pursuit of still greater expressivity, organists since the 16th century have often employed an accessory called a tremulant, which by repeatedly interrupting the flow of wind to the wind-chest creates a pulsation in the tone of the pipes.

Since the 14th century, one department of the organ has commonly been played from a keyboard controlled by the organist's feet. The pedal department is basically like the manual departments but controls predominantly longer pipes. Modern organs normally have pedal keyboards of up to 32 notes.

The organist sometimes wishes to combine the stops of two different manuals or to couple one or more of the manuals to the pedals. This is effected by a simple mechanism, called a coupler, that is controlled at the console.

Certain combinations of stops on each manual are more commonly needed than others; in order that these combinations can be readily available, the console may be provided with several short pedals disposed above the pedal keyboard, or pedalboard. Each of these short pedals, called combination (or composition) pedals, is connected to one commonly needed combination of stops. When a combination pedal is depressed, the stops connected to it are drawn on, and any others that are already drawn are pushed off.

In the simplest mechanical action, the connection from key to pallet is by a series of cranks, rollers, and levers that transmit motion horizontally and vertically from keyboard to wind-chest. The overall distance may be considerable, and the main distance is bridged by trackers, slender strips of wood, metal, or plastic, which are kept in constant tension. Adjustment screws are employed to take up slack occasioned by wear and changes of humidity.

The trackers

The mechanism of the organ as described so far is entirely mechanical, and such organs, including the great majority of those built before the late 19th century, are said to have tracker action. Tracker action is also used in many modern organs, especially those built according to historical principles. Many organists prefer tracker action to all other forms because it affords superior sensitivity of touch. Organs may, however, have pneumatic, direct electric, or electropneumatic action, although these actions result in a loss of sensitivity and responsiveness. In very large organs with tracker action, considerable strength may be necessary to depress the keys. Also, where the layout of the building is inconvenient and the departments of the organ have to be widely separated, tracker action is not practicable. To overcome these difficulties, especially with the object of lightening the touch, other forms of action were devised.

The first effective system was developed in the 1830s by Charles Spackman Barker, an Englishman. It consisted of a series of small, high-pressure pneumatic bellows or motors, one attached to each key of the main manual at the console. When a key was depressed, compressed air was admitted to the motor, which, in turn, operated the tracker action. Lacking encouragement at home, Barker

went to France, where the great French builder Aristide Cavaillé-Coll employed the Barker lever almost exclusively from 1840 on.

Later, the trackers were supplanted by lead tubes, and the connection from key to pallet was solely by compressed air traveling through these tubes. This system was called tubular pneumatic action. At its best, it was remarkably effective, being reliable, long-lived, reasonably silent in action, and perfectly prompt in operation. At anything but its best, it was none of these things, and its worst fault usually lay in sluggish operation. Tubular pneumatic action is almost never used in modern times.

As early as 1860, electric action was used experimentally, and it came into wide use at the end of the 19th century. Direct electric action, in which an electromagnet pulls the pallet open, is sometimes used, but a combination of electric and pneumatic mechanism is more general. In this system the depression of a key completes an electrical circuit, which energizes an electromagnet, allowing wind to enter a pneumatic motor attached to the wind-chest, and this motor opens the pallet. The stops may be operated in exactly the same way, but, where they are operated electrically, the sliders are often replaced by a series of valves, one to each pipe. The organ is then said to have a sliderless chest, and the most usual type is the pitman chest, so called because it contains a type of floating valve called a pitman. This action is commonly known as electropneumatic.

The pitman chest

The combination pedals can also be operated electropneumatically. They are usually supplemented by a series of buttons, or pistons, placed below each manual, where they are conveniently operated by the organist's thumbs. The pistons may easily be made adjustable so that the organist can quickly alter the combination of stops controlled by each one.

A compromise has been used successfully with tracker action for each department, with the coupler action operated electrically. This arrangement has considerable merit, since the coupling together of three or four manuals with tracker action results in a very heavy touch. Electric stop action may also be combined with tracker key action, enabling the use of electric (including solid-state) combinations—an invaluable aid in quickly changing groups of stops, especially in larger instruments.

Flue pipes. There are two main categories of organ pipes: flue pipes and reed pipes. Flue pipes (made either of wood or metal; their construction is basically similar in principle) account for about four-fifths of the stops of an average organ. Figure 12 shows a front view and a vertical section of the most typical sort of metal flue pipe. The pipe consists of three main parts: the foot, the mouth, and the speaking length.

The pipe stands vertically on the wind-chest, and wind enters at the foot hole. The foot is divided from the speaking length by the languid, a flat plate; the only airway

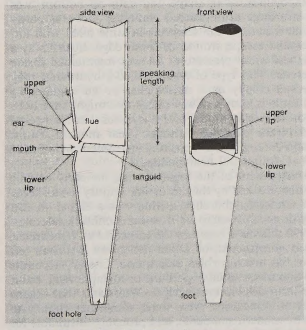


Figure 12: Typical flue pipe (principal).

connection between the foot and the speaking length is a narrow slit called the flue. The wind emerges through the flue and strikes the upper lip, producing an audible frequency, the pitch of which is determined by and amplified in resonance by the speaking length of the pipe. A pipe of this kind is, in fact, identical in principle with a recorder or a tin whistle; but, whereas they have holes along the speaking length, which the player covers and uncovers with his fingers to secure the notes of the musical scale, in an organ there is a separate pipe for each note.

The tone of a pipe is determined by many factors, including the pressure of the wind supply, the size of the foot hole, the width of the flue, the height and width of the mouth, and the scale, or the diameter of the pipe relative to its speaking length. The material of which the pipe is made also exerts an influence; it may be an alloy of lead and tin, wood, or, more rarely, pure tin or copper, and for the bass pipes zinc. The pipes may also vary in shape, a common variant being an upward taper in which the pipe is smaller in diameter at the top than at the mouth. Or, the top of the pipe may be completely closed by a stopper. Such a pipe is said to be stopped; a stopped pipe sounds an octave lower in pitch than an open pipe of the same speaking length.

Factors affecting tone

Open pipes of large diameter are said to be of "large scale," and open pipes of small diameter are said to be of "small scale." Large-scale pipes produce a fluty or foundational quality of tone that is free from the higher harmonics (the numbered series of partials, or component tones). Small-scale pipes produce a bright quality of tone that is rich in harmonics, recalling bowed strings. Stopped pipes can be particularly foundational in tone, and they favour the odd-numbered at the expense of the even-numbered partials. Tapered pipes are somewhere between stopped and open pipes in tone quality.

Flue pipes are tuned by increasing or decreasing the speaking length. In the past, several methods of tuning were employed, but in modern times this is often done by fitting a cylindrical slide over the free end of the speaking length and sliding it up and down, lengthening or shortening the pipe as required. In stopped pipes the stopper is pushed farther down to sharpen the pitch or is pulled upward to lower it.

Tuning and voicing

The pipe maker thus broadly fixes the type of tone that a pipe will produce; but this is further controlled within fairly wide limits by the wind pressure and, finally, by the voicer, who adjusts the tone of each pipe by manipulating the foot hole, flue, and upper and lower lips. The attack of the note may also be greatly influenced by cutting a series of small nicks in the edge of the languid. Heavy nicking, commonly practiced in the early 20th century, produces a smooth and sluggish attack. Light nicking or no nicking, as used up to the 18th century and in some more advanced modern organs, produces a vigorous attack, or chiff, somewhat like tonguing in a woodwind instrument. If not excessive, this chiff enhances the vitality and clarity of an organ. The voicer is the artist upon whom the ultimate success of any organ depends. The tonal designer or architect is hardly less important, however; it is he who decides upon the choice of stops, their disposition in the organ, and the scales to be followed by the pipe maker. A completely successful organ depends upon the effective cooperation of designer and voicer.

Reed pipes. Organ reeds were probably originally copied from instrumental prototypes. A reed stop may have a beating reed like that of a clarinet or a free reed (a type discussed below in connection with reed organs).

The shallot of a beating reed pipe, seen in cross section in Figure 13, is roughly cylindrical in shape, with its lower end closed and the upper end open. A section of the wall of the cylinder is cut away and finished off to a flat surface, as shown in the inset to Figure 13. The slit, or shallot opening, thus formed is covered by a thin brass tongue that is fixed to the upper end of the shallot. The tongue is curved and normally only partially covers the shallot opening. But, when wind enters the boot, the pressure of the wind momentarily forces the tongue against the shallot, completely closing the opening. Immediately, the elasticity of the brass asserts itself, and the tongue

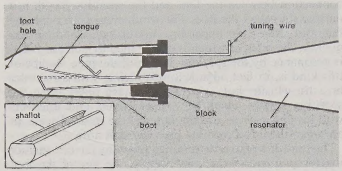


Figure 13: Section through a reed pipe (trumpet).

reverts to its curved shape, thus uncovering the opening. This process is repeated rapidly. The frequency of the pulsations of air that enter the shallot is determined by the effective length of the reed and, in turn, determines the pitch of the note. Thence, the pulsations pass out into the tube, or resonator, which further stabilizes the pitch and decides the quality of the note. Most reed resonators have a flared shape, as shown in Figure 13. As in flue pipes, a wide scale favours a fundamental tone, and a narrow scale favours a bright tone. Cylindrical resonators produce an effect similar to that of stopped flue pipes, the note being an octave lower than the equivalent flared pipe and the tone favouring the odd partials. Some reed pipes, such as the vox humana, have very short resonators of quarter or eighth length. Pipes the resonators of which have no mathematical relationship to the pitch are known as regals; regal stops were popular in the 17th century, particularly with the North German school, and their use has been revived in modern times. Their short resonators have varying and peculiar shapes, which produce a highly characteristic snarling tone; they can be difficult to keep in tune.

Reed length and pitch

Reed pipes are tuned by moving the tuning wire, thus shortening or lengthening the tongue (Figure 13). As in flue pipes, the scale and shape of the resonator largely determine the quality of tone to be produced; but the wind pressure, the shape and size of the shallot, and the thickness and curvature of the tongue also have important influence. The tongues may also be weighted with brass or felt; this weighting produces a smoother quality of tone, especially in the bass notes.

Organ stops. It has already been explained that the pitch of any pipe is proportional to its length. Most modern organs have a manual compass of five octaves, from the second C below middle C to the third C above; an open pipe sounding the low C is about 8 feet (2.5 metres) in speaking length (64 vibrations per second). The shortest pipe in the same rank, or stop, is thus about 3 inches (8 centimetres) long (2,048 vibrations per second). While large- and small-scale ranks often imitate the tones of flutes and bowed strings respectively, and are named accordingly, the most characteristic tone of the organ is produced by its diapason, or principal, stops. These are of medium scale (usually about 6 inches diameter at the 8-foot open pipe) and moderate harmonic development—*i.e.*, neither particularly dull nor bright. Such a tone quality becomes boring if heard for a long time. Also, when greater power is required, there is a distinct limit to what can be done by adding more stops of unison pitch. From the earliest times, stops, especially the principals, were arranged in choruses, and the principal chorus is the very backbone of any organ.

Diapasons, or principals

A chorus consists of stops of roughly similar quality and power but at a variety of pitches. A unison principal is known as principal 8 foot because of its longest (8-foot) pipe, and the figure 8 appears on the stop knob or tablet (rocking tablets are often used in place of knobs with electric action) at the console to give an indication of its pitch. The first step toward a chorus is to add a stop sounding an octave above 8-foot ranks (*i.e.*, at octave pitch), the largest pipe of which is therefore 4 feet long. Next comes a 2-foot stop, while the suboctave pitch is represented by a 16-foot stop. The top pipe of a 2-foot stop has a speaking length of only three-quarters of an inch, and this is about the practical upper limit. Nevertheless, an organ with nothing higher in pitch than a 2-foot stop would be lacking in brilliance, especially in the lower parts of the compass.

From the earliest times, organs have, therefore, been supplied with what are known generically as mixture stops, which have several high-pitched pipes to each note. But, since, for example, a 1-foot rank could not be carried right up to the top note, it breaks back an octave at some convenient point in the compass. Ranks pitched even higher will break back more than once. Thus, in the bass, a mixture adds definition to the slow-speaking, low-pitched pipes; in the treble, where the small pipes tend to be lacking in power, it duplicates the unison and octave ranks. A mixture, therefore, helps to maintain a balance of power between bass and treble, while adding harmonious power of a kind that is completely peculiar to the organ and can be produced in no other way.

Mixtures and mutations

Mixture stops also contain ranks sounding at pitches other than in octaves with the 8-foot principal. In chorus mixtures these sound at a fifth above the unison (*e.g.*, G above C), although ranks sounding at a third above and even at a flat seventh (*e.g.*, E and B♭ above C) and their respective octaves are also found; but these are best restricted to mixtures intended for somewhat special effects. The theoretical justification for these quint- (fifth) and third-sounding ranks is that they reinforce the natural upper partials of the harmonic series, but they were included in organs long before this was understood. The fact is that they were found to sound well, and large organs without mixtures and off-unison ranks have been generally unsuccessful. The colourfulness and vitality of organ music depend largely upon copious, artistically voiced mixtures.

Off-unison ranks are also available as separate stops, mostly sounding at an interval of a 12th (an octave and a fifth; $2^2/_3$ feet), 17th (two octaves and a third; $1^3/_5$ feet), or 19th (two octaves and a fifth; $1^1/_3$ feet) above the unison. These are used melodically to colour the unison and octave stops, and they may be wide or narrow in scale. Such stops are known as mutation stops, as opposed to the mixtures, or chorus stops. Their use is essential for the historically (and therefore artistically) correct performance of organ music written before 1800 and of much modern music as well. After a period of disuse throughout the 19th century, they are again included in all but the smallest modern organs.

History of the organ to 1800. The earliest history of the organ is so buried in antiquity as to be mere speculation. The earliest surviving record is of the Greek engineer Ctesibius, who lived in Alexandria in the 3rd century BC. He is credited with the invention of an organ very much on the lines of the single-manual, slider-chest organ already described, except for its wind supply, which made use of a principle that was most ingenious, though applicable only to a very small instrument. A piston pump operated by a lever supplied air to a reservoir; at its upper end, this reservoir communicated directly with the wind-chest. The reservoir, cylindrical in shape and with no bottom, was placed in a large drum-shaped container that was partly filled with water. As the reservoir became filled with air, the air would escape around its lower edge. In this way a more or less equal pressure of air was maintained inside the reservoir. This type of organ, called a hydraulus, may have served chiefly as a noisemaker or an engineering marvel. Little is known of any music that might have been played on it. A clay model of a hydraulus was discovered in 1885 in the ruins of Carthage (near modern Tunis, Tun.), and the remains of an actual instrument were found in 1931 at Aquincum, near Budapest.

The hydraulus

The development of the organ during the early Middle Ages is obscure, but by the 8th or 9th century it was being used in Christian churches, perhaps as a signal to call congregations to worship or in other nonliturgical roles. About 990 a famous organ in the cathedral at Winchester, Eng., was constructed, of which the monk Wulfstan left a famous but much garbled description. Literary accounts of early organs are often hyperbolic or metaphorical, but it appears from descriptions such as Wulfstan's that organs like that at Winchester were loud, somewhat clumsy to operate by modern standards, and probably unsuitable for all but the simplest music.

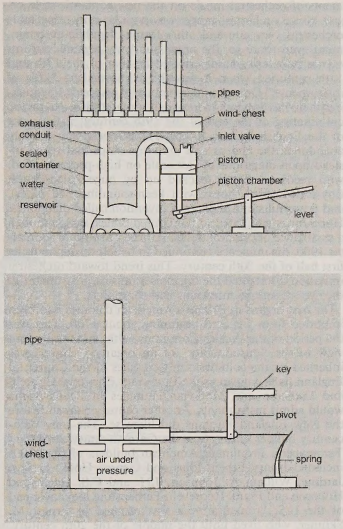


Figure 14: Blowing mechanism of the hydraulus.

From S. Sadie (ed.), *The New Grove Dictionary of Musical Instruments*, vol. 2, © Macmillan Press Limited 1984

The artistic history of the organ begins with the development of the chromatic keyboard (*i.e.*, having 12 keys per octave). By 1361 the cathedral organ at Halberstadt, Ger., had three chromatic keyboards and pedals; the keys, however, were much wider than those of the modern keyboard. The modern size of keys was fairly generally established by the end of the 15th century. Although the Halberstadt organ had three manuals, it had no stop mechanism. The main keyboard controlled a huge mixture stop, and the other keyboards controlled reduced groups of stops.

Ctesibius' slider arrangement was probably rediscovered some time in the early 15th century, and it became common soon after 1450. Reed stops began to appear at the same time, and by 1500 the organ had reached a stage in northern Germany in which all the important features of the modern organ were present. In the 16th century the organ began to develop an idiomatic repertoire distinct in style from that of instrumental ensembles, although written organ music of the Renaissance gives no clues as to how the different stops and keyboards were employed.

During the Middle Ages and the Renaissance, three diminutive forms of the organ were widely used. These were, first, the positive (in which category are included most chamber organs of the period), a small organ capable of being moved, usually by two men, either on carrying poles or on a cart. The second type, the portative, was smaller still, with only one set of pipes and a manual of very short compass. It was carried by the player, who worked the bellows with one hand and played the keys with the other. Such instruments were used in processions and possibly in concerted instrumental ensembles. Between the last two in size was the third type, the regal, which usually had only one reed stop, a regal, as previously described.

Portable organs

Since national styles of organ building vary widely and it is necessary to know something about them before the music of each nation can be performed intelligently, the more important styles must next be considered briefly. Of the basic medieval organ, prior to the development of national styles, little if any material survives, except in the old cathedral at Sion in Switzerland, where a large proportion of the seven-stop organ appears to date from about 1400. Although voiced on low wind pressure, the tone of the chorus is brilliant, colourful, and powerful.

Italy. Italy is mentioned first because its organs developed to their maturity soon after 1500 and remained relatively unaltered until about 1800. The Italian organ had one manual and usually only an octave of pedal keys, which had no pipes of its own (except an occasional independent 16-foot *contrabasso*) but was coupled permanently to the manual. The manual chorus (*ripieno*) had the peculiarity that there was no collective mixture; all the ranks were drawn by separate stops. Each rank broke back an octave as it reached the $1\frac{1}{2}$-inch pipe. In addition, there were flute stops of 4-foot, $2\frac{2}{3}$-foot, and 2-foot pitch and a register called the *fiffaro* or *voce umana* (not to be confused with the French *voix humaine* or German vox humana, which are regals), a principal rank found only in the treble and tuned sharp so that when it is played together with the *principale* one hears an audible beat. It was the forerunner of the similarly constructed voix céleste stop popular in the 19th-century romantic organ. The scale of the classic Italian *principale* was not much different from its counterpart in the north, but its mouth was narrower, its voicing more delicate, and there was a notable lack of chiff. Reeds were not found until late in the 16th century and were never considered essential.

Spain and Portugal. The Iberian organ followed the Italian tradition, but, later, many reeds were added, most notably the *trompetas reales* ("royal trumpets") and other horizontal (*en chamada*) reeds arrayed in fanlike projections from highly ornamental cases. These reeds were on extremely low wind pressure and achieved amazingly full sounds that filled the huge edifices.

Like their Italian counterparts, Spanish and Portuguese organs had only a few rudimentary pedals. The manuals, however, were divided, with keys up to middle C controlled by a draw knob to the left and keys up from C♯ by a draw knob to the right. This enabled the playing of a solo voice against an accompaniment on the same manual. A unique feature of Iberian churches was the presence of several separate and distinct instruments in one building, enabling interesting uses of antiphony, or contrasting masses of sound.

Germany. From 1500 to 1800 Germany led the world in organ building and the composition of organ music. The organ builders reached the peak of their achievement about 1700 in the work of Arp Schnitger. Schnitger made organs with four manuals, pedals, and as many as 60 speaking stops, but he made some instruments with fewer than 30 speaking stops that are capable of dealing with the whole pre-Romantic repertoire. His was the organ of the high Baroque; but his countrymen Andreas and Gottfried Silbermann were equally the masters of the slightly later, more sophisticated style of the mid-18th century.

The Schnitger organs

Seventeenth- and 18th-century German organs were usually constructed on *Werk*-principle lines: each department of the instrument, or *Werk*, was separately cased, the Hauptwerk (main manual) in front of and above the player, with the pedals at each side and the *Rückpositiv* (auxiliary manual) behind on the gallery railing. Each department, including the pedal, had its own principal chorus, complete up to at least one mixture. All departments were roughly equal in power but varied in pitch, having, respectively, a 16-foot, 8-foot, and 4-foot preponderance (and 32-foot and 2-foot as well in larger instruments). Each manual department had a set of flutes and mutations that could be combined in a variety of ways to provide accompaniment and melody or the balanced but contrasting tone qualities essential for duet and trio passages. Although the pedal department consisted mainly of its principal chorus, it could be coloured for solo and obbligato passages by 2-foot flute and reed stops. The reeds were not much louder than the flue stops, and the pedal 16-foot and 8-foot reeds were frequently drawn with the principal chorus for improved definition. When used in this way, they by no means caused the pedal to overwhelm the Hauptwerk. Such an instrument could deal with the

requirements of all 15th- through 18th-century organ music, although its limited supply of manual reeds placed it at some disadvantage in French music of the period.

France. As far as the manual departments are concerned, French organs differed little from the German type, but the principal choruses were generally larger in scale. The separate, large-scaled Tierce (1⅗-foot) was also universal, and there were many cornet stops. These mixture stops consisted of five pipes to each note: a stopped unison (8-foot) and large-scale open 4-foot, 2⅔-foot, 3-foot, and 1⅗-foot. They extended only from middle C upward and were largely melodic in use. They were never drawn with the principal chorus (Plein Jeu) but generally were used with the reed chorus (Grand Jeu). Apart from this, the Plein Jeu, Grand Jeu, and Jeux de Mutation were seldom or never intermixed in French music.

The pedal department of the French organ prior to 1700 was regarded largely as a sort of solo section that consisted usually of only 8- and 4-foot flutes and 8- and 4-foot trumpets. Only in the largest 18th-century French organs were 16-foot stops included, although there were often as many as three on the Grand Orgue (the manual analogous to the German Hauptwerk and the English Great Organ). When French organs had more than two manuals (Grand Orgue and Positif), the others (Récit and Écho) were usually of short compass; but if, as sometimes, there was a fifth manual, it was a Clavier de Bombardes, consisting of 16-, 8-, and 4-foot trumpets and a cornet. Unlike its German counterpart, the main case housed all divisions except the Positif, which was in its usual location on the gallery railing.

French use of reed pipes

French organs were notable for their reeds, and the highly stylized French music of the 17th and 18th centuries calls for their frequent use. Surviving specimens in good order are rare; but unaltered, late 18th-century, four-manual organs survive at Poitiers cathedral (by the noted builder François-Henri Clicquot) and at Saint-Maximin, Provence (by Jean-Esprit Isnard).

Great Britain. Few British organs before the Commonwealth (1649–60) had two manuals, and none had pedals. Mixtures and reeds seem to have been unknown, and mutations were restricted to a single 12th.

After 1660 a new school rapidly grew up, and, although the two principal builders had both been abroad during the Commonwealth (Bernard Smith in Germany or Holland and Renatus Harris in France), their British work owed little to foreign influence. Only the Great Organ had a complete diapason chorus, and the Choir, or Chayre, organ usually extended upward only to a single two-foot. Almost every organ had a cornet, and the reeds in common use were trumpet, vox humana, and cremona, or krummhorn, with half-length, cylindrical resonators. There were no pedals, but the manual compass almost invariably extended to the third G below middle C. If there was a third manual, it consisted of a short-compass echo department in which all the pipes were shut up in a box to produce the echo effect. In 1712 the builder Abraham Jordan first fitted the echo box with shutters that were controlled by a pedal at the console; this arrangement produced what Jordan described as the swelling organ, but it was not to reach its full development until 150 years later; no 18th-century organ music demands a swell box. There are hardly any surviving examples of British instruments of this period in original condition.

Developments after 1800. Because of the increasing interest in orchestral and operatic music, the organ fell out of favour during the 18th century, and by 1800 it survived only as an ecclesiastical drudge. From the middle of the 19th century, however, a revival took place under the leadership of two great builders, Aristide Cavaillé-Coll of France and Henry ("Father") Willis of England. In Britain during the first half of the 19th century, the introduction of pedals made it possible for the first time to play the organ music of J.S. Bach and his German contemporaries and predecessors. While retaining respectable vestiges of the classical chorus, Cavaillé-Coll and Willis developed the solo stops, especially reeds, and Willis, in particular, provided new aids to registration.

Organists found that they could play effective arrangements of orchestral music on the new romantic-style organ. Since orchestral music was popular and respectable orchestras very rare and other forms of public entertainment even more so, the organ suddenly regained an immense popularity hardly rivaled by that of the 17th and 18th centuries, when it was the acknowledged "king of instruments." Organ builders naturally responded by making their instruments increasingly orchestral in character, culminating at the end of the 19th century in the work of the English builder Robert Hope-Jones, who entirely abandoned the chorus and mutation stops and relied instead upon diapasons of vast scale on high-pressure wind, with reeds to match, backed up by huge-scaled flutes, tiny-scaled string stops (with keen-sounding flue pipes), and powerful stops of his own invention called diaphones. Hope-Jones emigrated to the United States, and, although a semblance of classical design returned to Britain soon after 1900, his influence continued to be felt throughout the first half of the 20th century. This trend toward orchestral imitation discredited the organ as a musical instrument in the eyes of serious musicians and composers.

First instruments in the colonies

The first organs in Britain's American colonies had been imported from England beginning about 1700. This was the period of the English Commonwealth, and the Puritan view of the "unsuitability" of an organ in church was inherited by the colonies. Only parishes of the Church of England (later known as the Protestant Episcopal Church) and Lutheran and Moravian churches in Pennsylvania would admit instruments. Another century elapsed before the New England Puritans did likewise. The only 18th-century builder of note was the German-American David Tannenberg. Prominent American builders of the 1800s included Henry Erben, Elias and George Hook, George Jardine, William A. Johnson, J.H. and C.S. Odell, and Hilborne and Frank Roosevelt. Perhaps the inevitable end of the U.S. "romantic" era was reached in Ernest M. Skinner, who lived until the middle of the 20th century. In Canada, Joseph Casavant built his first organ in Quebec province in 1837. Two of his sons visited France in 1878–79 and brought back to North America the Cavaillé-Coll tradition.

Albert Schweitzer, organist, philosopher, and later medical missionary, wrote a booklet, *Deutsche und französische Orgelbaukunst und Orgelkunst* ("The Art of German and French Organ Builders and Players"), in 1906 outlining the inadequacies of the 19th-century organ for the performance of the music of J.S. Bach and his contemporaries. It was not until 1926, however, with Karl Straube, that the revival of 18th-century and earlier styles of organ building began. Straube, organist at Bach's Tomas Church in Leipzig, noted editor of Baroque organ works, and leading exponent of the Romantic works of Max Reger, renounced the Romantic approach to the organ and called for a return to Baroque principles. Certain historically minded organ builders in Germany, soon followed in other European countries and in North America, heeded Straube's call by constructing instruments based tonally and structurally upon Baroque models and by restoring old but altered tracker-action organs to their original specifications. While even the best of such specialized organs may not accommodate large-scale works by Romantic and later composers, their musical qualities and sensitivity to the player's touch render them artistically superior to unwieldy all-purpose organs, some of which have more than 150 ranks.

The late 20th century has seen a decline in production of pipe organs, with several large manufacturers going out of business in the United States. However, small firms building highly refined tracker-action instruments have proliferated. Increasingly, their organs adopt tuning systems other than equal temperament, pitches higher or lower than usual, short-octave keyboards, and other retrospective features that allow performers to re-create organ music of the 16th through 18th centuries in ways that would have been familiar to composers of those times.

The reed organ. The term reed organ normally refers to a keyboard instrument in which sound is produced by free reeds. Accordions and concertinas are examples of small, hand-held reed organs. Free reeds are thin, flexible strips

Free reeds

of metal, usually brass, that are secured at one end over or under close-fitting openings in plates that are mounted over a wind-chest. Suction or wind pressure causes the free end of the reed to vibrate in and out of its aperture when its key is depressed to open a valve, or pallet, in the wind-chest. The pitch of each reed is determined by its length, though tuning can be accomplished by thinning or weighting the reed. No resonator is required to modify the tone quality, which is affected chiefly by the shape, thickness, resilience, and curvature of the reed.

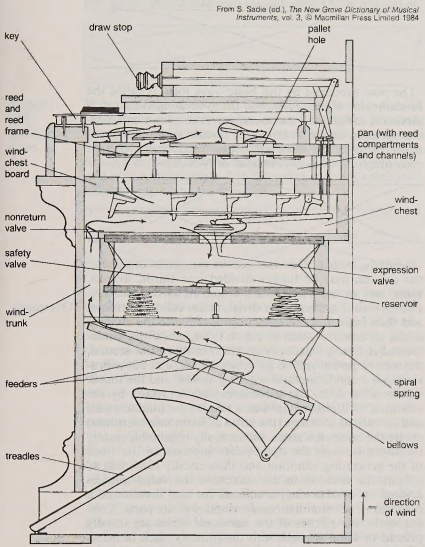


Figure 15: Reed organ operated with wind under pressure.

It is not known when the free reed was first introduced to Europe from Asia, where as early as 1100 BC free reeds were incorporated into mouth organs such as the Chinese *sheng*. The *sheng* itself was known in Europe by 1777, by which time free reeds had already appeared in experimental organs. The tuning stability, small size, and low cost of free reeds were quickly recognized as virtues, and by the early 19th century small organs using free reeds in place of or in addition to pipes and with bellows pumped by the player's feet were being manufactured in Europe and the United States. Occasionally free reed stops appeared as an adjunct to pianos and in mechanical instruments such as Johann Nepomuk Maelzel's panharmonicon, first exhibited in Vienna in 1804.

Because of their simplicity, portability, and ease of maintenance, by the mid-19th century reed organs had become popular domestic instruments, rivaling the piano in numbers though not in quality or quantity of repertoire. In churches and other institutions, especially less affluent ones in rural areas, reed organs with up to three manuals, a pedal keyboard, and five or more sets of reeds often served in place of costlier pipe organs. The versatile and expressive harmonium (a compact reed organ patented in 1842 by the Frenchman Alexandre-François Debain and later developed by others) attracted the efforts of major composers such as Antonín Dvořák and Cesar Franck.

The harmonium

While European reed organs generally operated with wind under pressure (supplied by feeder-bellows), a type that employed suction to sound the reeds was developed in the United States, notably in New England, where seraphines, lap organs, and melodeons (as some varieties were called) were patented and manufactured in great numbers after about 1830. In 1847, Emmons Hamlin, an employee of the George A. Prince melodeon factory in Buffalo, N.Y., greatly improved the tonal quality of free reeds by bending them in various ways; the Boston firm that Hamlin founded with Henry Mason in 1854 became an international leader in producing "cabinet organs" of modest size.

Although reed organs continued to be manufactured into the 20th century and were occasionally employed in ensemble music by serious composers such as Arnold Schoenberg and Kurt Weill, they suffered from defects such as sluggish response, cloying tone, and limited expressive capability. In the face of unrelenting competition from cheap upright pianos (which they often resembled in appearance) and, later, from electronic instruments, reed organ production declined in the second quarter of the century, though fine old examples in playable condition remain numerous. Production of small reed organs has continued in India, where they provide drone accompaniments for, for example, sitar music. (C.Cl./La.L.)

Wind instruments

GENERAL CONSIDERATIONS

Classification. Prominent in the music of all cultures since prehistoric times, wind instruments exhibit great diversity in structure and sonority. A system of classification of these instruments must reflect and categorize the relationships and the differences between the many varieties. The conventional division of the symphony orchestra into sections has simplified the grouping of wind instruments into woodwinds and brasses, but this is an inaccurate classification that generally does not apply outside of Western culture. The fact that some modern woodwinds, such as flutes and saxophones, are made of metal, while several ancestors of present-day brasses, such as the cornett and serpent, were typically made of wood, illustrates the unsuitability of a classification according to material.

The standard method of instrument classification was introduced in 1914 by Curt Sachs and Erich von Hornbostel. It is based on the acoustical principles of an instrument's sound, regardless of its stylistic or cultural context. In this system, all wind instruments—that is, all instruments in which air itself is the primary vibrating medium for the production of sound—are called aerophones, whether or not the air is enclosed in a tube.

Sachs-Hornbostel further classifies aerophones as free aerophones, edge instruments, reedpipes, and trumpet-type instruments according to their manner of tone production. Free aerophones, which include a variety of primitive instruments as well as such technologically sophisticated devices as reed stops in organs (see *Keyboard instruments: The organ* above), are distinguished from the other categories because the vibrating air is not contained by a tube. The bull-roarer exemplifies the primitive. A spatulate stone, bone, or board, sometimes carved in the shape of a fish, is tied through a small hole to a string, which in turn is attached to a stick; when the instrument is whirled around, it produces a sound by its disturbance of the air.

Free aerophones

The reeds of the mouth organ, accordion, reed organ, and the reed stops of the pipe organ, known as free reeds, are all considered free aerophones as well: the reed vibrates above or through a slot, setting the air into pulsations. The resulting pitch is determined by the thickness and length of the vibrating reed.

In edge instruments (or flutes), an airstream directed against a sharp edge sets an adjoining air column within a tube into regular pulsations, producing sound. Flutes are divided into so-called true flutes and whistle flutes (also called duct flutes or recorders). Like all aerophones, flutes may be simple or complex, depending on their construction, the transverse flute being simple, and panpipes, organs, and other multiple-tube instruments being more complex.

In true flutes, a ribbon-shaped column of air is produced

between the player's lips and directed against the edge of an aperture. The player blows against either the sharp rim at the upper, open end of the tube (end-blown), or against the rim of a hole in the side of the tube (side-blown). The Japanese *shakuhachi* is an end-blown flute, consisting of a wide bamboo tube with a notch at the top, four front finger holes, and one rear thumbhole. The modern transverse flute and piccolo are side-blown. In a further subcategory, globular flutes, the body of the flute pipe is vessel-shaped, not tubular. Such flutes, of various materials, are found in North and South America, Africa, China, and Oceania.

The player of a whistle flute, by contrast, blows through a mouthpiece. The air passes through a duct, or windway, between a plug in the mouthpiece and the flute wall; the duct directs the air against the sharp edge of another hole further down the body of the instrument. Because the airstream is shaped and directed by the duct rather than by the player's lips, whistle flutes are simpler to play than true flutes. The recorder, the ocarina, and the open flue stops of the organ are all whistle flutes.

Reedpipes

In the third category of aerophones, reedpipes, the column of air is activated by the vibrations between the two parts of a double reed or those between a single reed and the mouthpiece. In the Sachs-Hornbostel system, all double reeds are generically classified as oboes, and the single reeds as clarinets. Accordingly, the bassoon is an oboe, and the saxophone a clarinet.

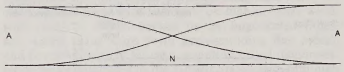
The fourth category, trumpet-type aerophones, includes instruments in which the vibration of the player's compressed lips sets the air column in motion. Depending on the shape of the bore, trumpet-type aerophones are either trumpets, whose bore is cylindrical, or horns, whose bore is conical, although in practice they are sometimes difficult to distinguish. (Some writers prefer to call horns those instruments known or believed to have descended from primitive instruments made from animal horns or tusks, terming the remaining lip-vibrated instruments trumpets.) Trumpet-type aerophones are further classified in two ways: (1) according to the position of the mouth hole—they are end-blown if it is located at the upper orifice of the tube and side-blown if pierced somewhere in the side—and (2) by the presence or absence of a mouthpiece. Finally, trumpet-type aerophones are classified according to construction designed to permit the playing of chromatic pitches. They are natural if not so constructed, such as the conch shell and the hoop-shaped baroque trumpet, and chromatic if built with finger holes, slides, or valves.

A possible fifth category, sometimes suggested as an addition to the Sachs-Hornbostel list, would be the human voice, which approximates the criteria for a double reed aerophone.

With the Sachs-Hornbostel classification well in mind, the common terminology can be used with the understanding that the term woodwinds refers to flutes and reed instruments and the term brasses to lip-vibrated aerophones.

The production of sound. Tubes used to produce a musical sound may be cylindrical, conical, or some combination of the two. They may also be straight or curved. Regardless of the material used, their interior surface must be smooth for best results. The relation of tube length to diameter varies widely but must remain within certain practical limits in order to produce musical pitches. The air contained within the tube is set into vibration by the breath, or in some cases a bellows, acting upon a sound-generating device. The pressure exerted against the molecules of air in the tube causes the particles to move forward along the tube until they bump into others, setting them in motion while the first bounce back. This process creates regular pulsations producing sound waves. Throughout the sounding length of the tube, the entire wave moves at the speed of sound. The air itself moves only slowly, and the phenomenon has been compared to the starting of a freight train, in which the first burst of energy from the engine jerks the car behind, which in turn passes the impulse of the car behind it, and so on throughout the length of the train. The impact of the cars also produces a reverse pressure as it moves along. Similarly, at the sounding length of the tube, the waves are reflected back upon themselves, creating a counter pressure that forms nodes and antinodes. The node results from interference between the forward and the reverse forces creating a static point; the antinode is the point of freest vibration in the sound wave. Antinodes always occur at the open ends of a tube, and it must be remembered that the end where the sound generates is also an open end, except in the clarinet types. In its simplest form, a node (N) is created at the exact middle between the two antinodes (A) at each end of the vibrating length.

Freight-train analogy

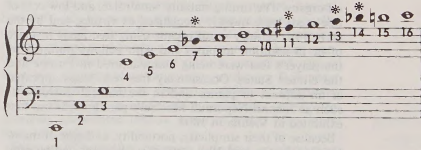


The note produced by this basic wave form is called the fundamental. If the pressure of the generating vibration is increased sufficiently, the sound waves divide in half, producing an antinode in the exact middle with consequent nodes between the three antinodes, producing a pattern consisting of A-N-A-N-A instead of A-N-A.



Overtones

Similarly, with further increase in the generating force, the column may be further divided into thirds, fourths, fifths, and so on. The process is known as overblowing. Pitches resulting from these divisions are called overtones, and their frequency increases in proportion to the division of the air column—that is, 1:2, 1:3, 1:4, etc. If the fundamental is C at a frequency of 128 vibrations per second, the second partial will be an octave higher, c at 256 vibrations per second; the third will be g at 384, and the fourth will be c′ at 512. The successive pitches created by the vibration of the air column as a whole (the fundamental) and its various divisions (the series of harmonic overtones) create the harmonic series, theoretically obtainable *in toto* on any tube with the appropriate increase in the force of the generating vibration and theoretically extending to infinity. In addition to the successive individual pitches created by overblowing, a column (or any division of a column) of air simultaneously vibrates in its parts. Consequently, the pitches of the harmonic series are usually present in some strength with the primary pitch heard as the fundamental. For this reason, the pitches of the harmonic series are known as partials and numbered in the order in which they appear. The following example shows the harmonic series for the fundamental pitch C. (Asterisked notes are noticeably out of tune with the tempered chromatic scale, which contains 12 equal semitones.)

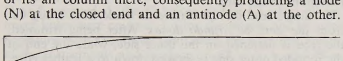


The relative strength of the various partials, which is controlled largely by the shape of the tube and the type of generator, is responsible for the timbre or colour of the pitch. It is this feature that allows the ear to distinguish between the quality of various tones.

It is notable that each successive interval of the harmonic series grows smaller, the number of partials doubles in each octave, and diatonic pitches of the major (*i.e.*, whole and half steps) scale become available in the fourth octave. The series is particularly significant among the natural trumpet-type aerophones (*i.e.*, those lacking valves, finger holes, keys, or slides), for the pitches that could be played are limited to a range of 1 to about 16 notes from this

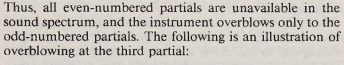
series without some device to alter the fundamental. The tubes of all trumpet-type aerophones are long in relation to their width and are differentiated according to whether the fundamental can be sounded. Instruments wide enough to sound the fundamental are called whole-tube instruments, those too narrow to do so are half-tube. The latter include those that can be overblown into the third and fourth octave, producing approximately 16 partials.

A pipe stopped at one end will have the static point of its air column there, consequently producing a node (N) at the closed end and an antinode (A) at the other.



Stopped and unstopped pipes

Because of the closed end, the column cannot be divided in half nor into any even-numbered multiples, for such divisions would require an antinode at the closed end. Thus, all even-numbered partials are unavailable in the sound spectrum, and the instrument overblows only to the odd-numbered partials. The following is an illustration of overblowing at the third partial:



The clarinet family and stopped flue pipes in the organ are the most commonly known instruments of this type.

Pulsating air within a tube in turn initiates pulses in the free air, creating sound waves roughly similar in a single dimension to the waves created on still water if a stone is dropped into it. Because free aerophones must create such eddies in the air directly, the capabilities of these instruments are extremely limited. Even organ reeds, which belong to this class, are capable of sophisticated music merely because of their number. Each reed produces only the pitch to which it is tuned, and the pipe, if present, does not determine pitch but serves only as a resonator for the reed.

Trumpet-type aerophones. As regards sound generation, trumpets and horns differ from other aerophones in their use of the so-called "lip reed," which is formed when the player's partially closed lips vibrate as they press against the rim of a mouthpiece or mouth hole (although the behaviour of the lips, strictly speaking, is not exactly comparable to the operation of a reed). When the lips vibrate, the resulting tremor in the flow of the breath is transmitted to the air in the tube, which resonates at the frequency that most closely matches that of the lips. The experienced player adjusts his embouchure to produce the desired frequency.

The mouthpiece, an important accessory to sound production in trumpet-type aerophones, is an adaptor used to widen the starting diameter of a bore otherwise too small to allow the lips to vibrate effectively. It has three internal elements—the cup; the throat, an opening at the base of the cup; and the backbore, which leads to the main tubing—the shape and relationship of which strongly influence an instrument's tone and technical capacity. Mouthpieces on Western orchestral trumpets have a hemispheric cup

From A. Clarke, *Musical Wind Instruments*, by permission of Macmillan, London and Basingstoke

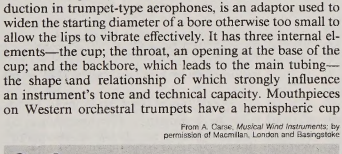


Figure 16: Mouthpieces of trumpet-type aerophones.

with shallow walls that meet the throat at a sharp angle; these effect a bright tone. Mouthpieces used with cornets and trombones are deeper, with rounded-off throats, and those for French horns are virtually funnel-shaped; these all produce a more mellow tone.

An instrument's bore also influences its tone, as reflected in the subtypes trumpet and horn in the Sachs-Hornbostel classification. Trumpets normally have narrow, cylindrical bores that expand in the final third of the tube's length and terminate in a small bell, which helps to radiate the sound and to bring the harmonics into tune. This bore configuration, in conjunction with a mouthpiece with a shallow cup, favours the production of high partials. Horns, on the other hand, have expanding bores through all or part of the tube's length and normally end in a large bell. Aided by a deep-cupped or funnel-shaped mouthpiece, they favour low partials and function most efficiently in a low range.

Pitch-changing devices

Ways of filling in the missing tones of the harmonic series on trumpet-type aerophones were known in the West as early as the 10th century when finger holes, which shorten the sounding length of the tube, were cut into instruments made from animal horns. The cornett, which was made from two halves of a hollowed-out block of wood that had been glued together and bound with leather, was similarly fitted with finger holes and was widely used in Europe from the end of the 15th through the 17th century. In the late 18th and 19th centuries, makers covered the holes of trumpets and horns with keys to enable them to play a complete chromatic scale; the keyed horn was invented in Bohemia around 1770, and keys were thereafter added to the trumpet and bugle.

Another solution to providing the missing tones was to increase the sounding length of the tube, thereby making the partials of different harmonic series available separately and producing a chromatic scale. As early as the 14th century, the term *sacabuche* (Spanish: "drawpipe," or "pull push") was used to refer to a lip-vibrated instrument, presumably with a single telescoping slide. Fifteenth-century Flemish paintings depict what appear to be slide trumpets, in which the player slid the entire instrument up and down along the long shank of the mouthpiece with one hand, steadying the mouth pipe with the other.

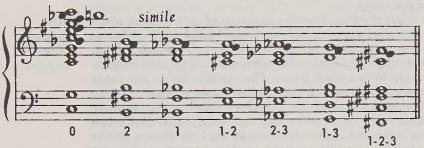
From this awkward beginning, it is easy to imagine bending the slide back upon itself, a less cumbersome alternative that appears to have been adopted in the mid-15th century. On so-called double slide instruments, such as the Renaissance sackbut and its successor, the modern trombone, two parallel inner tubes of the slide mechanism are attached at their upper ends to the body of the instrument by a cross stay. The mouthpiece is fit into the top of one tube, and the bell section fits on the other. The U-shaped slide moves along the two stationary tubes, lowering the fundamental by a half step with each lower slide position and making available the notes of seven harmonic series.

Crooks, detachable lengths of tubing, also were used to increase the sounding length and lower the pitch of trumpets, trombones, and horns. They are of two types: "terminal" crooks, which attach to the mouthpiece receiver, and "medial" crooks, which are inserted in a wider portion of an instrument's tubing. First mentioned in the mid-16th century, both types of crooks are clearly depicted in Praetorius' *Syntagma musicum* (1619). Praetorius' illustration of trombones, for example, features crooks inserted between the slide and bell sections. Terminal crooks were common on trumpets from the 17th through the 19th century. They were also used, singly and in combination, on the horn until the mid-18th century, when sliding medial crooks were added to the tubing inside the hoop of the German horn known as the *Inventionshorn*.

Hand stopping

In the early 18th century, horn players in Bohemia discovered that the gaps in the instrument's harmonic series could be filled by using the hand to partially stop the bell. When the hand was cupped to form an extension of the air column, the pitch of the note being played was lowered one-half step. Hand stopping, which became known throughout Europe in the 1750s thanks to the Bohemian hornist Anton Hampel, was later applied to the trumpet.

About 1815, either Heinrich Stölzel or Friedrich Blühmel, both of Berlin, invented the valved horn. When the valve was opened by depressing a key, it deflected the airstream into extra tubing, changing the effective length of the tube and lowering its pitch. The two valves of the original valved horns were used in combination: the first lowered the pitch one step; the second, one-half step; together they lowered the pitch one and a half steps. Later, a third valve, which lowered the pitch yet another step and a half, became a standard feature of such instruments. Used singly and in combination, these valves made the instrument completely chromatic above the second partial. The illustration below shows the harmonic series made available by the depression of different valves and combinations of valves; notes shown in black are slightly out of tune with the tempered scale.



Perhaps because the natural horn had more notes available than did 19th-century natural trumpets and also because the valve system, particularly on the early horns, affected the purity of tone, valved horns were accepted slowly. At first, valves were considered a convenient substitute for crooks—in effect, a means to modulate (change key) quickly—but band musicians were quick to develop virtuoso techniques of rapid chromatic playing.

Despite their convenience, valves are inherently defective in that they open a fixed amount of tubing. If the first valve on an instrument in C is depressed, lowering the pitch a whole step, the fundamental pitch of the instrument is changed from C to B♭. Using the second valve and its corresponding length of tubing (intended for a C instrument) to lower the instrument, now in B♭, one-half step requires slightly more tubing than needed to lower a C instrument one-half step. In many cases, the player can correct such discrepancies by adjusting his embouchure, decreasing slightly the speed of lip vibration to flatten the pitch without destroying its tone quality. The greater the amount of tubing, however, the worse the discrepancies in tuning. Most trumpets now have compensating slides that operate either manually or automatically to add length to the tubing on the first and third valves. For some large instruments, such as tubas, this device is impractical, and extra valves are added.

Flutes and reeds. Sound is generated by different methods in the aerophones designated as flutes and reeds in the Sachs-Hornbostel system. In flutes, the airstream is directed against a sharp edge; in reeds, the air column in the tube is caused to vibrate between two parts of a beating double reed or between a beating single reed and a mouthpiece.

Reeds and reed-making

Essential to sound production in reedpipes is the reed itself. Those used on most Western instruments are typically made from the stems of the large semitropical grass *Arundo donax*, commonly referred to as cane, grown on the Mediterranean coasts of France, Spain, and Italy. (Substitutes for cane—wood, whalebone, silver, and plastic—also have been tried.) Seasoned over a period of years, cane reeds may be purchased finished or be made by the player himself.

The double reed for an oboe or bassoon is made from a strip of cane about twice the length of the finished reed. The inner surface is gouged thin, shaped to be narrower at the ends, and notched in the middle. The reed is then soaked in water and folded in half at the notch. The free ends are bound with thread and, for oboes and English horns, mounted on a short, tapered metal tube called a staple. A bassoon reed is bound with thread and wire over a steel mandrel, which is later removed to leave a hollow rounded stem. To finish the reed, the halves are separated at the notch and the tips scraped to a feather edge on the outside. The form and degree of "scrape" applied to the tip of the reed has a profound influence on its behaviour and may vary a great deal from player to player. In playing, the double reed of the oboe and bassoon is held by the tension of the lips drawn in over the teeth. The opening between the two blades of the reed alternately opens and closes with the pressure of the breath to generate the pulsations in the tube.

The single reed for the clarinet is made from a slip cut from the stem of *Arundo donax*. After being trimmed, the reed is flattened on the inner side, while the end of the rounded outer side is scraped down to a feather edge. The thick end of the reed is attached, flat side down, to the mouthpiece by a metal ligature or length of twine. In playing, the thin end of the reed vibrates, alternately closing and opening the space between the reed and the mouthpiece. The vibration carries through the wedged-shaped tone chamber in the mouthpiece and into the air column in the tube.

The body of some folk instruments is itself a length of reed, made into an instrument by cutting and raising a rectangular tongue from the tube below a natural knot. The tongue is sometimes kept from closing down completely by inserting a hair at the base of the cut.

Because the tubes of flutes and reed instruments (in contrast to those of trumpet-type aerophones) are short in relation to their diameter, they are generally capable of sounding the fundamental and respond best to pitches low in the harmonic series. To play in the upper register, the player must overblow, breaking the air column up into parts, each of which vibrates at a frequency that is in direct proportion to the fundamental. Oboes, bassoons, and saxophones—all open tubes with conical bores—overblow at the octave; clarinets, whose cylindrical bore acts as a closed pipe, overblow at the 12th.

Overblowing

In overblowing, the player tightens his lips on the reed. Increasing lip pressure is not always sufficient by itself, however, and a variety of techniques and mechanisms have been developed to assist the player in making the notes of the upper register emerge clearly and instantaneously. For example, on flutes and bassoons, the first finger hole is positioned so that when it is opened on certain high pitches low partials are prevented from forming; opening a special key on the clarinet, saxophone, and modern oboe serves the same purpose. Overblowing is not a universal practice: the double and single reeds of some non-Western and early European reedpipes are inserted directly into the oral cavity or covered by a reed cap and hence, being uncontrolled by the lips, do not overblow.

Because of the acoustic characteristics of flutes and reeds,

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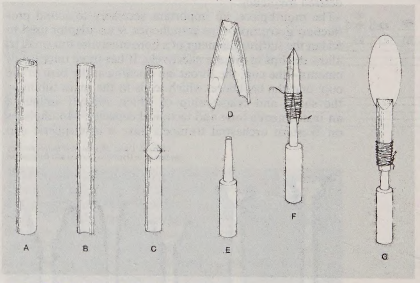


Figure 17: *Stages in the making of oboe reeds.*
(A) Cane is cut to desired length and (B) split in thirds, lengthwise, (C) nicked in the centre, and (D) folded over and cut in the desired shape. The folded cane is mounted on (E) the oboe's staple and (F) is tied, and (G) the tips of the reed are separated by a thin metal tongue.

only a few pitches are available on instruments lacking finger holes. Hence instruments with finger holes are known in most developed cultures, as are fingering systems. Typical of such systems in the West is the six-hole system, so named because the six finger holes of the Baroque transverse flute and oboe—there were no thumbholes—were controlled by the first, second, and third fingers of both hands. (The left hand normally took the higher position on the pipe, but this did not become standard until the mid-18th century.) Both instruments were pitched in D and sounded d (the D below middle C) when all six finger holes were covered. Lifting the fingers one by one, beginning with the lowest, shortened the sounding length of the instruments and produced e, f♯, g, a, b, and c♯—the remaining notes of the D-major scale; the octave (d′) was overblown.

Cross-fingering

On six-hole transverse flutes and oboes, chromatic pitches were obtained by closing one or more holes below an open one, a technique known as cross-fingering. For example, to produce f rather than f♯, the player uncovered the fifth hole with the second finger of his right hand while keeping the sixth hole (and the first through fourth holes) covered. (Because this arrangement of the fingers looked vaguely like the tines of a fork, some musicians call it a fork fingering.) With the six-hole configuration, however, no cross-fingering could produce e♭/d♯, because there was no hole to cover below the fundamental, d. Consequently, a seventh hole was bored between the sixth and the end of the transverse flute and oboe; it was covered by a closed key controlled by the fourth finger of the right hand. (A closed key covers the hole when at rest.)

In the late 18th century, additional keys were introduced to ease various difficulties of fingering and intonation. At first, open and closed keys were fitted to instruments through slots cut in rings or knobs of wood left after the body of the instrument was turned on a lathe; the key was secured in the slot with a metal pin. In the first quarter of the 19th century, as the number of keys increased, this type of mounting became increasingly inconvenient for builders. Brass saddles, which included the key mount, came to replace wooden knobs, first on bassoons and later on other woodwinds. Both these methods of affixing keys were eventually superseded by the use of metal pillars screwed directly into the wood, to which were attached the key and axle. In addition, 19th-century reformers like Theobald Böhm made other more radical changes in instrument construction (to be discussed below). Changes of the type Böhm championed, along with the constantly expanding key system, brought with them a transformation in tone quality, as the valves did to the brasses. Although some connoisseurs consider these changes regrettable, they have made possible technical dexterity in all keys.

From A. Carse, *Musical Wind Instruments*; by permission of Macmillan, London and Basingstoke

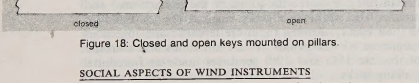


Figure 18: Closed and open keys mounted on pillars.

SOCIAL ASPECTS OF WIND INSTRUMENTS

To understand the importance of wind instruments throughout the world, one must first appreciate the great diversity of social contexts in which they are used. Which types are played, who plays them, and why? This discussion will examine the function and symbolism of wind instruments in various world cultures. Next, some relations between cultures as revealed by the dissemination of wind instruments will be surveyed. Finally, the decorative aspects of wind instruments will be treated. The instruments discussed below as illustrations have been chosen to provide the widest possible sampling of a vast selection.

In primitive cultures. For nonliterate peoples, music often serves purposes other than entertainment or aesthetic enjoyment. Certain wind instruments are closely associated with the supernatural, and their sounds connote powerful magic. Australian Aborigines, for instance, identify the sound of a bull-roarer with the voices of supernatural beings; for the Plains Indians, the same sound signifies an awesome natural phenomenon, such as thunder. Wind instruments are often among a group's most important ritual objects, and in some cultures they are specially venerated. The Kamairua Indians of the Amazon rain forest keep their giant flutes (three to four feet long), wherein spirits are believed to dwell, in a special shrine where they are worshiped. The flutes and drums of New Guinea are similarly housed and worshiped.

Ritual use of wind instruments

Wind instruments in primitive cultures also serve nonreligious functions. In New Guinea, bamboo trumpets were once played to frighten an enemy during battle and to alert a village that the victorious warriors were coming home with the corpses of the foes. Conch-shell trumpets are used for signaling in the Pacific coastal regions of Colombia and in the Ecuadoran highlands. Trumpets also may be associated with the office of king or chief, as in West Africa, where their use is strictly controlled by tribal law.

A variety of wind instruments in primitive cultures are used for personal amusement, and some are known to accompany vocal performance and dance. For example, the didgeridoo of the Australian Aborigines, which is found across the northern coastal areas from west to east, supplies introductions, interludes, and conclusions, as well as accompaniments for the singing of songmen and their clapping sticks; it also provides intricate aural counterparts to the foot movements of dancers. The player's technique, which involves both blowing and singing into the instrument, is very elaborate.

It is common in primitive cultures for musical instruments to have symbolic significance. The form of an instrument or its decoration may relate to tribal myths, as do North Pacific coast whistles carved in the shapes of birds and African ivory horns stained with human blood. Wind instruments in particular often have sexual connotations. Among the Tucano Indians of Colombia, the number of tubes on a set of panpipes depends on the age of the male performer and the development of his sexual organ. Boys between five and nine years of age play instruments with only three pipes, while men's panpipes have eight or nine. Wind instruments are also made to resemble the male and female sexual organs. The phallic shape of flutes, which are played exclusively by men in many primitive cultures, is self-evident. Instruments reserved for women are often round or curved and may bear associations with the Moon or water. (Oceans respond to tides, tides to the Moon; the Moon marks the female menstrual cycle.) No symbolism is universal, however, and an instrument's sexual connotations may conflict: for example, a conch shell, which by its shape and derivation from a water animal is female, is generally made into a trumpet, usually considered a male instrument.

Symbolic associations of wind music

Not only the shapes but also the sounds of primitive instruments are often rich in symbolism. The sound of the flute, for example, is widely associated with love magic. Among the tribes of the northeast and Great Plains of North America, young men played the flute to serenade young women; in New Guinea, flutes and flute music are connected with rites of sexual initiation. In some cultures, instrument symbolism is highly developed. For the Tucano Indians of Colombia, instrument sounds constitute a symbolic taxonomy comprising three levels: whistling, vibration, and percussion. The whistling of a flute connotes sexual invitation, while vibration, represented by such instruments as the indigenous clarinet and the bull-roarer, symbolizes a warning or threat. Percussive sounds produced by drums and various rattles symbolize the uniting of male and female.

In Asia. In the literate cultures of Asia, wind instruments are used in a variety of social contexts, not least in religious ritual. In Taiwan, the transverse flute (*di*) and free-reed mouth organ (*sheng*) are played in celebrating Confucius' birthday; it is the only surviving music thought to resemble that of ancient Chinese court rituals. The Chinese-inspired ritual music of Japan's Shintō religion likewise employs the flute and mouth organ, along with the oboe (*hichiriki*). In Tibet, the low-pitched chanting of

Buddhist monks is accompanied by a variety of instruments, the most spectacular of which is the long copper *rag-dung*. These straight, conically bored natural horns vary in length from some 5 to 20 feet (1.5 to 6 metres) and are sometimes made in sections that can be telescoped to enhance portability; they provide drones for chanting. The only melodic instrument in Tibetan religious orchestras is the double reed *rgya-gling*, which is used to play preludes and interludes to the chants.

Wind instruments are used in many different ways in Asian classical and folk music (see below *The music of wind instruments*); thus, the distinctions between art and folk instruments are not always clear-cut. In China, for instance, transverse flutes may be played in modern folk ensembles as well as in ritual and local theatre orchestras. This diversity of use has affected manufacture: although flutes are still made in irregular temperaments for traditional music, many are now constructed in equal temperament for use in the concert hall. Folk instruments also have been brought into classical music traditions elsewhere. The *śahnāī* of India, a conical oboe with a metal bell and six to eight finger holes, was traditionally associated with outdoor performance and largely with folk music; it is now played on the concert stage, in mosques, and in temple compounds.

Military use of wind instruments

In western Europe. European society has long valued wind instruments, from their earliest use in rituals down to the present day. In the Carolingian era, signal horns became closely associated with the military and nobility. The oliphant, an end-blown horn made from an elephant tusk, is prominently mentioned in the medieval epic *Song of Roland*. Later, European armies used shawms and straight metal trumpets (*buisines*) to sound military calls and to rally troops in battle, following the practice of Islāmic military bands. Wind instruments may also have been incorporated into medieval liturgical services, although much of the early evidence supporting this is found in religious art and may refer less to ritual practice than to symbolic or allegorical meanings of the instruments depicted.

Wind bands consisting of shawms, trumpets, and trombones were associated in the Renaissance with the nobility, who sought to demonstrate wealth and power in the musical events they sponsored; court documents and pictorial sources testify to the wide use of winds in processions and other ceremonies. Collecting instruments also may have been considered a mark of wealth and prestige, since some nobles assembled enormous collections, in which winds figure prominently. The household inventory of Georg Raymund Fugger of Augsburg, for example, lists about 400 instruments, including 111 flutes. In England, 272 of 381 instruments in Henry VIII's collection were winds.

During the same period, groups of professional wind-instrument players were formed in municipalities across Europe. *Stadtpfeifer*, as these musicians were known in Germany, played for ceremonies, weddings, and sometimes with singers in performances of elaborately scored sacred polyphony. In France during the reign of Louis XIV, the Grande Écurie (an ensemble that provided music for royal occasions) cultivated wind instruments and contained within their group the finest players and wind-instrument makers. At a different level, amateur musicians included the famous English diarist Samuel Pepys, whose love of the recorder was matched only by his devotion to his viol and lute. As public concerts began, contemporaneously with Pepys, the middle classes became further involved in music-making. Among the amateurs of note was Frederick II the Great of Prussia, who hired the German musician and composer Johann Joachim Quantz to teach him the flute. Folk music was still supplied with its share of wind instruments, and in its own milieu many instruments of earlier times are still preserved.

With the passing of patronage from royal establishments to the public, art music found a broader base for support, while amateur music continued to thrive at its own level. The 20th century marks another high point in the cultivation of wind instruments; the quantity of instruments is greater than ever, and technical development has reached new heights, while never before have so many become competent performers.

Dissemination. When an instrument is introduced to a different geographic area, the new instrument that develops there generally retains some connection to its predecessor: a similar name or function, a shared physical characteristic, or an association with a particular social class. Instrument dissemination, then, reflects the relationships between cultures. The dissemination of the *zūrnā*, an oboe found throughout the Arab world, in Turkey, and in parts of Europe and Asia, is a useful illustration.

The *zūrnā* first became known in Islāmic areas, where it emerged from a synthesis of earlier types from Iran, Mesopotamia, Syria, and Anatolia. In its basic, four-piece form, with flared body, reed, staple, and pirouette (a disk or cylinder that partly covers the reed), it spread rapidly to lands conquered by the Arabs. It also was known by the 12th century in western Europe (shawm) and later in the Balkan region (*zurla*). With the spread of Islām, the *zūrnā* was introduced from the Middle East and Persia to India, Southeast Asia, and China. The Persian *surnāy* (or *surnā*), for instance, became the *sānāyī* of northern India and the *so-na* (*suona*) of China. The latter contrasts with the indigenous Han Chinese oboe (*guan*), which has a short cylindrical tube that does not overblow at the octave.

First used as a signaling instrument in military bands, the Arabs later employed the *zūrnā* for a variety of functions: to greet important persons, to mark the beginnings of pilgrimages, and to accompany other ceremonies. Some of these functions were spread along with the instrument. Thus, the *zūrnā* was heard at funerals in the Arab world, as well as in Armenia and Sri Lanka. Other extramusical associations suggest different cultural connections: the *sarunai* of Malaysia, for example, was used mainly for shadow puppet plays, as the *zūrnā* had been employed in the Turkish shadow theatre. Today the *zūrnā* survives as a folk instrument in Islāmic areas and other regions, including Greece, Cyprus, and Armenia. It is used mainly in festive village music and is played in small ensembles by members of the lowest social classes.

Craftsmanship. The high value placed upon musical instruments within a culture is generally reflected in their craftsmanship. Instruments of a primitive society, for example, may be decorated with symbolic designs; more technologically advanced cultures may provide elaborate inlay and elegant carving.

The Chinese *so-na*

The form of a wind instrument may itself be decorative. The symmetry of the *so-na*, a Chinese oboe whose conical shaft terminates in a bell section of brass, is reminiscent of a pagoda. The tube of the instrument is gracefully indented for each finger hole, leaving the impression of a series of diminishing concentric circles, which are capped by the small brass pirouette and a short reed. The related Arabic *surnāy* may be decorated with inlay. In Europe in the Middle Ages, the oliphant was highly prized not only for the ivory from which it was made but also for its sometimes elaborate carvings.

Similar, if less striking, attention to design is encountered in European woodwinds. The bulges that typify the profile of the Baroque oboe and recorder are at once utilitarian (they reinforce the joints of the instruments) and artistic. The addition of ivory rings at the joints added to their beauty. Among the more fantastic and ingenious specimens of woodwinds are certain flutes and clarinets of the late 18th and 19th centuries made as functional walking sticks.

Undecorated brass instruments with their graceful curves demand little additional garnishment; yet even these graceful instruments were frequently embellished with engraving on the rim of the bell or on the bell itself, particularly by the famous Nürnberg makers of the 17th and 18th centuries. Seams and joints in the brass tubing were often reinforced by ornate but functional metal tubes and rings (sleeves and pommels). The most elaborate and fantastic decorations, possibly inspired by the Chinese, emerged in the Renaissance, when unusual brass instruments were commissioned for ostentatious dramatic performances intended for royalty and their guests. Trumpets were made in the shape of dragons, the bell of these (and other) instruments being transformed into the dragon's head. At times a tongue was even inserted to vibrate when the instrument

was blown, and fishlike scales were painted on the outside. Such extravagances appeared sporadically in the following centuries, especially in late 19th-century Italy. Elaborate key mechanisms have inhibited decoration in woodwinds in the 20th century, and makers of brasses have generally been satisfied with the beauty of the functional design of their instruments.

THE HISTORY OF WESTERN WIND INSTRUMENTS

Contributions of Curt Sachs

In the study of musical instruments the name of Curt Sachs looms so large that, despite the studies made since his death in 1959, no one has yet achieved his eminence in the field of musical instruments. The origins of musical instruments extend to prehistoric times, and frequently only fantastic legends survive; yet, by combining information from anthropology, history, and linguistics, Sachs made discoveries, developed theories, and drew conclusions that have stimulated much research in and given purpose to the entire field. Much of the following material leans on his research and perception.

Early history. The sources of information are often nebulous. In a few instances, actual instruments have been preserved for thousands of years. Many depictions of instruments remain, but few give accurate detail. Legend and written records reveal other facts. Finally, among the instruments of contemporary primitive civilizations, those of some non-Western cultures, and those of folk cultures are some that have not changed basically in thousands of years. The study of what information is available reveals many facts and allows much plausible speculation when facts are obscure.

There are many conjectures concerning the origin of wind instruments, and, since they are found widely scattered over the face of the Earth, it is quite likely that the process of vibrating the lips against a hole in a branch, a bone, a shell, an animal horn, or a tusk may have been discovered independently in many early cultures. Their origin may, in fact, have transcended even the first lip buzzing. Many primitive cultures employ these same mediums as masks with which to disguise the voice in magical or religious rites; their use as musical instruments appears to have been an afterthought. Such megaphones are still used today in as widely dissimilar cultures as those of Switzerland and the Brazilian Indians. The conch shell, the most frequent of marine shells used to produce sound, probably began its service to music as a voice distorter, later to become an effective trumpet.

Trumpets. Bamboo, cane, and the limbs or trunks of trees form other materials for primitive trumpets. The Australian didgeridoo, for instance, can be made from either cane or, more frequently, a eucalyptus branch, often hollowed out by termites. From the New Kingdom of Egypt in the tomb of King Tutankhamen (d. *c.* 1350 BC) was found the earliest specimen of a silver trumpet. Later the *salpinx*, also a straight trumpet, was known in Greece. A beautiful specimen made of 13 fitted sections of ivory with a bronze bell (Museum of Fine Arts, Boston) is ascribed to the 5th century BC. The Roman equivalent, the tuba, was bronze and reached Rome from the Etruscans.

Another Roman trumpet was the *lituus*, a J-shaped instrument whose immediate origin was also Etruscan. Its inspiration, visible in its earliest examples, was a simple hollow cane with a cow horn for a bell. Similar instruments are also found in China, where the *cha chiao* adds a shallow and flat mouthpiece to the same basic design. Another long trumpet of Rome was the cornu, which was curved to a G-shape for portability and braced crosswise for carrying over the shoulder.

Horns. As ancient as the trumpet is the natural horn, which was derived from an animal horn or a tusk. With the multifarious species of horned animals, the African countries achieved a rich variety of shapes, sizes, and pitches. The earliest and the most progressive horns were end-blown, but many side-blown horns remain in use even today, particularly in Africa.

The shofar

The shofar deserves special mention, for it has served the Jewish religion since the beginning of historic times and is now retained for Rosh Hashana (New Year's) and Yom Kippur (Day of Atonement) in most congregations. The instrument is merely a goat's or ram's horn, flattened and bent in a steaming process. The various ritual blasts use the second and third partial only, and its mighty sound was considered efficacious in reaching the ear of Yahweh.

The Roman version of the animal horn was the *buccina*, which was originally an ox's horn, sometimes supplied with a mouthpiece. Although ostensibly the *buccina* was a shepherd's instrument, it had a bronze counterpart that was suitably decorated for use in the Roman army.

More impressive, however, were the *lurer* (singular *lur*), the early bronze horns of the Scandinavians. Conical and shaped in pairs, like the curves of mammoth tusks, they have a funnel-shaped mouthpiece and end in a flat studded disk. Although their origin was once thought to have been as early as 3000 BC, 1600 to 1000 BC now appears more likely. The line of development would appear to have passed from metal-studded animal horns to the impressive bronze pieces, many of which have been excavated in Denmark. The effective mouthpiece allowed production of tones to the 11th or 12th partial, but it appears unlikely that these unusual instruments had much influence on later European horns.

Flutes. Flutes were ubiquitous in antiquity. In early depictions they are sometimes confused with reedpipes. Their most primitive forms have already been mentioned. In early historical periods they were known in Sumer and Egypt, and in the latter country specimens have been found in tombs, excellently preserved through the centuries by the arid climate. The Egyptian flute is vertical, about a yard long and a half-inch wide, and is easily end-blown because of its narrow embouchure. Near the lower end there are two to six finger holes. The instruments still exist today and are known by the Persian name *nāy*. In Greece panpipes, undoubtedly derived from the more sophisticated Chinese instruments, were shepherds' instruments. A series of graduated closed-end tubes were bound like a raft and end-blown.

The idea of the hydraulos, a water organ, may have stemmed from the multitubed panpipe. Its main development appears to have been around Alexandria from the 3rd century BC. Air under hydraulic pressure activated the pipes as controlled by an elementary keyboard. The tone was reported to be loud and penetrating. Despite the invention of pneumatic power, the hydraulus lasted at least through the 5th century AD.

The ancient Egyptian clarinet

Reedpipes. Egypt also made clarinets, instruments composed of two canes with three sides of a rectangle cut obliquely in the upper end of the two single reeds. The term idioglottic is used to describe a reed cut from the tube itself. From four to six equidistant finger holes are cut in each cane, and blowing with the entire reed engulfed in the mouth cavity produces a pungent, tremulous sound. The slight deviation of pitch between the two tubes creates the beats that cause the tremolo. (The device was rediscovered and copied in organ pipes late in the 15th century in Germany.) Sachs noted a double clarinet on a relief dated 2700 BC in the Egyptian Museum in Cairo. The same instrument is known today as *zummārah* wherever Islāmic civilization flourished; and closely related instruments—the *arghūl* of the Middle East, which has one long drone pipe and one short fingered pipe, and the *launeddas* of Sardinia, which consists of three pipes—also preserve the same shrill, reedy sound that must have been characteristic four centuries ago.

The New Kingdom (1567–1085 BC) yields the Egyptian oboe, known only as *mat*, the generic name of pipes. Like the flute, the oboes were made of narrow cane but were about two feet long; and, like the clarinet, they were blown in pairs, the left playing a drone while the right fingered a melody. Such instruments with their rich, penetrating sound have been known through the ages under various names and shapes. Their effect has long been considered intoxicating. The Greek version of the double reed was the aulos. The two divergent narrow pipes activated by a large reed would create a loud, pungent sound highly prized by the Greeks. Probably no wind instrument has received as much praise over such an extended period of time.

Developments in the Middle Ages. Western society in the Middle Ages went through crises that created decisive

changes in music and musical instruments. Except for the *tibia,* which was the Roman equivalent of the aulos, Rome showed little interest in Greek instruments, preferring the more powerful brasses that could be heard in such spectacular events as those given at the Colosseum. So Greek music dissolved, and its instruments dispersed to the countryside. The invasions of migratory tribes began in AD 150, culminating in the fall of Rome in AD 476 and continuing long past that date. With Greek and Roman culture in decline, the migratory peoples might have established their own music; but they brought few musical instruments. The Christians, who controlled the Roman Empire after the conversion of the emperor Constantine (AD 312), had little love for the musical instruments associated with earlier persecutions. Folk instruments, of course, remained, and such documents as the Utrecht Psalter (*c.* 830; Utrecht, Library of the State University) contain drawings showing instruments, but there is little to indicate a flourishing musical culture. The great centres of learning in general as well as the cultivation of music and the playing of instruments remained in the Middle East.

Influence of Islām on medieval musical instruments

The most significant movement affecting the history of medieval musical instruments was the spread of Islām in the 7th and the first half of the 8th centuries, by which time it had arrived at its maximum expansion—west across Africa as far as southern Spain, south down the coast of eastern Africa to Madagascar, and east through Persia, northern India, and Indochina to Indonesia and the southernmost Philippine Islands. The Christians began pushing back the Muslims in the 9th and 10th centuries in Spain, Sicily, and Sardinia. In addition to this most obvious contact, the trade routes brought continuous Muslim products into the European cities engaged in Eastern commerce, especially Venice, Genoa, and Pisa; and from the late 11th to the early 13th centuries the Crusades took Christians to Muslim homelands, where they further absorbed Middle Eastern ideas and customs. Finally, a slower, less dramatic route existed across the Balkans and to the north, by which musical instruments drifted from the Middle East or Byzantium into the countries of northern Europe and on west to Iceland. Neither the Christians nor the Muslims attained their political or religious objectives in their conflicts, but the stimulation of the progressive civilization of the Muslims nevertheless had a profound effect in Europe.

In the 13th-century Spanish manuscript of the *Cantigas de Santa Maria,* illuminations depict Muslims in their own costumes playing their instruments next to Christians, who are playing closely related specimens. If the West had not had strength and some tradition, Western music today might not differ significantly from that of the Middle East. Instead, the West modified the instruments and developed them in special ways. The Eastern melody and drone, combined with rhythm, were retained through the period and, indeed, to this day in much of Western folk music. The development of polyphony forced changes in many musical instruments. With voice parts covering much the same general range, each instrument had to possess a distinctive colour and a power of penetration to delineate its musical part.

Among the earlier instruments, the animal horn remained, often decorated and even provided with holes to allow the production of melody but leaving little evidence that it contributed to cultured music. The trumpet in the mid-14th century was bent back upon itself in the shape of a very flat S, making it easier to hold and carry. The peculiar idiom of the trumpet limited it mostly to fanfares and signals, however; it was only occasionally joined with other wind instruments.

As with the trumpet, other important woodwind instruments of the Middle Ages did not appear until the Gothic period. The vertical flute, single and double, came from the Middle East and remains today in the Balkans. A single short pipe, always associated with the drum (tabor), still persists in the Basque regions of Spain and France. Too narrow to sound the fundamental, the pipe needs only two finger holes and a thumbhole to complete its scale, and it can thus be played with the left hand alone, freeing the right hand to beat the tabor and leaving the legs free to dance. The transverse flute moved from the Byzantine Empire to Germany in the late Middle Ages. Although associated with the fiddle during the Minnesinger period of the 12th and 13th centuries, it became linked with the drum and military music in the form of the fife.

A folk clarinet, often double, used a cow horn for a bell and occasionally a second cow horn to provide a wind chamber around the reed. Known as the hornpipe in England, the instrument is called by various names from Wales along the Mediterranean to India. It may also appear with the reeds enclosed in a calabash (*magudi* or *pungi* of India) or in sheep's bladder (bladder pipe).

Origin of the bagpipe

Ostensibly, the bagpipe appears to have been a development of the simpler enclosed reed instruments, but actually the bagpipe was known to Rome (Latin *utriculus*), where it was presumably a recent import from Asia in the 1st century AD. The bag was formed originally from the entire hide of a sheep or goat, with the chanter, the pipe with finger holes, fitted into a wooden stock at the neck. When drones are present, they emerge from stocks in the forelegs. A blowpipe is necessary to fill the bag with air, and an arm over the bag provides pressure to activate the pipes. The chanter has seven holes in front and a thumbhole behind.

The pneumatic organ appeared around the 2nd century AD as a portative variety—that is, an organ small enough to be carried. These organs consisted of one or more ranks of flue pipes controlled by a keyboard. To aid portability, the usual two octaves had only the essential chromatic notes. From the Gothic period, portatives were frequently found both in pictures of processions and in seated ensembles. Depictions show the player operating a bellows with his left hand while manipulating the keys with the second and third fingers of his right hand. Various references show the presence of organs of many sizes throughout the Middle Ages. By the 10th century the nonportable positive organ began its distinguished career as the earliest form of church organ.

The Renaissance. The major accomplishment of music in the Renaissance was the emancipation of instrumental from vocal music. As polyphony developed, the two- and three-part music of the 13th century expanded to a norm of four parts in the art music of the 15th century and to five or six parts by the middle of the 16th. Early in this vertical expansion the voice parts were differentiated in range, forming a texture extending to approximately three to three and a half octaves. Apart from the organ, no winds possessed a diatonic range of that size. Furthermore, as the voice parts spread, the penetrating and contrasting quality so advantageous for the crossing parts in medieval music became less desirable. The music of the time then demanded the building of instruments in different sizes for the various parts in order to secure a smooth blend throughout the texture. Such ensembles were called consorts. Wind instruments flourished. At no time in the history of music was the choice of available timbres greater, and within the 16th century as many instruments as possible were built in families. The common sizes, built a fifth apart, were called the treble, tenor, and bass, usually with corresponding pitches in winds of a, d, and G. Flutes and recorders were an octave higher. A descant and a great bass were introduced for music that exceeded the combined range of the standard instruments. Woodwinds, in general, were made in one piece in a plain design, and Venice appears to have been an early centre of wind-instrument manufacture.

The new concept of blending tone quality was applied to the flutes and recorders. Both were made with a relatively large cylindrical bore, which emphasized the low partials. As a result, the upper range was limited, but the effective octave and a half that remained was sufficient for Renaissance music. Since the transverse flute adapted less well to various sizes, it was more often used with other instruments.

Double-reed instruments

Double reeds were particularly numerous during the Renaissance, and in many species the reeds were capped. The best-known of these was the crumhorn (German *Krummhorn*), an instrument of narrow cylindrical bore whose unusual J shape complemented its pungent, buzzy

tone. The reed cap may have been inspired by bladder pipes or bagpipes in which the reed is activated without lip contact. The cap made it impossible for a player to exert lip pressure on the large reed within, so the instrument could not be overblown. Its seven finger holes, one thumbhole, and one upper key gave a range of only nine notes. Nevertheless, the crumhorn consort made an excellent ensemble, and some fine early sets of instruments still survive as testimony.

Other soft-toned capped double reeds, known largely from written descriptions and pictorial sources, are the Italian *cornamusa,* probably little more than a crumhorn without the nonfunctional curved area, and the *dolzaina,* appearing much the same as the *cornamusa.* A loud capped reed was the *schryari,* made in the three principal sizes. The outer shape was inverse conical, but, since no specimens remain, the contour of the bore is unknown.

Shawms were a particularly important family of loud double reeds, with related instruments spread across all Asia. Their wide conical bore, large double reed, and seven front finger holes provided them with a loud, reedy tone, reminiscent of Middle Eastern reed instruments of today. The player could rest his lips on a wooden pirouette into which the reed was inserted and activate the reed without contact in the wind chamber formed in his mouth. Nevertheless, the reed could be controlled if desired, and the instrument was overblown partly through the second octave. Shawms were made in progressive sizes from the small descant in a′ to the great bass in G or F, the latter attaining a length of 8 to 9 feet (about 2½ metres). The power of the shawms enabled them to consort with trombones and to carry well in the outdoor tower music of central European cities.

The more gentle curtal (German *Dulzian;* Italian *fagotto;* French *basson*) was a noncapped double reed with its conical bore doubled back within the same block and ending in a small bell. It was activated by a long, carefully trimmed double reed connected with the instrument proper by a short tube called the *bocal.* Six front finger holes, two thumbholes, and two keys gave it a range of two octaves and a second. First mentioned in 1540, its bass (sometimes called the double curtal in England and the *Choristfagott* in Germany) soon became the most important size, particularly at the beginning of the Baroque period, when it was needed for a bass whenever higher winds were scored. German church composers of the 17th century normally used the *Choristfagott* as a bass for violins and violas as well. The double reeds with doubled back cylindrical bores were an interesting development. The *sordone* (French *courtaut*) was such an instrument, its narrow bore terminating in a side vent near the *bocal.* Most extraordinary was the racket, whose narrow bore went through a cylinder of ivory or wood as many as nine times to make a double-bass instrument from a cylinder length of a few inches. The instrument plays an octave below notation and forms the lowest of the Renaissance winds. The Renaissance reeds that were not adaptable to outdoor music vanished early in the 17th century, except for the curtal. The shawm survived somewhat longer.

The cornett

Another important woodwind was the *cornetto* (an Italian name Anglicized as cornett; also known under its German name, *Zink*), the descendant of the medieval cow's horn with finger holes. The treble cornett in g was made from two pieces of wood, hollowed out and glued together to create a mildly conical tube, usually octagonal and most often curved in the shape of its prototype. A covering of leather, protecting the surface and sealing any leaks, was frequently decorated at the upper end. The cornett was made in larger sizes, but only the descant was widely used.

The trumpet maintained its usefulness as a ceremonial instrument and developed in the direction more fully described in the next section. The trombone blended nicely in consort with cornetts as the treble instrument or in the loud consort in the company of shawms.

The Baroque and Classical periods. Dramatic events in music around 1600 in Italy profoundly affected the music of Europe during the Baroque era. A group of literary men and musicians who called themselves the Camerata gathered in the home of Giovanni Bardi, Count di Vernio, in the last decade of the 16th century to experiment with a type of drama that would use music as an adjunct to poetry. The musical result was the negation of polyphony, the reduction of melody to a position subservient to the text, and the creation of a bass line with improvised accompanying harmony to support the drama in the singing voice, altogether a direct repudiation of the ideals of the Renaissance. A 17th-century Italian composer, Claudio Monteverdi, referred to the style as *seconda prattica* and within his lifetime developed it into a much finer medium than the experimental style he inherited.

The new style greatly affected instrumental practice. Those instruments that could not produce expressive sounds and that could not imitate the passions as represented by the skilled singers were relegated to the middle or lower register of the ensemble, where they could serve either as an inconspicuous background or as a contrasting support for the predominantly expressive melody. If the Renaissance was the era of woodwinds, the Baroque was the era of strings, and the violin family assumed a dominant position throughout both Baroque and Classical periods. Nevertheless, wind instruments were not overlooked, and before the end of the period they were altered in order to compete with the strings. In the meantime, the winds were useful for dance music and municipal music (*i.e.,* for town ceremonies). Particularly in Germany, the loud winds of the Renaissance continued to be used. They maintained their 16th-century functions of being played regularly from towers, and they were always available for music in churches and palaces.

By the early 1730s, however, when J.S. Bach and Handel were producing many of their great works, reaction set in against the presumed pretentiousness of the elaborate Baroque style, and a premium was placed on simplicity and clarity. The importance of the bass line diminished, and the counterpoint, reborn in the 18th-century style, was again abandoned. By mid-century the sentimental style of an ornamented simple melody over an uncomplicated texture of basic tonal harmony had taken over, and it was on this foundation that Haydn and Mozart based their composition of a mature Classical style. Wind instruments of Renaissance type were then preserved only in rural areas or as folk instruments; and the new winds, developed in the 18th century, challenged but never quite captured the supremacy of the strings.

The Baroque opera demanded the depiction of the grand and majestic; so, obviously, the trumpet was important. The instrument was now compactly folded once to reduce seven feet of tube to only a little over two feet of length. The normal keys of the period were D or C, a terminal crook lowering the D instrument when C was desired. The leading trumpeter played in the high or clarino range, which included the pitches of the fourth octave, where the tone was particularly magnificent and where the available diatonic notes permitted the playing of melodies, trills, and various ornaments. Other trumpets played successively lower pitches. The trombone (German *Posaune;* English sackbut; French *saquebute;* Spanish *sacabuche*) was used in opera and church orchestras. By the Baroque period it was made in three sizes—f alto, B♭ tenor, and F bass—sizes that remained in use in Germany through much of the 19th century. The treble cornett gained a new use in the Baroque. Since its range equaled that normally used by the violins in the 17th century, it could substitute for them or contrast them and also effectively contrast the soprano voice. Consequently, it was useful in Monteverdi's opera *Orfeo* (first performed 1607) and in many German church cantatas, as well as instrumental ensembles. Difficult to play, it was extremely treacherous, and to be played with sufficient control it needed not only a good musician but also one with luck. The names of the Renaissance wind instruments are familiar to many music lovers since the Baroque organ adapted so many stops imitating the colour of these instruments. The beating reed adapted in the Renaissance regal was brought into the organ proper and formed a variety of useful colours.

Brass in Baroque opera

Woodwind instruments were far too valuable for their individual tone colours to remain subservient to the ubiquitous violins; and in Paris the musician and instrument

builder Jean Hotteterre, his family and associates all skilled wood turners, redesigned first the oboe and later the recorder, transverse flute, and bassoon—all in the last half of the 17th century. With the advent of these instruments, Renaissance woodwinds gradually vanished. The new instruments were turned in short sections, peculiarly with a broken profile—that is, an unevenly expanding or contracting bore between sections—a feature not long retained.

The oboe. The oboe (French *hautbois*) was first to compete with the violin. The upper register, difficult and incomplete in the shawms, had to be developed. Hotteterre narrowed the bore of the treble shawm, reduced the size of the finger holes, and considerably narrowed the reed, which was attached to a staple and inserted directly into the top section as in the musette. With the pirouette abandoned, the more delicate reed could be carefully controlled by the player and pinched between the lips to produce fast enough vibrations for overblowing. Hotteterre also lowered the customary d′ pitch in descant to c′ by fitting a "butterfly" key at the end—*i.e.,* in two-winged shape to accommodate the little finger of either hand. The oboe was immediately successful; in fact, it became the most favoured woodwind in the 18th century. Its tone was rich and expressive, and its better players could imitate all subtleties and expressive characteristics of highly trained operatic sopranos. A tenor form and a rare bass were not cultivated in art music. After the Renaissance, families of instruments were not generally made, and expressive playing was largely in demand in the soprano range. The English horn, or the alto oboe, was adopted around 1720 but made no great impact. The instrument was curved as a horn in its early form and covered with leather. Bach called it oboe da caccia and used it occasionally for its dark, smooth tone colour.

Success of the oboe

The bassoon. The bassoon underwent far less radical changes in the hands of Hotteterre than the oboe. The former curtal was simply built in four sections and lengthened to produce B♭,. The date of the bassoon's introduction into the orchestra is uncertain since the double-reed instrument in the bass range was frequently taken for granted; but a French composer, Jean-Baptiste Lully, scored specifically for it in 1674. The standard bassoon for most of the 18th century had four keys, but six were common by the end of the century. The range was a remarkable three octaves, although the top b♭′ was available on few bassoons. As with the curtal, whose sound was mellow and obtrusive, the bassoon was praised for its tone and compared to the human voice, the ultimate in contemporaneous praise. Such comments testified to its success in playing expressively; and a considerable solo literature, rare among low-pitched instruments, bears further witness to its flexible melodic capabilities. Its service as a wind bass was indispensable. Some small bassoons, tenoroons and fagottini, were built in the century but remained obscure. More important was the contrabassoon, whose sporadic appearance in score probably reflected on its rarity more than its usefulness.

The flute. The Renaissance recorder blended well in consort but was weak in its upper register and needed modification to meet the demand for an expressive melodic style. The very nature of the instrument, with its lack of lip control, prevented much dynamic control; but the Baroque changes nevertheless went far toward producing an expressive instrument. It is to be remembered that throughout the Baroque period the Italian term *flauto* referred to the recorder; the cross flute was normally called transverso or *flauto traverso* and was so indicated on scores. Although many ambiguous cases exist, the recorder was the type of flute called for in much of Baroque music. The redesigned recorder was built in three sections with an inverse conical bore in the middle and foot. Although the full consort sizes and many others were made, the treble recorder (with a bottom written note of f′; *i.e.,* today's alto recorder) was the principal instrument used for solos and orchestral performance.

Developments in the recorder

The transverse flute was also built in three sections with an inverse conical bore; and this flute as well as the recorder spoke better in the upper register. The E♭ key, as mentioned earlier, was soon added to make the instrument completely chromatic throughout its range (d′ to b♭‴). Intonation on the flute was nevertheless difficult. The necessary cross-fingerings caused a somewhat muffled quality. Consequently, the flute sounded best and its technique was most facile in the key of D. Only rarely did Baroque composers of flute music venture far from the keys in one, two, or three sharps. To alleviate some of these problems and to adapt to the varying pitches at that time, after 1720 the middle section was often divided. Then the flute could be provided with from three to six different lengths for the upper of these sections (*corps de rechange*). In spite of these difficulties, the one-keyed flute had a lovely tone, softer than the modern flute. Keys were soon added to solve difficulties of intonation and tuning. By 1760 some London makers added keys for f′, g♯′, and b♭′, eliminating the usual cross-fingerings in the first octave. By the end of the 18th century, the flute was lengthened and the keys added for c′ and c♯′, thus matching the range of the oboe. The tone quality of the instrument changed little and its versatility improved.

The military fife, which retained the one-piece construction of the Renaissance, remained useful for its limited repertoire, and the piccolo in B♭ or C was only occasionally used.

The clarinet. One of the most significant contributions to Western art music in the 18th century was the addition of the clarinet. The various cane instruments with a single reed and stemming from antiquity still remained in the area around the Mediterranean as folk instruments. Furthermore, the bagpipe had adapted the single-reed pipe as its chanter. The chalumeau, one of these single-reed folk instruments, occasionally emerged into art music, when the two oboists of the orchestra would use chalumeaux to imitate the sound of trumpets. Johann Christoph Denner, the renowned 16th-century recorder maker from Nürnberg, saw the possibilities of the instrument. He made them of boxwood, gave them an attached reed, and doubled their length, achieving a chalumeau register, as it is still called, from f to b♭′. Using the back key as a speaker, the instrument overblows at the 12th, making a clarino register from c′ to f‴. Soon keys for b♭′, c♯″, and e♭″ were added, completing the classical clarinet. These extra keys also produced e, f♯, and a♭ in the so-called chalumeau register, providing a total usable range of three octaves and one note. The clarinet had then emerged. Again, those describing the instrument compared its virtues to the human voice, and the instrument was adopted wherever players were available. Compared to the instruments of today, the cylindrical bore was narrow and the reed smaller to fit the long, narrow mouthpiece. Furthermore, the mouthpiece was inserted so that the reed, attached with cord, was on the upper side of the instrument.

Early clarinets were made largely in C or B♭, sometimes with an A section to use on the B♭ instrument. Small F clarinets were available for use in bands; but, as with the other woodwinds of the time, a pair of treble clarinets were sufficient for the orchestra.

A more important auxiliary instrument than, say, the tenor oboe was the basset horn, which provided an extension of the bore to take the chalumeau range down to c. The untimely demise of the basset horn in the 19th century has been regretted by many, for modern experimentation has shown it to be vastly superior to the alto clarinet in E♭ commonly used in bands.

The basset horn

The French horn. Another major contribution in the 18th century was the emergence of the French horn as an orchestral instrument. Early in the century the tone of the horn was appropriate for its use in signaling during the hunt. By mid-century, the mouthpiece had been altered and the hand inserted in the bell to provide the warm, mellow quality in midrange that Classical composers found so useful. Consequently, much experimentation to increase its usefulness ensued, resulting in the crooks and in hand stopping. Even with its severe limitations, the horn of the Classical period became an essential colour.

The trumpet. After the mid-18th century, high melodic parts in the trumpet appeared less necessary to an aesthetic that spurned the majestic for a simpler style. Trumpets

were built in many keys, but for the most part trumpets in F replaced those in D and C; and the notes of the fourth octave, which were most difficult on the shorter instrument, were abandoned. In short, the complete clarino style disappeared along with those players of the privileged guild who had learned to master that treacherous range. The F trumpet remained standard in Europe through the 19th century.

The Romantic period. In the 19th century the pendulum swung from the restraint of the classic to the expressive. The aesthetic demanded an emphasis on the personal, on the dramatic, and on the passionate. Music responded with modulation to remote keys and required instruments in increased range, more facile technique, and wider dynamic contrast. Obviously, instruments had to be adjusted. Families of instruments again became important, and new tone colours were introduced.

The entire period has sometimes appropriately been called the age of mechanization. Around the first quarter of the century, the period of Beethoven's major orchestral works, more keys were added to existing woodwinds, and evidence from one passage in Beethoven's Ninth Symphony implies that the fourth horn player already had one valve on his instrument. Almost immediately afterward more drastic changes were necessary in order to fulfill the demands of the composers.

The central figure in the changes in woodwinds was a Munich flutist and instrument builder, Theobald Böhm. Profiting by the experiments of many others, Böhm devised the long axle to allow control of holes from some distance and then proceeded to redesign the flute on acoustic principles. Böhm made the holes in his flute as large as possible and changed all closed keys to open keys to allow full venting. He then placed all holes in an acoustically correct position, providing for comfort in fingering by using ring keys on the long axle to close holes that players could not reach easily. At this stage the Böhm conical flute of 1832 appeared. By 1847 Böhm had become convinced that only a cylindrical bore would solve certain problems in intonation, and by using covered finger holes he could make them even larger. The Böhm experiments changed the character of the flute considerably, producing more volume and a more brilliant tone; with his improvements, along with the subsequent minor changes, the flute became one of the most versatile instruments of the orchestra, performing superbly in all keys.

Böhm's innovations in instrument building

Similar changes were made about the mid-century in other woodwinds, the Böhm system (1843) adaptations to the clarinet finally conquering other key arrangements except in Germany. Charles Triébert and his son modified the oboe, finally adding some features from the Böhm flute to produce the "conservatory system." Certain improvements were made in the bassoon in 1825 by Carl Almanräder, a chamber musician of Biebrich. Since the improvements were accompanied by deficiencies in tone, the French preferred to develop the classic bassoon. Although the Heckel family (Johann Adam Heckel and Wilhelm, his son and successor), also of Biebrich, eventually corrected the faults, the difference between the French and the German bassoon still remains, the former having a reedier, more individual tone, the latter with its comparative richness blending better. First the Americans and finally the British accepted the German instrument.

The classic orchestra reached a certain perfection in balance between strings, woodwinds, and brass, which was distorted at the beginning of the 19th century by the addition of two horns and three trombones. From there on, the orchestra grew, and families of instruments again became important for additional colour and for balance. In his *Principles of Orchestration* (1913; written 1896–1908), the Russian composer Nikolay Rimsky-Korsakov developed the theory that the four basic woodwinds had a vast range of expression. At each end of the entire range were areas useful for their individual colour, and the instruments of smaller and larger sizes intensified those colour effects. This theory formed the basis of his orchestration and had profound effects on the art music of the early 20th century, even to the popular hotel dance bands of the 1930s in America.

The piccolo was accepted early, carrying upward and intensifying the brilliance of the top octave of the flute. It remained for the 20th century to exploit the low tones of the piccolo. By the end of the 19th century the alto flute, a weak instrument dynamically, joined the orchestra but was exploited most effectively by the French composers of the early 20th century—for example, Claude Debussy. The oboe developed no satisfactory descant, but the English horn, first used notably in Hector Berlioz's *Roman Carnival Overture* (1844), became increasingly useful for its peculiar dark and melancholy expression. A small clarinet in D (E♭ in wind bands) proved suitable for bright, strident effects, while the bass clarinet added a mysterious piquancy as an extension of the dark and colourful chalumeau register. The contrabassoon gained importance as the most effective wind double bass and the lowest instrument of the orchestra.

Woodwinds of the 19th-century orchestra

Little needs to be added about the trumpet and French horn. By mid-century, valves were established for horns and trumpets, but even through the early works of the 20th-century German composer Richard Strauss these were considered largely as a means for instant transposition of the instrument. At the same time, however, the full chromatic possibilities were exploited by such composers as César Franck and Peter Ilich Tchaikovsky.

Since 1590 a wooden cup-mouthpieced instrument, the serpent, had been built to support voices in French choirs; but by the mid-18th century it was serving as a double bass for the woodwind choir. The serpent and its derivatives, the Russian bassoon and the bass horn, were eventually replaced by the contrabassoon. The ophicleide, the bass of the keyed bugle, was prominent in the second quarter of the 19th century as a brass double bass.

The invention of the bass tuba by a German instrument builder named Johann Gottfried Moritz in 1835 provided a more reliable and more even brass bass. Tuned in F or E♭, its range was, respectively, B♭$_{1}$–e♭^{1} and C–f^{1}. Later a BB♭ (double B-flat) contrabass became available. The tuba was distinguished by a wide conical bore and a deep cup mouthpiece, both of which favoured the fundamental and lower partials. It was built in many sizes to provide a rich and mellow brass choir for the wind band, of which the cornet of similar proportions was the lead melodic instrument, in contrast to the more penetrating trumpet of the orchestra. The flügelhorn, slightly more conical than the cornet, is also an appropriate treble for the tuba family. The tubing of the various instruments could be and was bent in many different shapes. Some even had bells pointing backward in order to send the sound toward marching soldiers in a parade. When the bass instrument was bent into an over-the-shoulder model, it was called a helicon. Later, the American bandmaster John Philip Sousa established his own variation of the helicon, and it became known as the sousaphone.

Also noteworthy are the Wagner tubas, especially built for Richard Wagner's operas *Der Ring des Nibelungen.* Narrower in bore than the baritone horn, they are supplied with a funnel-shaped mouthpiece in order to form a tone intermediate between the French horn and the tuba. Built in tenor and bass ranges, the instruments fulfill their purpose admirably.

The 19th century gave rise to families of reed instruments. The Belgian instrument maker Adolphe Sax patented the saxophone in 1846, combining a wide conical bore with a large single reed and producing an instrument that overblows at the octave and covers a written range of b♭ to f‴. Sax's patent covered instruments in 14 different sizes, and others were added later. Intended for the military band, the saxophone has found only occasional use in the orchestra. It has been used most familiarly in America in jazz ensembles from the 1930s on.

The saxophone

The Chinese *sheng,* which had reached Europe in the late 18th century, inspired the invention of three distinct musical instruments in the West: the mouth organ, the accordion, and the reed organ. It is a mouth organ consisting of free-reed pipes vibrating under wind pressure from a globular wind chamber blown into by the player. The pitch is determined by the reed itself, which activates vibrations in the surrounding air.

The Western mouth organ, invented about 1825, has two reeds of the same pitch, one of which vibrates as the player exhales, the other, as he inhales. The slotted edge that the player puts in his mouth directs air to and from the reeds. Tones are eliminated by covering the slots, so that a skillful player can produce a single pleasant tone at a time. Although a few players have developed a skilled technique, the instrument is normally completely diatonic and is largely confined to folk and popular music.

Invented in 1822 by Friedrich Buschmann of Germany, one of the mouth-organ patenters, and operating on the same principle was the accordion, in which a bellows substitutes for the breath and buttons or keys open channels to free reeds. Melody is controlled by the right hand, the bass and accompanying chords, by the left. Although originally a diatonic instrument, by mid-century it became chromatic. Accordions with keyboard for the right hand have also become popular.

The reed organ dates from about 1810. It was a free-reed instrument with a foot-operated bellows providing wind pressure to vibrate reeds whose access was controlled by a keyboard. The instrument was provided with an assortment of Greek-derived trade names, of which the harmonium appears to be most prominent for those organs operating on the principle of pressure bellows. An instrument operating on sucker bellows was later developed and became especially popular in the United States; in fact, all such suction instruments are commonly known as American organs. In the 19th century the reed organ, mellow in tone and inexpensive, became an important instrument in homes and small churches.

The 20th century. The 20th century began with few radically new ideas in instruments. Many people were still debating the merits of Wagner and Brahms while Richard Strauss, the Impressionists, and the Russian nationalists were each continuing the exploitations of the tone colour and technical capacities of the expanded orchestra. Challenged by these works, instrument makers continued to make minor alterations to solve fingering problems or to produce even tone. For a time the standards of increased size and greater technical capacity were most important, but eventually such works as Arnold Schoenberg's *Pierrot Lunaire* (1912) and Anton von Webern's *Five Pieces for Orchestra* (1911–13) disturbed the overripe late Romanticism, and the emphasis on bigness evaporated. The entire aesthetic became disunified. In general, after the first quarter of the century, ensembles became smaller and an anti-Romantic if not a purely Classical trend was discernible. In instruments, two diverse directions became apparent: (1) a return to the historically accurate sounds for the music of the repertoire and (2) the application of electrical power to do everything from duplicating known tone colours with artificial amplification to the creation of entirely new instruments.

Revival of Baroque woodwinds

With the early music revival came the reproduction of early brasses and woodwinds. Around 1925 an English musician and instrument builder named Arnold Dolmetsch began making Baroque recorders, which had been in eclipse for more than 100 years and which again became one of the most widely played wind instruments. More recently, reproductions of other historical instruments became available, including crumhorns, shawms, *Rauschpfife*, Renaissance flutes and recorders, Baroque transverse flutes, Baroque oboes, and Baroque trombones. The Baroque trumpet was again made, although few trumpeters returned to the valveless eight-foot D trumpet of the period; with a discreet use of narrow bores, shallow mouthpieces, and valves, they obtained trumpets that give the range and character of the clarin trumpet.

As regards the second trend, there has been considerable interest in adapting electronic technology to wind instruments since the early 1970s. Synthesizer control devices that treat the sound of the wind instrument as input to be manipulated electronically have been used successfully, as have synthesizers with breath-operated control. Digital technology permits the "sampling" and manipulation of wind instrument acoustics—in effect, the digital equivalent of a tape playback system (see below *Electronic instruments*). (R.A.Wa./J.M.Bo.)

THE MUSIC OF WIND INSTRUMENTS

In western Europe. The diversity of wind instruments and their musical use in post-antiquity is reflected in medieval literature and art. From this evidence it can be inferred that wind instruments were grouped according to volume of tone—that is, as either loud or soft (*haut* or *bas*). Loud winds—trumpets, shawms, and bagpipes—accompanied outdoor processions and dancing; trumpets also were brought into church to play the sustained lower parts of primarily vocal motets and masses. Soft wind instruments, such as the recorder, transverse flute, cornett, and portative organ, were mostly played indoors and, together with bowed and plucked strings, likely performed instrumental arrangements of songs and motets.

Unmixed consorts in the Renaissance

During the Renaissance, wind instruments were grouped into unmixed consorts whose homogeneous sound derived from the texture of contemporaneous vocal ensembles. (A typical wind consort of the early 16th century comprised three sizes of the same instrument type, usually an alto, two tenors, and a bass; a century later, some winds were made in as many as eight sizes, which, however, were grouped into two different ensembles, one at four-foot, the other at eight-foot pitch.) In addition to polyphonic dance music, these consorts performed arrangements of secular songs such as those published in 1533 by Pierre Attaignant, which bear designations as appropriate for either transverse flutes or recorders. The preference for unmixed consorts was so strong by the late 16th century that even at large musical events involving many musicians, different groups played whole pieces or portions of them in alternation rather than at the same time.

The Baroque period. At certain centres, particularly Venice, it was the practice in the late 16th century to combine and contrast an instrumental consort (mainly winds) with voices in a type of religious composition called the sacred concerto. In the *Sacrae symphoniae* (1597 and 1615) of Giovanni Gabrieli, for example, an ensemble of three cornetts, two trombones, and tenor violin accompanies solo voices, alternates with and accompanies one or two choirs, or performs alone. Gabrieli adopted a similar approach in his instrumental music. His *Sonata pian' e forte* (1597), the first musical composition for which instrumentation is specified, employs two ensembles of equal size—three trombones and cornett; and three trombones and a viola da braccio—sometimes playing together, sometimes separately.

Large ensembles of singers and instrumentalists also were divided into forces of different size. In some sacred concerti of the early Baroque, a large group of supplementary instrumentalists, who doubled the choral parts, was contrasted with instrumental soloists, or concertino (violinists or virtuoso cornettists), who played in dialogue with the vocal soloists. This disposition of instruments, in conjunction with the antiphony perfected by Gabrieli, gave rise to the concerto grosso. Some concerti grossi, notably those of Arcangelo Corelli, employ a solo group made up of two soprano-range instruments and bass, a combination known as "trio sonata" texture that had wide currency in the Baroque era. (While Corelli's trio sonatas were written for strings, a bassoon might virtually double the bass line, and the repertoire as a whole contains works written for wind instruments in one or both of the upper parts.) By the late Baroque, concerti grossi had in effect become concerti for solo instruments. J.S. Bach's *Brandenburg Concertos, Nos. 1, 2, 4 and 5* (pre-1721), which involve extended virtuoso passages for winds, are outstanding examples of this transition.

Programmatic associations of Baroque winds

Before the mid-16th century, instrumentation depended less on tone quality or the composer's preference than on what instruments were available. Winds and strings were largely interchangeable. After that time, however, some wind instruments began to establish their autonomy. In the Florentine *intermedi* (staged musico-dramatic presentations generally based on pastoral or mythological themes), particular winds were associated with particular characters or situations, such as trombones with the netherworld. Many associations established in the *intermedi* were later retained in 17th-century opera, oratorio, and ballet. As members of the violin family displaced

winds as the preferred instruments of Baroque ensembles (both inside and outside the theatre), the theatrical uses of winds became more pronounced and composers increasingly sensitive to their extramusical associations. Also characteristic of Baroque opera and oratorio was the obbligato use of winds in a manner stylistically analogous to writing for solo voice.

The Classical period. The Classical technique of winds doubling strings emerged in scoring for opera orchestras in the mid-17th century and continued to be important through the next century in the compositions of Haydn and Mozart. (Most 18th-century orchestras included at least four winds, usually two oboes and two horns; by the 1770s, Mozart was writing for double flutes, oboes, and bassoons, a brass section of pairs of horns and trumpets, plus timpani and four-part strings.) In effect, this rendered winds less prominent in the texture of the Classical orchestra compared with the Baroque, in which the distinctive sonorities of winds had been used to highlight the different contrapuntal lines. In Classical orchestration, oboes and bassoons generally double the string parts, while brasses reinforce the harmony in relatively slow note values or play idiomatic fanfares and horn calls. Wind instruments did, however, retain their programmatic associations in church music and opera—"magical" instruments in Mozart's *The Magic Flute* (1791; *Die Zauberflöte*) include the flute and piccolo, the latter representing Papageno's reed pipes. They also were used for obbligato accompaniments. Sesto's aria "Parto, parto, ma tu ben mio" from Mozart's *La Clemenza di Tito* (1791; "The Clemency of Titus"), for example, features a basset clarinet obbligato.

In the late Classical period Beethoven's orchestration at first seems a continuation of the conservative Classical practice, with considerable doubling of parts. His use of winds, however, particularly in the symphonies, at times tends toward theatricality bordering on the operatic. Familiar examples are the "false" entrance of the horn before the recapitulation in the first movement of the *Eroica* (1804; *Symphony No. 3 in E Flat Major*), and the oboe solo in the first movement of the *Symphony No. 5 in C Minor* (1808). Beethoven's dramatically charged approach to wind scoring in nominally abstract music profoundly influenced later composers. In such late 19th-century works as Gustav Mahler's first three symphonies and the tone poems of Tchaikovsky and Rimsky-Korsakov, wind parts have strongly connoted extramusical significance.

Another use of winds in the Classical and later periods was in small ensemble music. French Baroque composer Jean-Baptiste Lully anticipated future developments with his marches, a tradition that continued either in the hands of later specialists (Anton Reicha's wind ensembles, John Philip Sousa's marches) or as exceptional works by great masters (the wind quintets of Mozart and Beethoven). Carrying forward Baroque practice, composers in the Classical era also wrote chamber works for mixed ensembles of winds with piano or strings, or wind concerti, such as those for clarinet and bassoon by Mozart. (J.M.Bo.)

The Romantic period. In the 19th century wind instruments underwent extensive improvements, which ultimately led to the expansion and diversification of the woodwind and brass sections of the orchestra. An early advocate of such enrichment was Berlioz, whose *Grand traité d'instrumentation et d'orchestration modernes* (1844; *A Treatise upon Modern Instrumentation and Orchestration*) dealt with the ranges, mechanical problems, and sound qualities of all wind instruments, including newly invented ones. Typical of Berlioz' own compositions, the *Te Deum,* Opus 22, calls for an expanded wind complement of four flutes, four oboes, four clarinets, four horns, four bassoons, alto saxhorn, two trumpets, two cornets, six trombones, and two tubas. Wagner augmented even these large forces in the service of the music drama, quadrupling in the *Ring* orchestra most of the woodwinds and scoring for eight horns (four of which doubled on tenor and bass Wagner tubas), a contrabass tuba, three trumpets and bass trumpet, one contrabass, and three tenor trombones. In the late 19th-century symphony and tone poem, as in opera, the large, variegated orchestra maintained close ties with programmatic or operatic impulses.

Berlioz' treatise on orchestration

Perhaps as a corollary of the expanding use of winds in the Romantic orchestra, the 19th century produced remarkably few concerti for solo winds and orchestra. There was a similar decrease in chamber music for winds. Among the few composers of music for solo winds with piano are Carl Maria von Weber, Robert Schumann, and Johannes Brahms. Brahms also wrote some outstanding chamber works for winds and strings, as did Franz Schubert.

The 20th century. Although the huge symphony orchestra was accommodated for a time in the early 20th century by such composers as Mahler and Igor Stravinsky, two important trends in instrumental music emerged between World Wars I and II. One of these was the ever-growing interest of composers in ensembles consisting predominantly of wind instruments. Stravinsky, for example, composed his *Symphonies of Wind Instruments* in 1920, *Concerto for Piano and Wind Instruments* in 1923–24, and *Symphony of Psalms* in 1930, the orchestration of the last being noteworthy for its lack of violins and violas. The other important trend was a relative increase in the proportion of new music for chamber ensembles, especially those with wind instruments. In this repertoire such composers as Debussy (*Syrinx,* 1912, for flute) and Stravinsky (*Three Pieces for Clarinet,* 1919) extended the level of technique and the range of special effects demanded of wind players. Experimentation continues to the present day, with the electronic amplification of winds and the development of new techniques, such as multiphonics, in which two or more pitches are sounded simultaneously on a single woodwind instrument. (E.J.E./J.M.Bo.)

Jazz. Throughout the 20th century, jazz has been one of the most vital sources of American wind music. The first jazz ensembles to feature solo winds—trumpet or cornet, clarinet, and trombone—were formed in New Orleans in the second decade of the 20th century. In this early style, the soloists either improvised simultaneously or adapted their playing to the musical texture, the clarinet ornamenting the trumpet lead, the trombone filling in the chord notes and outlining the bass notes. By the mid-1920s, however, Louis Armstrong, arguably the most important wind instrumentalist of early jazz, had developed a dramatic solo style that did not depend on ensemble interaction; this style became a model for later jazz soloists. The following decade was the principal era of the "big bands," the best-known being those led by Duke Ellington and Count Basie. During the 1930s and '40s the wind sections of such groups grew from 6 (three reeds, two trumpets, and trombone) to a standard of 13 (five reeds, four trumpets, and four trombones). After World War II, the big bands gradually were supplanted by smaller "bebop" groups, which almost invariably included trumpet and saxophone. The recorded performances of alto saxophonist Charlie Parker, whose improvisational ability is legendary, are still studied and greatly admired. Since the 1960s, jazz musicians, particularly trumpeter Miles Davis, have been among the instrumentalists who are experimenting with new sonorities and—with the aid of electronic technology—forging new links between jazz and the music of the American and European avant-garde. (J.M.Bo.)

Influence of Louis Armstrong

In folk traditions. Wind instruments play an important role in the folk music of many cultures. Most folk music for winds imitates vocal models, such as the folk music for harmonica played by both black and white Americans, the love songs for flute played by Native American men, and the bagpipe music of eastern Europe, which usually consists of richly ornamented versions of local folksongs. (Many kinds of bagpipes are found throughout eastern and western Europe. These vary from the very simple ones found in Hungary, Czechoslovakia, and Poland to the beautifully fashioned instruments with three and four pipes [drones] found in Scotland, Ireland, and the north of England.)

A few types of folk music are idiomatic to wind instruments. In Poland, perhaps because of the proliferation of instruments, including several basic types of flutes and bagpipes, folk music is dominated by instrumental tunes, most of them for dancing. In the Basque region of northern Spain and southwestern France, dances and pro-

cessions are often accompanied by a single musician who plays a three-holed flute with one hand and a six-stringed dulcimer with the other. In certain African instrumental ensembles, percussion instruments sometimes are joined by teams of flute or horn players, each of whom plays a single note whenever it occurs in the melody. The Mbuti of Zaire often use up to six flutes, each playing variations of a different ostinato pattern. (E.J.E./J.M.Bo.)

In Asia. Wind instruments occupy a prominent place in the concert and theatre music of several Asian cultures. In the many regional types of Chinese opera, for example, singing and action are accompanied by a small onstage orchestra. The orchestra of Peking opera, the most widely known type, consists of two sections: percussion, which plays preludes and punctuates the singing and action; and the string and wind ensemble, which accompanies the singing and plays interludes. Winds in the latter group include the *sheng* (mouth organ) and various types of transverse flutes, including the *di*, one of whose seven holes is covered with a reed membrane to produce a distinctive buzzing sound. Many virtuoso solo pieces have since the 1960s been written for the *di*, which, as a result, has become an important concert instrument in Hong Kong and the United States.

The nōkan

In Japan the side-blown flute (*nōkan*), used in the traditional music for nō drama, is the only melody instrument of the nō ensemble (*hayashi*), which also includes the shoulder drum, side drum, and floor drum played with sticks. The *hayashi* mostly plays dance accompaniments, although the flute is also used to mark off sections of the play and to evoke different moods. The *nōkan* is also used in the larger ensemble for Japanese Kabuki theatre. In the Japanese court orchestra, the basic melody instrument is the double-reed *hichiriki*, which frequently is joined by flutes, a mouth organ (*shō*), and percussion.

The instrumental ensembles of Southeast Asia typically include winds. The *pī* oboe, for example, is the only nonpercussive instrument in the *pī phāt* bands of Thailand, which are used in theatre music; the bamboo duct flute (*khlui*) is sometimes substituted for the *pī* in the *pī phāt* when reduced volume is desired and is also played in some other Thai ensembles. Perhaps the most distinctive instrument of Southeast Asia, the free-reed *khāēn* (related to the Chinese *sheng*), is played as a solo instrument or to accompany a singer. (J.M.Bo.)

Electronic instruments

EARLY DEVELOPMENTS IN ELECTRONIC INSTRUMENTS

Precursors of electronic instruments. Electricity was used in the design of musical instruments as early as 1761, when J.B. Delaborde of Paris invented an electric harpsichord. Experimental instruments incorporating solenoids, motors, and other electromechanical elements continued to be invented throughout the 19th century. One of the earliest instruments to generate musical tones by purely electric means was William Duddell's singing arc, in which the rate of pulsation of an exposed electric arc was determined by a resonant circuit consisting of an inductor and a capacitor. Demonstrated in London in 1899, Duddell's instrument was controlled by a keyboard, which enabled the player to change the arc's rate of pulsation, thereby producing distinct musical notes.

The largest, and perhaps most advanced, of early electric instruments was Thaddeus Cahill's Telharmonium. Completed in 1906, this instrument employed large rotary generators to produce alternating electric waveforms, telephone receivers equipped with horns to convert the electric waveforms into sound, and a network of wires to distribute "Telharmonic Music" to subscribers in New York City. Complex and impractical, the Telharmonium nevertheless anticipated electronic organs, synthesizers, and background music technology.

Early electronic instruments. The dawn of electronic technology was marked by the invention of the triode vacuum tube in 1906 by Lee De Forest. The triode gave musical instrument developers unprecedented ability to design circuits that would produce repetitive waveforms (oscillators) and circuits that would strengthen and articulate waveforms that had already been produced (amplifiers). In the time period between World Wars I and II, many new musical instruments using electronic technology were developed. These may be classified as follows:

Classification

1. Instruments that produce vibrations in familiar mechanical ways—the striking of strings with hammers, the bowing or plucking of strings, the activation of reeds—but with the conventional acoustic resonating agent, such as a sounding board, replaced by a pickup system, an amplifier, and a loudspeaker, which enable the performer to modify both the quality and the intensity of the tone. These instruments include electric pianos; electric organs employing vibrating reeds; electric violins, violas, cellos, and basses; and electric guitars, banjos, and mandolins.

2. Instruments that produce waveforms by electric or electronic means but use conventional performer interfaces such as keyboards and fingerboards to articulate the tones. The most successful of these was the Hammond organ, which implemented the same technical principles as the Telharmonium but used tiny rotary generators in conjunction with electronic amplification in place of large, high-power generators. The Hammond organ was placed on the market in 1935, and it remained a commercially important keyboard instrument for more than 40 years. Other, more experimental early electronic keyboard instruments used rotating electrostatic generators, rotating optical disks in conjunction with photoelectric cells, or vacuum-tube oscillators to produce sound.

3. Instruments that were designed for performance in the conventional sense but which implemented novel forms of performer interfaces. Of these, Leon Theremin's theremin (1920), Maurice Martenot's ondes martenot (1928), and Friedrich Trautwein's trautonium (1930) have been widely used. The theremin is played by the motion of the performer's hands in the space around a pair of metal antennas; the ondes martenot player uses the right hand to determine the tone's pitch on a special keyboard while the left hand manipulates a set of buttons and levers to articulate the tone; and the trautonium is played by simultaneously manipulating a fingerboard-like resistance element with one hand and a set of panel controls with the other hand. Composers of the stature of Richard Strauss, Paul Hindemith, Arthur Honegger, Darius Milhaud, Olivier Messiaen, André Jolivet, Edgard Varèse, and Bohuslav Martinů have written for one or more of these instruments.

4. Instruments that were not intended for conventional live performance but instead were designed to read an encoded score automatically. The first of these was the Coupleux-Givelet synthesizer, which the inventors introduced in 1929 at the Paris Exposition. This instrument used a player-piano-like paper roll to "play" electronic circuits that generated the tone waveforms. Unlike a player piano, however, the Coupleux-Givelet instrument provided for control of pitch, tone colour, and loudness, as well as note articulation. The principles of score encoding and sound control embodied in this instrument have become increasingly important to contemporary composers as electronic musical instrument technology has continued to develop.

THE TAPE RECORDER AS A MUSICAL TOOL

The next stage of development in electronic instruments dates from the discovery of magnetic tape recording techniques and their refinement after World War II. These techniques enable the composer to record any sounds whatever on tape and then to manipulate the tape to achieve desired effects. Sounds can be superimposed upon each other (mixed), altered in timbre by means of filters, or reverberated. Repeating sound-patterns can be created by means of tape loops. Tape splicing can be used to rearrange the attack (beginning portion) and decay (ending portion) of a sound or to combine portions of two or more sounds to form striking juxtapositions of sound with arbitrarily great length and complexity. By changing the speed of the tape, wide variations in the pitch and tempo of the recorded material can be effected; by playing the tape backward, a sound's evolution can be reversed. Thus, the composer can exercise precise control over every aspect of his original sound material.

Tape composition techniques

Although Hindemith, Ernst Toch, and others had experimented with it previously, the development of tape music began in earnest in 1948 with the work of Pierre Schaeffer and his associates at the Club d'Essai in Paris, under the auspices of Radio-diffusion et Télévision Française. They called their creations musique concrète—a term emphasizing their choice of a variety of natural sounds as raw material. These sounds were shaped, processed, and then put together (composed) to form a unified artistic whole. The *Symphonie pour un homme seul* ("Symphony for One Man Only"), composed by Schaeffer and his collaborator, Pierre Henry, is one of the landmarks of musique concrète, for it laid the technical and aesthetic foundations for much of the later tape music.

In 1951 a studio for *elektronische Musik* was founded at Cologne, W.Ger., by Herbert Eimert, Werner Meyer-Eppler, and others, under the auspices of the Northwest German Broadcasting Studio. While the composers associated with this studio used many of the same techniques of tape manipulation as did the French group, they favoured electronically generated rather than natural sound sources. In particular, they synthesized complex tones from sine waveforms, which are pure tones with no overtones. Certain compositions of Karlheinz Stockhausen, such as the *Gesang der Jünglinge* (*Song of Youth*), are illustrative of the resources available in the Cologne studio.

(Ca.G./R.A.M.)

POST-WORLD WAR II ELECTRONIC INSTRUMENTS

Advances in electronic technology during World War II were applied to electronic instrument design in the late 1940s and '50s. The Hammond Solovox, Constant Martin's Clavioline, and Georges Jenny's Ondioline are examples of commercially produced monophonic (capable of generating only one note at a time) electronic instruments. These instruments used small keyboards and were designed to mount immediately under the keyboard of a piano. They were capable of simulating a wide variety of traditional orchestral timbres, which the player selected by setting an array of tablet-shaped switches along the front of the instrument.

Also during this postwar period, electronic organs became one of the largest segments of the musical instrument industry. These multikeyboard, polyphonic (chord-playing) instruments were first modeled after traditional pipe organs, but they later evolved into a new class of musical instruments for domestic use. The electronic home organ offered a variety of timbres, which were oriented toward popular music, as well as such performance assists as automatic rhythm production, easily enabling it to replace the player piano in popularity.

Score-reading instruments

Instruments capable of reading and performing encoded scores were developed during the 1940s and '50s. Unlike commercial keyboard-controlled organs and related instruments, the score-reading instruments were large, experimentally oriented devices. One example, the Hanert Electrical Orchestra, built in 1944–45 by John Hanert at the Hammond Instrument Co. in Chicago, consisted of a roomful of electronic tone-generating equipment controlled by an elaborate, motor-driven scanner. The scanner, which was mounted on a carriage that rolled along a 60-foot table, read an encoded score that was drawn on cardboard cards that covered the table. Another, somewhat more advanced score-reading instrument was the RCA Electronic Music Synthesizer, designed by Harry Olson and Herbert Belar at RCA Laboratories at Princeton, N.J., U.S. The RCA synthesizer was capable of producing four musical tones simultaneously. Pitches, tone colours, vibrato intensities, envelope shapes, and portamento of the four tones were encoded in binary form on a perforated paper roll. The perforations, which the composer made with a special typewriter-like keyboard, specified the sounds' properties for every $1/30$ second, thus enabling the composer to produce musical changes faster and more precisely than traditional musicians are capable of playing. Two RCA synthesizers were built; the second (called the Mark II) was installed in 1959 at the Columbia-Princeton Electronic Music Center in New York City and was used extensively by Milton Babbitt and several other composers.

The development of tape music as a compositional medium, the advancement of the technology of score-reading music systems, and the commercial proliferation of electronic organs and other keyboard-controlled electronic instruments all set the stage for the appearance of the electronic music synthesizer in the 1960s. Other contributing factors were the advancement of electronic technology itself and the domination of popular music by the electric guitar and other amplified instruments.

THE ELECTRONIC MUSIC SYNTHESIZER

The word synthesize means to produce by combining separate elements. Thus, synthesized sound is sound that a musician builds from component elements. A synthesized sound may resemble a traditional acoustic musical timbre, or it may be completely novel and original. One characteristic is common to all synthesized music, however: the sound qualities themselves, as well as the relationships among the sounds, have been "designed," or "composed," by a musician. The notions that synthesized music is intended to imitate a more traditional entity and that synthesized music is generated by automated, mechanical means without control by a musician are generally not true.

A traditional musical instrument is a collection of acoustic elements whose interrelationships are fixed by the instrument builder. Thus, for instance, a violin consists of four strings (the vibrating elements) which are positioned over a fingerboard (playing surface) and coupled through the bridge to the instrument's body (acoustic resonator). The violinist brings the strings into contact with the fingerboard and a bow to cause the strings to vibrate; but he does not change the position of the strings relative to the bridge, the position of the bridge relative to the body, or the configuration of the body itself.

A synthesist, on the other hand, views his instrument as a collection of parts that he configures to produce the desired timbre and response. This is often called "programming," or "patching," and may be done before or during performance. The elements, or parts, that a synthesist works with depend on the design of the instruments that he is using. Generally, synthesizers include oscillators (to generate repetitive waveforms), mixers (to combine waveforms), filters (to increase the strength of some overtones while reducing the strength of others), and amplifiers (to shape the loudness contours of the sounds). Other sound-producing and -processing elements, which can exist as electronic circuits or as built-in computer programs, may also be available. To facilitate the musical control of these elements, a synthesizer may have any combination of a conventional keyboard; other manual control devices, such as wheels, sliders, or joysticks; electronic pattern generators; or a computer interface.

Synthesizer components

The appearance of high-quality, low-cost silicon transistors in the early 1960s enabled electronic instrument designers to incorporate all the basic synthesizer features in relatively small, convenient instruments. The Synket, built by the Italian engineer Paolo Ketoff in 1962, was designed for live performance of experimental music. It had three small, closely spaced, touch-sensitive keyboards, each of which controlled a single tone. Its foremost exponent was John Eaton, who concertized widely on his Synket throughout the 1960s and '70s, performing his own compositions.

The synthesizers of the Americans Donald Buchla and Robert Moog were introduced in 1964. These instruments differed primarily in the control interfaces they offered. The Buchla instruments did not feature keyboards with movable keys; instead, they had touch-sensitive contact pads that could be used to initiate sounds and sound patterns. Buchla's instruments were widely employed by experimental composers, especially Morton Subotnik, whose compositions *Silver Apples of the Moon* (1966), *The Wild Bull* (1967), and *Sidewinder* (1970) appeared on long-playing records.

Moog's instruments featured conventional keyboards as well as other control devices, which enabled them to be used more easily in the performance of traditional music. *Switched-on Bach,* the music of J.S. Bach transcribed for

Moog synthesizer and recorded by Walter Carlos and Benjamin Folkman in 1968, achieved a dramatic commercial success. In the years following the appearance of *Switched-on Bach,* many synthesizer recordings of traditional and popular music appeared, and synthesizer music was frequently heard in movie soundtracks and advertising commercials. Throughout the 1970s, commercial electronic-instrument manufacturers produced smaller, more convenient versions of Buchla's and Moog's designs, and these were widely used by keyboard musicians in the popular music idioms.

Analog and digital synthesizers

Most electronic music synthesizers that were designed before 1980 are called analog synthesizers, because their circuits directly produce electric waveforms that are analogous to the sound waveforms of acoustic instruments. This is in contrast to digital synthesizers and music systems, the circuits of which produce series of numbers that must then be converted to waveforms. The first digital music synthesis systems were general-purpose computers.

THE COMPUTER AS A MUSICAL TOOL

The direct synthesis of sound by computer was first described in 1961 by Max Mathews and coworkers at the Bell Telephone Laboratories, Murray Hill, N.J., U.S. Computer sound synthesis involves the description of a sound waveform as a sequence of numbers representing the instantaneous amplitudes of the wave over very small successive intervals of time. The waveform itself is then generated by the process of digital-to-analog conversion, in which first the numbers are converted to voltage steps in sequence and then the steps are smoothed to produce the final waveform.

Unlike the electronic music synthesizers of the 1960s and '70s, in which electronic circuits performed specific waveform generation and processing functions, computer-based music composition systems are capable of performing any function that can be described as a computational procedure, or algorithm. The algorithm is written by a composer or programmer as a series of instructions that are stored in digital media (*i.e.,* punched cards, magnetic tape, or magnetic disks) and "loaded" into the computer when the music is to be realized. The composer then also writes a score that specifies properties of the individual sound events that make up the composition.

A great variety of sound-synthesis and music-composition algorithms have been developed at research institutions around the world. Music V, created in 1967–68, is the most widely used sound-synthesis program to have been developed at Bell Laboratories. Music V consists of computer models of oscillator and amplifier modules, plus procedures for establishing interactions among the modules. Another widely used synthesis algorithm is Frequency Modulation (FM) Synthesis. Described by John Chowning of Stanford University (Palo Alto, Calif., U.S.) in 1973, FM produces a wide variety of complex timbres by rapidly varying the frequency of one waveform in proportion to the amplitude of another waveform.

FM Synthesis

As computer technology developed and computers became more powerful and less expensive during the 1970s and '80s, the flexibility and sound-production capability of computer-based music systems attracted an increasing proportion of experimental music composers. By the end of the 1980s, computer music systems surpassed tape studio techniques and analog synthesizers as the electronic composition medium of choice among modern and experimental music composers.

DIGITAL SYNTHESIZERS, THE MUSIC WORKSTATION, AND MIDI

Digital synthesizers. During the 1980s, commercial electronic instrument manufacturers introduced many performance-oriented keyboard instruments that used digital computer technology in combination with built-in sound-synthesis algorithms. One of the earliest and best-known of these was the Yamaha DX-7, which was based on the results of Chowning's research in FM Synthesis. Introduced in 1983, the DX-7 was polyphonic, had a five-octave touch-sensitive keyboard, and offered a wide choice of timbres, which the player could adjust or change to suit his requirements. Well over 100,000 DX-7s were sold, and Yamaha adapted their FM technology to a line of instruments ranging from portable, toylike keyboards to rack-mounted modules for studio and experimental use. Another important early digital synthesizer was the Casio CZ-101, a battery-powered four-voice keyboard instrument using simple algorithms that were modeled after the capabilities of analog synthesizers. The CZ-101 was introduced in 1984 at a price approximately one-quarter that of the DX-7 and achieved widespread popularity.

Sampling instruments; music workstations. A sound waveform from a microphone or tape recorder can be digitized, or converted to a sequence of numbers that is the digital representation of the waveform. Instruments that enable a musician to digitize a sound waveform and then process it and play it back under musical control are called sampling instruments. The first commercial sampling instrument was the Fairlight Computer Musical Instrument (CMI), developed in Sydney, Australia, during the late 1970s. The Fairlight CMI was a general-purpose computer with peripheral devices that allowed the musician to digitize sounds, store them, and then play them back from a keyboard. The instrument was sold with programs that enabled the musician both to synthesize sound "from scratch" and to manipulate digitized sound using techniques that were developed in tape studios.

The Fairlight CMI

In 1980 Roger Linn introduced the Linn Drum, an instrument containing digitized percussion sounds that could be played in patterns determined by the musician. In 1984 Raymond Kurzweil introduced the Kurzweil 250, a keyboard-controlled instrument containing digitally encoded representations of grand piano, strings, and many other orchestral timbres. Both the Linn and the Kurzweil instruments were intended for composition as well as for performance, since they contained digital memories into which the musician could enter a score.

By the end of the 1980s, many instrument manufacturers had combined the technologies of the digital computer, digital sound synthesis, and sampling (digital sound recording) into integrated composition and sound-processing systems called music workstations. The Synclavier series, manufactured by New England Digital Corp. since 1976, is representative of this class of instruments.

Musical Instrument Digital Interface. In 1983 several commercial instrument manufacturers agreed on a way of interconnecting instruments so that they could work together or in conjunction with a personal computer. The resultant specification, called Musical Instrument Digital Interface (MIDI), has become universally accepted by musicians and instrument builders. MIDI embodies the means for transmitting commands that tell which notes are being played, what timbre is desired, what nuances are being produced, and so forth. With a personal computer and the appropriate software (programs), MIDI-equipped instruments are capable of performing as a system similar to the larger music workstations. By the end of the 1980s, MIDI systems had become very popular with amateur as well as professional musicians. (R.A.M.)

ASSESSMENT

Electronic instruments have contributed to a tremendous expansion of musical resources. Their increasing sophistication has made available to the composer a palette of sounds ranging from pure tones at one extreme to the most complex sonic structures at the other. In addition, it has made possible the rhythmic organization of music to a degree of subtlety and complexity previously unattainable. One consequence of the use of electronic instruments has been the wide acceptance of a new definition of music as organized sound. Another consequence is the acceptance of the notion that the composer may communicate directly with an audience without the need for a performer as interpreter. Yet another consequence is the democratization of both experimental and traditional music composition through the availability of high-quality, reasonably priced instruments and computer software.

Some observers have felt that the elimination of the performer as interpreter, while it may enable the composer to realize perfectly his intentions, is nevertheless a serious

loss. Performance, it is argued, is a creative discipline complementary to that of composition itself, and varieties of interpretation add richness to the musical experience; moreover, the physical presence of the performer infuses drama into what would be otherwise a purely aural, intellectual, and, by implication, somewhat lifeless event. But in fact many compositions for electronic instruments may be performed live with virtuosity and drama. With contemporary electronic instrument technology, the composer is free to choose whether or not the creative contribution of a performer will serve his artistic goals.

(Ca.G./R.A.M.)

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(E.A.Bo./T.Gr./La.L./J.M.Bo./R.A.M.)

Mystery Religions

Mystery religions were secret cults of the Greco-Roman world that offered to individuals a way to feel religious experiences not provided by the official public religions. They originated in tribal ceremonies that were performed by primitive peoples in many parts of the world. But, whereas in these tribal communities almost every member of the clan or the village was initiated, initiation in Greece became a matter of personal choice. The mystery religions reached their peak of popularity in the first three centuries AD; at that time an individual could choose among many religions of this type. Their origin, however, goes back to the earlier centuries of Greek history.

Etymologically, the word mystery is derived from the Greek verb *myein* ("to close"), referring to the lips and the eyes. Mysteries were always secret cults into which a person had to be "initiated" (taken in). The initiate was called *mystēs*, the introducing person *mystagōgos* (leader of the *mystēs*). The leaders of the cults included the *hierophantēs* ("revealer of holy things") and the *dadouchos* ("torch-bearer"). The constitutive features of a mystery society were common meals, dances, and ceremonies, especially initiation rites. These common experiences strengthened the bonds of each cult.

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HISTORY

Hellenic roots. *Dionysiac.* In every Greek city the god Dionysus was worshipped by fraternities and sororities and also by mixed communities. Dionysus was a god of fruitfulness and vegetation but especially of wine. The Dionysiac festivals provided an opportunity for stepping outside of the daily routine. The festivals included not only drinking wine and engaging in sexual activity but also participating in such significant features of Greek civilization as choral singing and mimes. In many cases, only the initiated could participate in the ceremonies. As almost every Greek did join in, initiation into the Dionysiac cult might be compared to tribal initiations. It seems that initiation into the Dionysiac Mysteries was accompanied by initiation into sexual life. The act of producing offspring, however, could never be wholly separated from the thought of death, so that the worshippers of Dionysus were aware of a mystic communion among the ancestors, the living generation, and the future members of the community.

Eleusinian. The most important sanctuary of Demeter (Ceres), the goddess of grain, and her daughter Kore (Persephone) was in the city of Eleusis in Attica, between Athens and Megara. Famous religious agricultural festivals—known as the Greater and the Lesser Eleusinian Mysteries—celebrating the sowing, sprouting, and reaping of the grain, were reenacted in this city. The cycle of the grain, pictured in the myth of Kore (Persephone), was thought to be parallel to the cycle of man. The myth, as told in the Homeric hymn to Demeter, tells how Hades (Pluto, or Pluton), god of the netherworld, wanted a wife and how he carried off Kore into the depths of the earth. Her mother, Demeter, through long days of searching, during which she came to Eleusis, refused to make the grain grow. Finally, Hades was bidden to send Kore back to earth. She came back to light as the grain maiden and gave birth to her son Plutus (Kore, "the maiden"; Pluton, "the rich one"; Plutus, "wealth," especially in grain). But, because Kore had eaten a pomegranate seed, a symbol of death and birth, she could not be completely released, and a compromise was reached by which she spent one-third of the year with her husband, the rest with her mother. Satisfied with this, Demeter caused grain to grow again and taught the Eleusinians her rites. The entire story of Demeter and Kore was elaborately reenacted in the Eleusinian ceremony. Just as in the myth Kore was carried away to marry Hades and to give birth to Plutus, so was grain thrown into the field and buried in the earth to bring forth new life. Just as grain came up out of the ground and was reaped to yield man's bread and to be used as seed, so was a girl taken from her parents and her virginity "killed" to bring forth new offspring. And when a man died, he was buried in the earth to partake mystically in the cyclic renewal of life. This was the message of Eleusis: out of every grave new life grows—for the initiates there are "good hopes" for a glorious immortality in the afterlife.

The myth of Kore

Although there were festivals of Demeter throughout Greece, the true Eleusinian Mysteries were celebrated at Eleusis only. At first, the cult of Demeter was local and initiation was tribal rather than personal. By participating in the mysteries, a man became a full member of the civic body. This was changed when Eleusis was annexed to the Athenian territory about 600 BC. Initiation lost its importance as a means of conferring civic status; it became a purely religious ceremony. Every Athenian was admitted to the Eleusinian Mysteries, and soon the mysteries were open to every Greek, so that the ceremonies received an "international" character. Whoever wished to be initiated, however, had to go to Eleusis. It was a day's journey from Athens, a longer distance from most of the other Greek cities. The mystery rite became no longer a tribal ceremony. Each person had to decide for himself whether or not he wanted to be initiated. This development was possible only because Athens had become a large city with a differentiated culture that gave the individual ample choice of a way of life, including religion.

Meaning of the Dionysiac and Eleusinian mysteries

Both Dionysiac and Eleusinian mysteries had a wide range of meaning. Their essence was not contained in any written record but only in the festivals themselves—the holy days of the community. Many participants appreciated only the superficial level of the ceremonies and considered them as an opportunity for having a good time—good company, good food, intoxication, and sometimes (in the Dionysiac cult) sexual pleasures. The ceremonies were open to a deeper understanding, however, that was not made explicit by any theology or by any set of creeds but by the religious action itself, which contained the meaning and conveyed it to the participants without the interposition of words. Therefore, it was not possible to disclose to the noninitiated the mysteries by words, but it was treachery to reveal the secret dances.

Secular mystery communities. A society of initiates could drop its religious connections and become merely a social club. But because secrecy, common meals, and common drinking were implied, the Greeks and Romans regarded such clubs as mystery societies; they did not differentiate between religious associations and private clubs.

The role of aristocratic clubs in Athenian politics was very important. In 415 BC the famous mystery scandal occurred. Several aristocratic societies conspired to overthrow the Athenian democracy. In order to pledge all members, a common crime was committed in which each member had to participate. One night the members of the social clubs took hammers and removed the genitals of the many Hermes statues in the city. Whoever would desert the common political cause would be denounced by his former friends for having committed a crime against religion, and many witnesses against him would be at hand. The people of Athens immediately understood that a conspiracy was developing. By a series of severe trials, the conspirators were traced and exiled. The speech of the orator Andocides, one of the conspirators, delivered in his defense in 400 or 399 BC, when the old affair was again taken up in a trial, still survives. The title of the oration is "On the Mysteries."

The secular mystery clubs continued throughout Greek and Roman history, and it was often difficult to distinguish them from religious associations. The Romans were especially distrustful of secret societies. This suspicion was justified in the case of Catiline, who led a conspiracy that attempted to overthrow the government in 63 BC. But Trajan, the Roman emperor from AD 98 to 117, did not allow the citizens of Nicomedia (modern İzmit, Turkey) to form a club that planned to provide a fire brigade, and he only reluctantly allowed the citizens of Amisus (modern Samsun, Turkey) to establish an association for charitable purposes.

Orphic. Besides community initiations, there were ceremonies for individual persons of deeper religious longing. Such persons were called Orphics after Orpheus, the Greek hero with superhuman musical skills who was supposedly the author of sacred writings; these writings were called the Orphic rhapsodies and they dealt with such subjects as purification and the afterlife. It is possible to reconstruct a common pattern for these initiations of individuals, although an Orphic "church" never existed, and the doctrines of the many small communities of individualists varied on a broad scale.

The Orphic sense of sin

Many Orphics seem to have had a strong feeling of sin and guilt. They believed that there was a divine part in man—his soul—but it was wrapped up in the body, and man's task was to liberate the soul from the body. This could be achieved by living an Orphic life, which included abstinence from meat, wine, and sexual intercourse. After death the soul would be judged. If a man had lived a righteous life, his soul would be sent to the meadows of the blessed in Elysium; but, if he had committed misdeeds, his soul would be punished in various ways and perhaps sent to hell. Following a period of reward or punishment, the soul would be incarnated in a new body. Only a soul that had lived a pious life three times could be liberated from the cycle.

Pythagoreans. The Orphic creeds were the basis of the Pythagorean brotherhood, which flourished in southern Italy beginning in the 6th century BC. The Pythagoreans were aristocratic fraternities that sometimes had a political scope. Their main achievements, however, lay in the fields of music, geometry, and astronomy. They discovered that these subjects could be explained by numbers and ratios. Combining Orphic eschatology (the study of the last things, especially death and afterlife) with their discoveries, they invested music, geometry, and astronomy with religious values. According to their doctrine, the original home of the soul was in the stars. From there it fell down to earth and associated with the body. Thus, man was a stranger on the earth, and he had to strive to liberate himself from the ties of the flesh and return to the soul's celestial home.

Platonists. The philosophy of Plato (*c.* 428–348 or 347 BC) by no means resulted from connections with a mystery cult. Yet Plato did take up many ideas from earlier Greek religion, especially from the Pythagorean brotherhood and from the Eleusinian communities, and often described his philosophy in terms derived from the mysteries. For example, the notion of searching and finding, so important in Eleusis, became an important notion in Plato's philosophy: the philosopher should never cease or relax in his quest for truth. A value was thus attached to the very act of searching. Later mystery religions, in their turn, borrowed freely from the rich imagery of Plato's dialogues and are thus deeply tinged with Platonism.

Plato's theory of the soul

In the *Timaeus,* which is an exposition of his theory of the universe, Plato also developed his theory of the soul. The earth is surrounded by the spheres of the seven planets; the eighth sphere is that of the fixed stars. Beyond the eighth sphere is the realm of the divine. The sphere of the fixed stars, moved by the divine, continuously turns to the right at an even speed. This clockwise rotation affects the spheres of the planets, although they have their proper movement, which runs to the left, or counterclockwise. The sphere of mortality begins with the planets. The original home of each soul is in one of the fixed stars. As a result of the movement of the spheres, the soul falls through the planetary spheres to earth, where it is united with the body. The soul must then try to liberate itself from the body and ascend to the fixed star from which it fell. In later generations this picture was vividly worked out. The soul, in the course of its fall through the planetary spheres, was thought to acquire the qualities of the planets: sloth from Saturn, combativeness from Mars, lust for power from Jupiter, voluptuousness from Venus, greed from Mercury. After death, when the soul returned to the fixed star, it discarded these qualities, just as the *mystēs,* in certain initiations, discarded his everyday garment before entering the sacred place.

Many other traditional religious images were taken over by Plato, including the music of the spheres, the migration of the soul, the soul's remembrance of its celestial origin, and the idea of rewards for the righteous and punishment for the wicked. Later mystery associations adopted these concepts, which Plato had expressed so beautifully, and were deeply influenced by Plato's explanations.

The Hellenistic period. When Alexander the Great conquered the Asiatic kingdoms as far east as the Indus River, the Greek world was extended immensely. The religious ideas in Greece itself and the western part of the Alexandrian Empire, however, changed very slowly, because the Greeks, now masters of the world, felt no need for change.

In the Messenian town of Andania mysteries were celebrated in honour of the goddesses Demeter and Kore. A long inscription of 92 BC gives elaborate directions for the conduct of the rites, although, naturally, it gives no details of what went on during initiation. The mysteries in honour of the Cabeiri (gods of fertility) on the island of Samothrace attracted great attention in this period. These gods were thought to be helpers of the seafarers, and initiation into their mysteries was looked upon as a general safeguard against all misfortune but particularly against shipwreck. The Dionysiac Mysteries, with their revels and merriment, continued throughout the whole of Greek history. Together with most of the elements of Greek civilization, this cult was transferred to Italy. In 186 BC a scandal about the Bacchanalia—the Latin name for the Hellenistic Dionysiac Mysteries—so upset the Romans that a decree of the Senate prohibited them throughout Italy, except in certain special cases. These mysteries were celebrated in a lower middle class milieu and involved gross sex parties and violence conducted under the cover of mystery secrecy.

Hellenistic Mysteries in the Greek Orient

The important developments in the mystery rites during the Hellenistic period took place in the Greek Orient, where elements from the Greek and Oriental religions were blended. Contact with Greek civilization completely changed life in the Orient, where the knowledge of writing had been confined to a few priests and scribes. Society first disintegrated after the conquest of Alexander and then developed along new lines. Changes in religion were inevitable, and some influence of Oriental traditions upon the Greeks was bound to follow. But the process was a slow one and became manifest only a few centuries later.

With regard to the institution of kingship, however, syncretism worked quickly. Ancient Near Eastern kingship was originally sacral. The Syrian and Egyptian inhabitants of the newly created Greek kingdoms inevitably regarded the Greco-Macedonian kings as semidivine beings. The

Greeks themselves soon submitted to this mixture of politics and religion. Such a mixture was perfectly natural to the Egyptians and Syrians, who did not perceive the structure of society as an abstraction, such as "the state" or "the nation," but saw the unity of the body politic in the person of the king. He was the symbol of the security and help that man derives from an orderly society. Mystery rituals, called royal mysteries, were developed especially in Egypt. According to traditional Egyptian religion, the ruling pharaoh was an incarnation of Horus (the sun-god), his mother or wife an incarnation of Isis (the heavenly queen), and his deceased father an incarnation of Osiris (the god of fertility). In Hellenistic times, Osiris was commonly known by the name Sarapis. These gods became equated with Greek gods: Isis with Demeter and Aphrodite; Horus with Apollo and Helios; Sarapis with Zeus, Dionysus, and Hades (Pluto). Both Greek and Egyptian myths were adopted for these divinities.

One of the suburbs of Alexandria, the newly constructed Greek capital of Egypt, was called Eleusis after the city of Demeter in Greece, and the Eleusinian Mysteries were instituted in a Greco-Egyptian adaptation. Dionysiac Mysteries were introduced on an even greater scale, so that the royal court was temporarily thrown into turmoil by the number of Bacchic ceremonies in which the king was considered to be a reincarnation of Dionysus. The Pythagorean concept of the migration of the soul was also taken over and was blended with the Egyptian belief in the reincarnation of the sun-god Horus in the reigning king.

The cult of rulers thus introduced ideas from the Greek Orient into Greek communities. But the mixture of religion and politics was a great obstacle for the propagation of the Greco-Oriental mysteries in the Mediterranean world. Even the numerous Greeks who lived in Egypt and Syria maintained the traditional Greek concept of the separation of god and man, and it was only after the political aspect of the mysteries was discarded that the religious elements could gain a life of their own. Inscriptions discovered on the Greek island of Delos demonstrate this well. The worship of Sarapis was introduced at Delos during the time the island was temporarily a naval base of the Greco-Egyptian kings. When the Egyptian influence on the island receded, the cult of Sarapis not only remained but reached new heights. The Romans later used Delos as a free port for the eastern part of the Mediterranean, and from there the worship of Sarapis and Isis spread to most of the harbours of the Greek world and to the cities in the Bay of Naples, whence it was brought by Italian merchants to Rome.

The combination of mystery elements with ruler worship is also evident in the kingdom of Commagene (eastern Turkey and northern Syria). Here, the kings assigned large funds to construct throughout the country gigantic sanctuaries, where festivals of the gods and the royal ancestors were celebrated annually on the kings' anniversary days. Long inscriptions discovered in the remains of these sanctuaries bear striking similarities to the language of the mysteries. The ceremonies, however, seem to have contained little true religion.

Roman imperial times. The great period of the mystery religions began when the Romans imposed peace upon the Mediterranean world. The Dionysiac, or Bacchic, societies flourished in the whole empire—in Greece proper, on the Greek islands, in Asia Minor, along the Danube River, and especially in Italy and at Rome. Hundreds of inscriptions attest to Bacchic Mysteries. In some circles, Orphic and Dionysiac ideas were blended, as in the community that met in the underground basilica near the Porta Maggiore (Major Gate) at Rome. There was also a blend of ideas in the community for which the Orphic hymns were written. The members of this community (probably in Asia Minor) assembled at night in a clubhouse and held their services by the light of torches. Their rite consisted of a bloodless sacrifice and included the use of incense, prayer, and hymns. In addition to the mystery cults that were familiar from earlier times, the national religions of the peoples of the Greek Orient in their Hellenized versions began to spread. A faintly exotic flavour surrounded these religions and made them particularly attractive to the Greeks and Romans. The most popular of the Oriental mysteries was the cult of Isis. It was already in vogue at Rome in the time of the emperor Augustus, at the beginning of the Christian era. The Emperor, who wanted to restore the genuine Roman religious traditions, disliked the Oriental influences. But men of reputation, such as Messalla, a general and patron of writers, were strongly inclined toward the Isis Mysteries. Isis, the goddess of love, was the patroness of many of the elegant Roman courtesans. The religion of Isis became widespread in Italy during the 1st and 2nd centuries AD. To a certain extent, the expansion of Judaism and Christianity over the Roman world coincided with the expansion of the Egyptian cults.

Mysteries from Asia Minor

Far less important was the influence of cults from Asia Minor. By 200 BC the Great Mother of the Gods (Magna Mater) and her consort Attis were introduced into the Roman pantheon and were considered as Roman gods. Their cult seems to have been encouraged especially under Emperor Claudius about AD 50. The Great Mother was characterized by her universal motherhood, especially over wild nature. The mysteries symbolized, through her relationship to Attis, the relations of Mother Earth to her children and were intended to impress upon the *mystēs* the subjective certainty of having been united in a special way with the goddess. There was a strong element of hope for an afterlife in this cult. The Persian god Mithra (Mithras), the god of light, was introduced much later, probably not before the 2nd century. The cult of Mithra was concerned with the origin of life from a sacred bull that was caught and then sacrificed by Mithra. According to Persian sources, the bull by its death gave birth to the sky, the planets, the earth, the animals, and the plants; thus Mithra became the creator of life. From Syria came the worship of several deities, of which Jupiter Heliopolitanus (the local god of Heliopolis; modern Ba'labakk, Lebanon) and Jupiter Dolichenus (the local god of Doliche in Commagene; modern Dülük, Turkey) were the most important. Adonis (a god of vegetation) of Byblos (in modern Lebanon) had long been familiar to the Greeks and was often considered to be closely related to Osiris; the myths and rituals of the two gods were similar. Adonis' female partner was Atargatis (Astarte), whom the Greeks identified with Aphrodite. At the time of Emperor Marcus Aurelius, in the latter half of the 2nd century AD, a pseudo-prophet named Alexander the Paphlagonian devised a great mystery spectacle centred around a holy snake called Glycon and had great success during his lifetime.

The height of Syrian influence was in the 3rd century AD when Sol, the Syrian sun god, was on the verge of becoming the chief god of the Roman Empire. He was introduced into Rome by the emperor Elagabalus (Heliogabalus) in about AD 220, and by about AD 240 Pythian Games (*i.e.*, festivals of the sun god Apollo Helios) were instituted in many cities of the empire. The emperor Aurelian (270–275) elevated Sol to the highest rank among the gods. Sanctuaries of Sol and the gods of other planets (*septizonium*) were constructed. Even the emperor Constantine the Great, some 50 years later, wavered between Sol and Christ. For some time his religious policy was devised so as to allow the coexistence of both religions. Finally, Christianity was accepted as the official religion.

The different mystery religions were not exclusive of one another, but they appealed to different sociological groups. The middle class of the Greek and Roman cities preferred the Dionysiac societies, the festivals of which were a cult of beauty and merriment. Isis was worshipped by lower middle class people in the seaports and trading towns. The followers of the Great Mother in Italy were principally craftsmen. Mithra was the god of soldiers and of imperial officials and freedmen. There were no special societies for slaves; but they were usually admitted to the societies, and, during the time of the festival, all men were considered equal.

BELIEFS AND PRACTICES

Common features in Roman imperial times. For the first three centuries of the Christian Era, the different mystery religions existed side-by-side in the Roman Empire. They had all developed out of local and national cults and later

Mysteries fostered by new social conditions in the Roman Empire

became cosmopolitan and international. The mystery religions would never have developed and expanded as they did, however, without the new social conditions brought about by the unification of the Mediterranean world by the Romans. In the large cities and seaports, men from the remotest parts of the empire flocked together. Many people were removed from their accustomed surroundings and suffered from loneliness. They longed for new acquaintances and for assimilation, and they needed the assurance that only the knowledge of belonging to a community can give. Economic and political conditions in the Roman Empire also accelerated the growth of the mysteries. Members of a mystery society helped one another. For a lawyer, a craftsman, or a contractor, membership in a club could be the road to success. Furthermore, there is less opportunity for private initiative in a society ruled by a monarch than in a democratic society. The individual who felt that his initiative was frustrated by the preponderance of the imperial structure might well turn to a community that offered him the hope of a better future. The mystery societies, thus, commonly satisfied both a taste for individualism and a longing for brotherhood. At least in principle, the members of the communities were considered equal: one man was the other man's brother, irrespective of his origin, social rank, or nationality.

Because membership in each of the mystery communities was a matter of personal choice, propaganda and missionary work were inevitable. In the religions of Isis and Mithra, missionary zeal was particularly obvious. The followers of Isis and Mithra considered Rome to be the centre of their worship, and the city was called *sacrosancta civitas* ("sacred city") in an Isis romance written in the 2nd century AD by the Latin author Apuleius.

Priesthood. The organization of the mystery religions was rather loose. The priests of Dionysus were wealthy laymen, as the priests in Greece always were. The Roman community of the Great Mother had a large group of priests (the *galli*), headed by a chief priest (the *Archigallus*). They were eunuchs who wore female garb, who kept their hair long and perfumed with ointment, and who celebrated the goddess' rites with wild music and dancing until their frenzied excitement found its culmination in self-scourging, self-laceration, or exhaustion. Besides the priests there were priestesses and many minor officials. The followers were organized according to their function in the ritual procession as bearers of the tree (*dendrophori*) or bearers of the reed (*cannophori*). The men who carried the statue in the rites of Jupiter Dolichenus were called the sedan-chair men (*lecticarii*).

The higher grades of the Isis Mysteries were reserved to persons born of the priest caste of Egypt. To be born into this caste was more important than talent or skill. This limited the quality of the priests and was a serious disadvantage in the community's competition with other religions. But a second way of advancement within the religious group was devised for men of Greek or Roman origin. In Egypt, there was a group of elevated laymen—the porters of the holy shrine (*pastophori*). They were inferior in rank to everyone of the priest caste; but in Greek and Roman countries the rank of the *pastophori* became a surrogate for the native priest caste of Egypt. The *pastophori* were, in fact, the religious leaders of the communities.

Rites and festivals. A period of preparation preceded the initiation in each of the mysteries. In the Isis religion, for example, a period of 11 days of fasting, including abstinence from meat, wine, and sexual activity, was required before the ceremony. The candidates were segregated from the common folk in special apartments in the holy precinct of the community centre; they were called "the chastely living ones" (*hagneuontes*).

In all the mystery religions the candidates swore an oath of secrecy; the oath of the Isis Mysteries is preserved on papyrus. Before initiation, a confession of sins was expected. The candidate sometimes told at length the story of the faults of his life up to the point of his baptism, which was commonly a part of the initiation ceremony, and the community of devotees listened to the confession. It was believed that the rite of baptism would wash away all the candidate's sins, and, from that point on, his life would be changed for the better, because he had enrolled himself in the service of the saviour god.

In the Mithraic ceremonies, there were seven degrees of initiations: Corax (Raven), Nymphus (Bridegroom), Miles (Soldier), Leo (Lion), Perses (Persian), Heliodromus (Courier of the Sun), and Pater (Father). Those in the lowest ranks, certainly the Corax, were the servants of the community during the sacred meal of bread and water that formed part of the rite.

Initiation ceremonies

The initiation ceremonies usually mimed death and resurrection. This was done in the most extravagant manner. In some ceremonies, candidates were buried or shut up in a sarcophagus; they were even symbolically deprived of their entrails and mummified (an animal's belly with entrails was prepared for the ceremony). Alternatively, the candidates were symbolically drowned or decapitated. In imitation of the Orphic myth of Dionysus Zagreus, a rite was held in which the heart of a victim, supposedly a human child, was roasted and distributed among the participants to be eaten.

The baptism could be either by water or by fire, and the rites often included actions that had an exotic flavour. Sulfur torches were used during the baptism ceremony; they were dipped into water and then—contrary to the expectations of the observers—burned when drawn out of the water. In a dark room a script would suddenly become visible on a wall that had been prepared accordingly. Instructions still exist for producing a nimbus effect—the appearance of light around the head of a priest. The priest's head was shaved and prepared with a protective ointment; then a circular metal receptacle for alcohol was fixed on his head; it was set aflame in a dark room and would shine for some seconds. In the Dionysus and Isis mysteries, the initiation was sometimes accomplished by a "sacred marriage," a sacral copulation. Two cases are known in which a priest speaking from the statue of the god ordered a credulous woman to come to the temple and be the god's concubine, the part of the god being enacted by the priest.

The initiation ceremonies were usually accompanied by music and dance and often included a large cast of actors. In the Dionysiac societies, especially elaborate provisions were made for mimic representations. The names of the sacred roles varied from place to place; among the roles were: Dionysus and Ariadne (a vegetation goddess and wife of Dionysus), Palaemon (a marine deity), Aphrodite (the goddess of love and beauty), Proteurhythmos (the inventor of elegant rhythm), the "foster-father of Dionysus," Kore, Demeter, Asclepius (the god of medicine), Pan (the god of flocks and shepherds), Curetes (long-haired youths), nymphs (minor nature goddesses), shepherds, sileni and satyrs (creatures of the wild, part man and part beast), maenads (female attendants who shared in the nocturnal orgiastic rites of Dionysus), the "guardian of the grotto," and centaurs (a race of beings half man and half horse).

The ceremonies always contained a prayer for the welfare of the emperor and for the good fortune of the whole Roman Empire. In fact, the amalgamation of religion and politics was sometimes so close that the designation "imperial mysteries" is used. The pattern of imperial mystery ceremonies could vary widely. This was especially true of the Dionysiac rites. In the clubs of the upper middle class and wealthy, for example, the festivals were chiefly social events. But the members of these communities were grateful for the security and peace and for the opportunity to make a good living that the emperor guaranteed to them. They felt loyalty toward the Roman Empire and expressed this by ceremonies of the imperial mysteries.

Dionysus was the patron god of the important international society of actors, and their reunions were celebrated in the mode of Dionysiac Mysteries. When an emperor travelled in the empire, responsibility for dignified receptions of him was handed over to the society of actors. Because his route was known beforehand, a voyage of the emperor was turned into a series of pompous festivals that were organized in a manner closely resembling mystery ceremonies.

The meetings of the mystery clubs were often named af-

ter the common meal. The Dionysiac meetings were called *stibas* ("straw") because the participants ate their dinner sitting on straw. The meals of the followers of Sarapis and Attis were called *klinē* ("couch"), because the diners lay on couches.

Festivals connected with agriculture

Seasonal festivals. The religions of Dionysus and Demeter and of Isis and the Great Mother had something of an ecclesiastical year. The seasonal festivals were inherited from old tribal ceremonies that had been closely associated with the sowing and reaping of corn and with the production of wine. The dates varied greatly according to the geographical conditions and the emphasis of the seasonal rites in the country in which the mysteries had originated. Dionysiac festivals were held in all four seasons; vintage and tasting of the new wine were the most important occasions. But the religion of Dionysus was closely associated with that of Demeter, and, thus, sowing and reaping were also celebrated in Dionysiac festivals. In the religion of the Great Mother, a hilarious spring festival celebrating the renewal of life was enacted in Rome.

The festivals of the Isis religion were connected with the three Egyptian seasons caused by the cycle of the Nile River (inundation, sowing, and reaping). About July 19, when the whole country was almost desiccated by the heat and the drought, the high waters of the new flood miraculously arrived from Ethiopia. On that day, just before sunrise, Sirius (the Dog Star, or the star of Isis) would make its first appearance of the season on the horizon. This was the sacred New Year's Day for the Egyptians, and the festival of the Nile flood was their greatest festival. There were, in addition, the festivals of sowing and reaping. But because the Egyptian year was a solar year of 365 days without intercalation (leap years), the seasonal festivals that were fixed upon a particular date were retarded by one day every four years and complete confusion resulted. The Romans fixed the calendar of Egypt by introducing an intercalary day every fourth year. In Roman times, important Isis festivals were held on December 25, January 6, and March 5. The March festival, as it was celebrated in Corinth, is described at length in Apuleius' *Metamorphoses,* or *The Golden Ass.* It was a spring festival that celebrated the beginning of the seafaring season. A ship was carried on a cart (*carrus navalis*) through the city. It was followed by a procession of choruses, candidates, *mystai* in bright clothes wearing masks, and priests carrying the insignia of the goddess. The ship was let into the sea, and the participants returned to the temple, where initiation ceremonies, banquets, and dances were held.

In the religion of Sol, the festivals were determined by astronomy. The greatest festival was held on December 24–25, at the time of the winter solstice. Because from this date the length of the day began to increase, it was regarded as the day of the rebirth of the god and of the renovation of life.

Literature. The mystery communities had religious hymns, but almost nothing of them has been preserved. The initial words of some hymns from the Sta. Prisca Mithraeum in Rome are known, and some Isiac poems exist. More important is a text of 40 sentences in which the goddess Isis reveals herself; it was found at four different and geographically distant places and was probably exhibited in every Isis sanctuary. Narratives of the miracles wrought by the gods were preserved in many temple libraries; examples of these narratives, on papyrus and on stone, have been found. According to a recent theory, the literary genre of the romance was developed from these narratives. The last part of the *Metamorphoses* of Apuleius is an Isis text and narrates in detail the initiation into the Egyptian mysteries.

Hermetic writings and *Chaldean Oracles*

Hermes Trismegistos, the Greek name for the Egyptian god Thoth, was the reputed author of treatises that have been preserved. Thoth was the scribe of the gods, the inventor of writing, and the patron of all the arts dependent upon writing; he was sometimes thought of as an attendant of Isis and sometimes as the repository of all wisdom. These treatises are not exactly mystery texts, but they are works of revelation on occult subjects and on theology. Because the pagan mysteries had no official creed, each congregation of initiates was free to construct a theology of its own and to change it again. The Hermetic writings were attempts to provide a theology for a particular community. Although no authorized interpretation could exist for a doctrine that was in constant fluctuation and although none of the Hermetic treatises could claim to be the correct interpretation of the pagan mysteries, nevertheless, the texts give an instructive picture of spiritual life in mystery communities.

There are some contemporary texts that shed light on the mystery communities. Plutarch, the Greek biographer, wrote the philosophical treatise "About Isis and Osiris," which gives an interpretation of the Isis Mysteries. Arnobius, a 3rd-century Christian apologist, described an interesting semiphilosophical, semireligious mystery community known as the *viri novi* ("the new men"). Arnobius seems to have lived among them in North Africa for a time before his conversion to Christianity. They had a religious doctrine of the soul, with marked affinities to the teachings of the Neoplatonic thinkers Plotinus and Porphyry.

Only fragments are preserved of the *Chaldean Oracles,* a theosophical text in verse that was composed by Julianus the Theurgist and his son late in the 2nd century AD and had great influence on the Neoplatonists. The work combined Platonic elements with Persian or Babylonian creeds and was regarded by the later Neoplatonists as their basic religious book, something of a heathen bible. The doctrine of the *Chaldean Oracles* was associated with esoteric fire rituals. Julianus and his followers were called theurgists—*i.e.,* men who could perform divine operations. Their religion was partly one of meditation about the hidden and wondrous magical processes within the cosmos.

Theology. The creeds of the mystery religions were never worked out to the same extent that the Christian creeds were. Nevertheless, the doctrines of the mysteries may be called a theology. One of the central subjects in mystery writings was cosmogony—the theory of the origin or creation of the world. In the Hermetic treatises, in the *Chaldean Oracles,* and in the little known writings of Mithraism, the cosmogony was modelled after Plato's *Timaeus,* and it always dealt with the creation of the soul and with the soul's subsequent fate.

The myth of the soul

The theological doctrine of the soul and the myth about its celestial home, its fall, and its redemption were inseparable. The sequence is beautifully told in the "Hymn of the Soul," preserved in the *Acts of Thomas,* an apocryphal account of the journeys and death of the apostle. The hero of the hymn, who represents the soul of man, is born in the Eastern (the yonder) Kingdom; immediately after his birth, he is sent by his parents on a pilgrimage into the world with instructions to take a pearl from the mouth of a dragon in the sea. Instead of wearing his heavenly garment, he dresses in earthly clothes, eats earthly food, and forgets his task. Then his parents send a letter to rouse him. As soon as he has read the letter, he awakes and remembers his task, takes the pearl, and begins the homeward journey. On the way, his brother (the Redeemer) comes to accompany him and leads him back home to his father's palace in the east. This myth is a figurative representation of the theological doctrine of the soul's fall and its return to heaven.

Many of the questions that were the subject of later Christian theological discussions were already eagerly debated in the mystery religions. In a Hermetic treatise, for example, the existence of God was proved from the evident order of the world. This argument, which had first been formulated by Zoroaster, a 7th-century Iranian prophet, was expressed in the form of questions: Who could have created the heavens and the stars, the sun and the moon, except God? Who could have made wind, water, fire, and earth (the elements), the seasons of the year, the crops, the animals, and man, except God?

Passionate debates were held about the question of whether man was subject to blind fate. The Stoics (proponents of a Greek and Roman school of philosophy holding that men should be free from passion and calmly accept all occurrences as unavoidable) had adopted the doctrine that all events are determined by the stars. Thus, for many Greeks and Romans astrology became the only

sensible method of studying man's life and fortune. But for others the idea that man could achieve nothing by his own will was frightening, and they wanted to be liberated from this fear; the mystery religions promised to liberate them. The theology of the mystery religions admitted that the stars ruled the world and especially that the planets had evil influences. But the highest god of the religion (for example, Sarapis in the Isis Mysteries) stood far above the stars and was their master. A man who decided to become a servant of this god stepped out of the circle of determination and entered into the sphere of liberty. The god could suspend determination, because he ruled over the stars; he could unravel the threads of the Moirai (the three spinners of fate); he could save his servant from illness and prolong his life, even against the will of fate. In the Isis Mysteries there was a theology of grace foreshadowing Christian doctrine.

In many of the mystery cults, there was a marked tendency toward henotheism—the worship of one god without denying the existence of other gods. Thus, Isis was the essence of all pagan goddesses; Sarapis was the name uniting the gods Zeus, Pluto, Dionysus, Asclepius, Helios, and even the Jewish god YHWH (Yahweh). In the religion of Sol, an elaborate syncretistic theology was developed to show that all known gods of all nations were nothing but provisional names for the sun god.

RELIGIOUS ART AND ICONOGRAPHY

Much of Greco-Roman art was executed for use in the mystery communities. The Dionysiac monuments are by far superior to all others in artistic quality. This is to be expected, because the worship of Dionysus often took the form of a worship of beauty. Nevertheless, the other communities also produced a great number of art objects.

Architecture. The mystery religions developed different types of edifices for their purposes. Every Greek city had temples and precincts of Dionysus. The Isis Mysteries adopted the Greek temples, frequently adding a cupola. Many Isis temples were modest in size, but the temple at Pergamum (modern Bergama, Turkey) was a great basilica with a vaulted roof and strong towers, in the fashion of the best Roman architecture. The Isis temple that the emperor Domitian erected on the Campus Martius (the Field of Mars) in Rome at the end of the 1st century AD was a stately building, and the Temple of Sarapis (the Sarapeum) at Alexandria was a huge construction. The subterranean basilica near Porta Maggiore in Rome (used by an Orphic or Pythagorean society) was a strong and magnificent structure hidden in a large garden. The Mithraic sanctuaries were artificial caves illuminated from above by light shafts. They were built for communities of 50 to 100 persons.

Isis temples

The buildings were designed to be functional for the religious ceremonies. The Mithraeum under the church of S. Clemente at Rome contained a system of underground galleries for initiation ceremonies. Beneath the temple of the Egyptian gods at Pergamum, subterranean passages existed for the use of the priests. One of the paths led into the huge, hollow statue of the god, so that the priest could speak from the mouth of the statue. By another secret way, an officiant could climb the huge corner towers of the temple to make announcements from there. The Sarapeum at Alexandria was directed toward the east; on a certain day of the year, at a certain time, sunbeams directly struck the head of the god's statue. This same temple was so arranged that those waiting to be initiated could hire rooms in an adjacent building during the time of preparation before the ceremony.

Because the use of water was such an important element in most of the mystery rites, the location of the temples was often determined by the availability of water; Mithraic sanctuaries were always erected on the spot at which a fountain had its source. In the temples of Isis, a cistern for holy water was required; in Delos and in a house at Pompeii in Italy, a system of water basins could imitate the flood of the Nile. The Dionysiac temple at Corinth had an underground system of tubes and barrels that could be operated by buttons from the outside. The priest showed the worshippers of the god a barrel filled with water. They left the temple together, and the door was sealed from without. By pressing the buttons, the water was let out of the barrel, and wine was poured in. The following day, when the seal was removed, the spectator witnessed the Dionysiac miracle of water turned into wine.

On the ground floor of the Mithraic sanctuaries at Ostia, mosaic pavements showed the seven grades of the initiation and their symbols together with the ladder of the seven steps that led to religious salvation. In initiation ceremonies the mosaic was perhaps used to indicate the place where the different participants were to take their places.

Statuary. A great many statues were exhibited in the temples and shrines of the mystery gods. They were usually executed in the traditional Greek style. In the sanctuary of Isis and Sarapis at Thessalonica (modern Thessaloníki), in northern Greece, there were statues of a whole series of Greek goddesses, each of whom was identified with Isis in one way or another to show that the Egyptian goddess was the essence and synthesis of Greek religion. In the 4th century BC the sculptor Bryaxis created a famous colossal statue of Sarapis in the temple at Alexandria. It represented the god—as a combination of the Greek gods Zeus (the father of the gods), Hades, and Dionysus—seated upon a throne, with Cerberus, the three-headed monster, beside him. An interesting statuette found at Cyrene (modern Shaḥḥāt, Libya) shows a female initiate of Isis. The woman is wrapped from feet to waist like a mummy; but the upper part of her body is free, and she is wearing the crown of Isis on her head. The statue thus showed how an initiate would first die and subsequently resurrect in triumph during the ceremony. Many terracotta statues of Isis and her son Horus have survived from Roman Egypt; they are similar to the later statues of the Christian Madonna and Child. Syrian statues of Jupiter Heliopolitanus represent the god in a rigid attitude, like a pillar. In the base of some of these statues are holes, into which sticks could be inserted for the purpose of carrying the statue in procession. In Mithraic sanctuaries a great number of statues, especially of the gods of the planets, were exhibited. Statues of the Mithraic time god were also frequent; they were often hollow and were constructed so that they could spit fire.

Reliefs. The Dionysiac reliefs are numerous. They show symbols of the religion, such as the shepherd's staff, the winnow (an ancient device for separating chaff from grain), and the phallus; they depict the gay life of satyrs and maenads, shepherds and shepherdesses; and they represent the "golden age" of the gods with tame and wild animals enjoying a peace that the god had instituted. A great silver dish dating from about the 4th century AD and found at Mildenhall, England, shows the swift and elegant dance of the maenads. Dionysiac sarcophagi represented Bacchic revels and the pastime of the Erotes and Psyches in afterlife. Many reliefs of the Isis Mysteries also survive. They display the mystical cista (a receptacle for carrying sacred objects) with the snake of Horus, the priest carrying holy water in a procession, female attendants with a ladle, and a man in a dog's mask, who represents Anubis (the guardian god). Other Isiac reliefs show Isis riding on a dog, symbolic of her position as goddess of Sirius (the Dog Star).

The "golden age" of the gods

In Mithraic caverns there was always a relief depicting the god sacrificing the bull. Representations of the sacramental meal were also frequent; a relief recently discovered in Konjic, Bosnia and Herzegovina, shows a banquet at which the initiates are wearing masks, among them a lion, a raven, a soldier, and a Persian. Two reliefs—at Rome (now at Modena, Italy) and at Housesteads, England (the best preserved fort along Hadrian's Wall)—depict the creation of the world out of an initial egg; in this case, Orphic and Mithraic ideas were amalgamated. Other episodes of Mithraic mythology that were commonly displayed include the birth of Mithra from a rock with the shepherds who welcome him and his dealings with the sun god.

The stucco reliefs in the subterranean basilica near Porta Maggiore are of outstanding quality. In the central episode, Sappho—an early Greek poetess who supposedly killed herself in a "lover's leap" from the island of Leucas into the Ionian Sea—is shown leaping toward Apollo, the

god of the sun; this symbolized the soul's transcendence into more favourable existence. Many of the reliefs in the basilica allegorize episodes from Greek mythology in the fashion of the Pythagoreans, who found a hidden religious or philosophical meaning behind the mythical tales of the Greek tradition.

Painting. There are few paintings from the temples of the mystery religions that have been preserved; nevertheless, some of these deserve comment. The superb Dionysiac frescoes of the Villa of the Mysteries (Villa dei Misteri) at Pompeii show the initiation of a girl into the Bacchic Mysteries: in one fresco she is lifting the cover of a sacred casket; in a second scene three followers of Dionysus are practicing lecanomancy (divination by the inspection of a bowl filled with water); in a third scene the girl is unveiling an erect phallus and because of this she is being flagellated; finally, she is seen dancing in happy bliss. A number of Isiac frescoes, preserved in the temple of Isis at Pompeii, show the sacred dance of the initiates, the presentation of an urn filled with the ritual holy water to the initiates, the coffin of Osiris and his resurrection, and episodes from the cycle of Io, a Greek heroine equated with Isis. Isiac frescoes dating from the time of the emperor Caligula in the 1st century AD are also found in the ruins on the Palatine at Rome. In the Mithraeum under Sta. Prisca in Rome, two layers of frescoes were found that show the procession of the initiates toward ritual sacrifice of a bull, called Suovetaurilia, and the sacred meal of the sun god and Mithra. Sometimes a fresco replaced the relief of the sacrifice of the bull. The initiation ceremonies are shown in the Mithraic sanctuary at Capua (in western Italy); the candidate, accompanied by the *mystagōgos,* is blindfolded, kneels down, and lies prostrate. At Rome, in the tomb of Vincentius and Vibia, who worshipped the god Sabazius (a Thracian form of Dionysus), frescoes show how Vibia was carried away by Death, as Kore had been carried away by Hades, how she was judged and acquitted, and how she was introduced by a "good angel" to the sacred meal of the blessed.

Mosaics. A mosaic at Antioch represents the Phoenix—the solar bird who died and resurrected from its own ashes and who was its own father and son at the same time—with sunrays encircling its head. A Dionysus mosaic at Cologne, Germany, depicts in several panels the life of satyrs and maenads and also Bacchic symbols such as the winnow (an implement of purification) and the oyster (which has to be liberated from the shell as the soul from the body). The room evidently was used for banquets and Dionysiac merrymaking.

MYSTERY RELIGIONS AND CHRISTIANITY

Similarities between mysteries and Christianity

Christianity originated during the time of the Roman Empire, which was also the time at which the mysteries reached their height of popularity. This was by no means an accident. The Christian theologian Origen wrote in the 3rd century that it was part of the divine plan that Christ was born under the emperor Augustus: the whole Mediterranean world was united by the Romans, and the conditions for missionary work were more favourable than ever before. The simultaneousness of the propagation of the mystery religions and of Christianity and the striking similarities between them, however, demand some explanation of their relationship. The hypothesis of a mutual dependence has been proposed by scholars—especially a dependence of Christianity upon the mysteries—but such theories have been discarded. The similarities must rather be explained by parallel developments from similar origins. In both cases, national religions of a ritualistic type were transformed, and the transformation followed similar lines: from national to ecumenical religion, from ritualistic ceremonies and taboos to spiritual doctrines set down in books, from the idea of inherited tradition to the idea of revelation. The parallel development was fostered by the new conditions prevailing in the Roman Empire, in which the old political units were dissolved, and the whole civilized world was ruled by one monarch. People were free to move from one country to another and became cosmopolitan. The ideas of Greek philosophy penetrated everywhere in this society. Thus, under identical conditions, new forms of religious communities sprang from similar roots. The mystery religions and Christianity had many similar features—*e.g.,* a time of preparation before initiation and periods of fasting; baptism and banquets; vigils and early-morning ceremonies; pilgrimages and new names for the initiates. The purity demanded in the worship of Sol and in the Chaldean fire rites was similar to Christian standards. The first Christian communities resembled the mystery communities in big cities and seaports by providing social security and the feeling of brotherhood. In the Christian congregations of the first two centuries, the variety of rites and creeds was almost as great as in the mystery communities; few of the early Christian congregations could have been called orthodox according to later standards. The date of Christmas was purposely fixed on December 25 to push into the background the great festival of the sun god, and Epiphany on January 6 to supplant an Egyptian festival of the same day. The Easter ceremonies rivalled the pagan spring festivals. The religious art of the Christians continued the pagan art of the preceding generations. The Christian representations of the Madonna and child are clearly the continuation of the representations of Isis and her son suckling her breast. The statue of the Good Shepherd carrying his lost sheep and the pastoral themes on Christian sarcophagi were also taken over from pagan craftsmanship.

In theology the differences between early Christians, Gnostics (members—often Christian—of dualistic sects of the 2nd century AD), and pagan Hermetists were slight. In the large Gnostic library discovered at Naj'Ḥammādī, in upper Egypt, in 1945, Hermetic writings were found side-by-side with Christian Gnostic texts. The doctrine of the soul taught in Gnostic communities was almost identical to that taught in the mysteries: the soul emanated from the Father, fell into the body, and had to return to its former home. The Greeks interpreted the national religions of the Greek Orient chiefly in terms of Plato's philosophical and religious concepts. Interpretation in Platonic concepts was also the means by which the Judeo-Christian set of creeds was thoroughly assimilated to Greek ideas by the early Christian thinkers Clement of Alexandria and Origen. Thus, the religions had a common conceptual framework. The doctrinal similarity is exemplified in the case of the pagan writer and philosopher Synesius. The people of Cyrene selected him as the most able man of the city to be their bishop, and he was able to accept the election without sacrificing his intellectual honesty. In his pagan period he wrote hymns that closely follow the fire theology of the *Chaldean Oracles,* later he wrote hymns to Christ. The doctrine is almost identical.

The similarity of the religious vocabulary is also great. Greek life was characterized by such things as democratic institutions, seafaring, gymnasium and athletic games, theatre, and philosophy. The mystery religions adopted many expressions from these domains: they spoke of the assembly (*ekklēsia*) of the *mystai;* the voyage of life; the ship, the anchor, and the port of religion; and the wreath of the initiate; life was a stage and man the actor. The Christians took over the entire terminology; but many pagan words were strangely twisted in order to fit into the Christian world: the service of the state (*leitourgia*) became the ritual, or liturgy, of the church; the decree of the assembly and the opinions of the philosophers (*dogma*) became the fixed doctrine of Christianity; the correct opinion (*orthē doxa*) about things became orthodoxy.

Differences between mysteries and Christianity

There are also great differences between Christianity and the mysteries. Mystery religions, as a rule, can be traced back to tribal origins, Christianity to a historical person. The holy stories of the mysteries were myths; the Gospels of the New Testament, however, relate historical events. The books that the mystery communities used in Roman times cannot possibly be compared to the New Testament. The essential features of Christianity were fixed once and for all in this book; the mystery doctrines, however, always remained in a much greater state of fluidity. The theology of the mysteries was developed to a far lesser degree than the Christian theology. There are no parallels in Christianity to the sexual rites in the Dionysiac and Isiac religion, with the exception of a few aberrant Gnostic communities.

The cult of rulers in the manner of the imperial mysteries was impossible in Jewish and Christian worship.

The mysteries declined quickly when the emperor Constantine raised Christianity to the status of the state religion. After a short period of toleration, the pagan religions were prohibited. The property of the pagan gods was confiscated, and the temples were destroyed. The precious metal used to coin Constantine's gold pieces was taken from heathen temple treasuries. To show the beginning of a new era, the capital of the empire was transferred to the new Christian city of Constantinople. The centres of pagan resistance were Rome, where the old aristocracy clung to the mysteries, and Alexandria, where the pagan Neoplatonist philosophers expounded the mystery doctrines. When Julian the Apostate, Roman emperor from AD 361 to 363, tried to reestablish pagan worship, he found allies at Rome and Alexandria. After his death, the pagan opposition to Christianity continued for one more generation. The Roman aristocrats multiplied their efforts to maintain the piety of the mysteries, and the pagan philosophers tried to refine their theology by oversubtle interpretations. In 391, however, the Sarapeum at Alexandria was demolished, and in 394 the opposition of the Roman aristocracy was crushed in battle at the Frigidus River (now called the Vipacco River in Italy and the Vipava in Slovenia).

Only remnants of the mystery doctrines, amalgamated with Platonism, were transmitted by a few philosophers and individualists to the religious thinkers of the Byzantine Empire. The mystery religions exerted some influence on the thinkers of the Middle Ages and the philosophers of the Italian Renaissance.

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Myth and Mythology

Myth is a collective term denoting a symbolic narrative in religion, as distinguished from symbolic behaviour (cult, ritual) and symbolic places or objects (temples, icons). Myths are specific accounts of gods or superhuman beings involved in extraordinary events or circumstances in a time that is unspecified but which is understood as existing apart from ordinary human experience.

As with all religious symbolism, there is no attempt to justify mythic narratives or even to render them plausible. Every myth presents itself as an authoritative, factual account, no matter how much the narrated events are at variance with natural law or ordinary experience. By extension from this primary religious meaning, the word myth may also be used more loosely to refer to an ideological belief when that belief is the object of a quasi-religious faith; an example would be the Marxist eschatological myth of the withering away of the state.

While the outline of myths from a past period or from a society other than one's own can usually be seen quite clearly, to recognize the myths that are dominant in one's own time and society is always difficult. This is hardly surprising, because a myth has its authority not by proving itself but by presenting itself. In this sense the authority of a myth indeed "goes without saying," and the myth can be outlined in detail only when its authority is no longer unquestioned but has been rejected or overcome in some manner by another, more comprehensive myth.

The word myth derives from the Greek *mythos,* which has a range of meanings from "word," through "saying" and "story," to "fiction"; the unquestioned validity of *mythos* can be contrasted with *logos,* the word whose validity or truth can be argued and demonstrated. Because myths narrate fantastic events with no attempt at proof, it is sometimes assumed that they are simply stories with no factual basis, and the word has become a synonym for falsehood or, at best, misconception. In the study of religion, however, it is important to distinguish between myths and stories that are merely untrue.

The term mythology denotes both the study of myth and the body of myths belonging to a particular religious tradition. The first part of this article discusses the nature, study, functions, cultural impact, and types of myth, taking into account the various approaches to the subject offered by modern branches of knowledge. In the second part, the specialized topic of the role of animals and plants in myth is examined in some detail. The mythologies of specific cultures, such as Germanic, Greek, and Roman, are covered in the article EUROPEAN RELIGIONS, ANCIENT.

For coverage of related topics in the *Macropædia* and *Micropædia,* see the *Propædia,* section 811, and the *Index.*

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The nature, functions, and types of myth

Myth has existed in every society. Indeed, it would seem to be a basic constituent of human culture. Because the variety is so great, it is difficult to generalize about the nature of myths. But it is clear that in their general characteristics and in their details a people's myths reflect, express, and explore the people's self-image. The study of myth is thus of central importance in the study both of individual societies and of human culture as a whole.

RELATION OF MYTHS TO OTHER NARRATIVE FORMS

In Western culture there are a number of literary or narrative genres that scholars have related in different ways to myths. Examples are fables, fairy tales, folktales, sagas, epics, legends, and etiologic tales (which refer to causes or explain why a thing is the way it is). Another form of tale, the parable, differs from myth in its purpose and character. Even in the West, however, there is no agreed definition of any of these genres, and some scholars question whether multiplying categories of narrative is helpful

at all, as opposed to working with a very general concept such as the traditional tale. Non-Western cultures apply classifications that are different both from the Western categories and from one another. Most, however, make a basic distinction between "true" and "fictitious" narratives, with "true" ones corresponding to what in the West would be called myths.

If it is accepted that the category of traditional tale should be subdivided, one way of doing so is to regard the various subdivisions as comparable to bands of colour in a spectrum. Within this figurative spectrum, there will be similarities and analogies between myth and folktale or between myth and legend or between fairy tale and folktale. In the section that follows, it is assumed that useful distinctions can be drawn between different categories. It should, however, be remembered throughout that these classifications are far from rigid and that, in many cases, a given tale might be plausibly assigned to more than one category.

Fables. The word fable derives from the Latin word *fabula,* which originally meant about the same as the Greek *mythos;* like *mythos,* it came to mean a fictitious or untrue story. Myths, in contrast, are not presented as fictitious or untrue.

Instructional value of fables

Fables, like some myths, feature personified animals or natural objects as characters. Unlike myths, however, fables almost always end with an explicit moral message, and this highlights the characteristic feature of fables—namely, that they are instructive tales that teach morals about human social behaviour. Myths, by contrast, tend to lack this directly didactic aspect, and the sacred narratives that they embody are often hard to translate into direct prescriptions for action in everyday human terms. Another difference between fables and myths relates to a feature of the narratives that they present. The context of a typical fable will be unspecific as to time and space; *e.g.,* "A fox and a goose met at a pool." A typical myth, on the other hand, will be likely to identify by name the god or hero concerned in a given exploit and to specify details of geography and genealogy; *e.g.,* "Oedipus was the son of Laius, the king of Thebes."

Fairy tales. The term fairy tale, if taken literally, should refer only to stories about fairies, a class of supernatural and sometimes malevolent beings—often believed to be of diminutive size—who were thought by people in medieval and postmedieval Europe to inhabit a kingdom of their own; a literary expression of this belief can be found in Shakespeare's *A Midsummer Night's Dream.* The term fairy tale, however, is normally used to refer to a much wider class of narrative, namely stories (directed above all at an audience of children) about an individual, almost always young, who confronts strange or magical events: examples are "Jack and the Beanstalk," "Cinderella," and "Snow White and the Seven Dwarfs." The modern concept of the fairy tale seems not to be found earlier than the 18th century in Europe, but the narratives themselves have earlier analogues much farther afield, notably in the Indian *Kathā-saritsāgara* (*The Ocean of Story*) and in *The Thousand and One Nights.*

Like myths, fairy tales present extraordinary beings and events. Unlike myths—but like fables—fairy tales tend to be placed in a setting that is geographically and temporally vague and might begin with the words "Once upon a time there was a handsome prince . . ." A myth about a prince, by contrast, would be likely to name him and to specify his lineage, since such details might be of collective importance (for example, with reference to issues of property inheritance or the relative status of different families) to the social group among which the myth was told.

Folktales. There is much disagreement among scholars as to how to define the folktale; consequently, there is disagreement about the relation between folktale and myth. One view of the problem is that of the American folklorist Stith Thompson, who regarded myths as one type of folktale; according to this approach, the particular characteristic of myth is that its narratives deal with sacred events that happened "in the beginning." Other scholars either consider folktale a subdivision of myth or regard the two categories as distinct but overlapping. The latter view is taken by the British classicist Geoffrey S. Kirk, who in *Myth: Its Meaning and Functions in Ancient and Other Cultures* (1970) uses the term myth to denote stories with an underlying purpose beyond that of simple story-telling and the term folktale to denote stories that reflect simple social situations and play on ordinary fears and desires. Examples of folktale motifs are encounters between ordinary, often humble, human beings and supernatural adversaries such as witches, giants, or ogres; contests to win a bride; and attempts to overcome a wicked stepmother or jealous sisters. But these typical folktale themes occur also in stories normally classified as myths, and there must always be a strong element of arbitrariness in assigning a motif to a particular category.

A different and important aspect of the problem of defining a folktale relates to the historical origin of the concept. As with the notion of folklore, the notion of folktale has its roots in the late 18th century. From that period until the middle of the 19th century, many European thinkers of a nationalist persuasion argued that stories told by ordinary people constituted a continuous tradition reaching back into the nation's past. Thus, stories such as the *Märchen* ("Tales") collected by the Grimm brothers in Germany are folktales because they were told by the people rather than by an aristocratic elite. This definition of folktale introduces a new criterion for distinguishing between myth and folktale—namely, what class of person tells the story—but it by no means removes all the problems of classification. Just as the distinction between folk and aristocracy cannot be transferred from medieval Europe to tribal Africa or classical Greece without risk of distortion, so the importing of a distinction between myth and folktale on the later European model is extremely problematic.

Sagas and epics. The word saga is often used in a generalized and loose way to refer to any extended narrative re-creation of historical events. A distinction is thus sometimes drawn between myths (set in a semidivine world) and sagas (more realistic and more firmly grounded in a specific historical setting). This rather vague use of saga is best avoided, however, since the word can more usefully retain the precise connotation of its original context. The word saga is Old Norse and means "what is said." The sagas are a group of medieval Icelandic prose narratives; the principal sagas date from the 13th century and relate the deeds of Icelandic heroes who lived during the 10th and 11th centuries. If the word saga is restricted to this Icelandic context, at least one of the possible terminological confusions over words for traditional tales is avoided.

Origin of sagas

While saga in its original sense is a narrative type confined to a particular time and place, epics are found worldwide. Examples can be found in the ancient world (the *Iliad* and *Odyssey* of Homer), in medieval Europe (the *Nibelungenlied*), and in modern times (the Serbo-Croatian epic poetry recorded in the 1930s). Among the many non-European examples are the Indian *Mahābhārata* and the Tibetan Gesar epic. Epic is similar to saga in that both narrative forms look back to an age of heroic endeavour, but it differs from saga in that epics are almost always composed in poetry (with a few exceptions such as Kazakh epic and the Turkish *Book of Dede Korkut*). The relation between epic and myth is not easy to pin down, but it is in general true that epics characteristically incorporate mythical events and persons. An example is the ancient Mesopotamian epic of Gilgamesh, which includes, among many mythical episodes, an account of the meeting between the hero Gilgamesh and Utnapishtim, the only man to have attained immortality and sole survivor (with his wife) of the flood sent by the gods. Myth is thus a prime source of the material on which epic draws.

Legends. In common usage the word legend usually characterizes a traditional tale thought to have a historical basis, as in the legends of King Arthur or Robin Hood. In this view, a distinction may be drawn between myth (which refers to the supernatural and the sacred) and legend (which is grounded in historical fact). Thus, some writers on the *Iliad* would distinguish between the legendary aspects (*e.g.,* heroes performing actions possible for ordinary humans) and the mythical aspects (*e.g.,* episodes involving the gods). But the distinction between

myth and legend must be used with care. In particular, because of the assumed link between legend and historical fact, there may be a tendency to refer to narratives that correspond to one's own beliefs as legends, while exactly comparable stories from other traditions may be classified as myths; hence a Christian might refer to stories about the miraculous deeds of a saint as legends, while similar stories about a pagan healer might be called myths. As in other cases, it must be remembered that the boundaries between terms for traditional narratives are fluid, and that different writers employ them in quite different ways.

Parables. The term myth is not normally applied to narratives that have as their explicit purpose the illustration of a doctrine or standard of conduct. Instead, the term parable, or illustrative tale, is used. Familiar examples of such narratives are the parables of the New Testament. Parables have a considerable role also in Ṣūfism (Islāmic mysticism), rabbinic (Jewish biblical interpretive) literature, Ḥasidism (Jewish pietism), and Zen Buddhism. That parables are essentially non-mythological is clear because the point made by the parable is known or supposed to be known from another source. Parables have a more subservient function than myths. They may clarify something to an individual or a group but do not take on the revelatory character of myth.

Etiologic tales. Etiologic tales are very close to myth, and some scholars regard them as a particular type of myth rather than as a separate category. In modern usage the term etiology is used to refer to the description or assignment of causes (Greek *aitia*). Accordingly, an etiologic tale explains the origin of a custom, state of affairs, or natural feature in the human or divine world. Many tales explain the origin of a particular rock or mountain. Others explain iconographic features, such as the Hindu narrative ascribing the blue neck of the god Śiva to a poison he drank in primordial times. The etiologic theme often seems to be added to a mythical narrative as an afterthought. In other words, the etiology is not the distinctive characteristic of myth.

APPROACHES TO THE STUDY OF MYTH AND MYTHOLOGY

The importance of studying myth to provide a key to a human society is a matter of historical record. In the middle of the 19th century, for instance, a newly appointed British governor of New Zealand, Sir George Grey, was confronted by the problem of how to come to terms with the Maori, who were hostile to the British. He learned their language, but that proved insufficient for an understanding of the way in which they reasoned and argued. In order to be able to conduct negotiations satisfactorily, he found it necessary to study the Maori's mythology, to which they made frequent reference. Other government officials and Christian missionaries of the 19th and 20th centuries made similar efforts to understand the mythologies of nations or tribes so as to facilitate communication. Such studies were more than a means to an end, whether efficient administration or conversion; they amounted to the discovery that myths present a model or charter for man's behaviour and that the world of myth provides guidance for crucial elements in human existence—war and peace, life and death, truth and falsehood, good and evil. In addition to such practically motivated attempts to understand myth, theorists and scholars from many disciplines have interested themselves in the study of the subject. A close study of myth has developed in the West, especially since the 18th century. Much of its material has come from the study of the Greek and Roman classics, from which it has also derived some of its methods of interpretation.

Myths as a model of human behaviour

The growth of philosophy in ancient Greece furthered allegorical interpretations of myth—*i.e.*, finding other or supposedly deeper meanings hidden below the surface of mythical texts. Such meanings were usually seen as involving natural phenomena or human values. Related to this was a tendency toward rationalism, especially when those who studied myths employed false etymologies. Rationalism in this context connotes the scrutiny of myths in such a way as to make sense of the statements contained in them without taking literally their references to gods, monsters, or the supernatural. Thus, the ancient writer Palaiphatos interpreted the story of Europa (carried off to Crete on the back of a handsome bull, which was actually Zeus in disguise) as that of a woman abducted by a Cretan called Tauros, the Greek word for bull; and Skylla, the bestial and cannibalistic creature who attacked Odysseus' ship according to Homer's *Odyssey*, was by the same process of rationalizing interpreted as simply the name of a pirate ship. Of special and long-lasting influence in the history of the interpretation of myth was Euhemerism (named after Euhemerus, a Greek writer who flourished about 300 BC), according to which certain gods were originally great people venerated because of their benefactions to mankind.

Influence of Euhemerism

The early Church Fathers adopted an attitude of modified Euhemerism, according to which classical mythology was to be explained in terms of mere men who had been raised to superhuman, demonic status because of their deeds. By this means, Christians were able to incorporate myths from the culturally authoritative pagan past into a Christian framework while defusing their religious significance—the gods became ordinary humans. The Middle Ages did not develop new theoretical perspectives on myth, nor, despite some elaborate works of historical and etymological erudition, did the Renaissance. In both periods, interpretations in terms of allegory and Euhemerism tended to predominate.

In early 18th-century Italy, Giambattista Vico, a thinker now considered the forerunner of all writers on ethnology, or the study of culture in human societies, built on traditional scholarship—especially in law and philosophy—to make the first clear case for the role of man's creative imagination in the formation of distinct myths at successive cultural stages. His work, which was most notably expressed in his *Scienza nuova* (1725; *The New Science of Giambattista Vico*), had no influence in his own century. Instead, the notion that pagan myths were distortions of the biblical revelation (first expressed in the Renaissance) continued to find favour. Nevertheless, Enlightenment philosophy, reports from voyages of discovery, and missionary reports (especially the Jesuits' accounts of North American Indians) contributed to scholarship and fostered greater objectivity. Bernhard Le Bovier de Fontenelle, a French scholar, compared Greek and American Indian myths and suggested that there was a universal human predisposition toward mythology. In *De l'origine des fables* (1724; "On the Origin of Fables") he attributed the absurdities (as he saw them) of myths to the fact that the stories grew up among an earlier, more primitive human society. About 1800 the Romantics' growing fascination with language, the postulation of an Indo-European language family, the study of Sanskrit, and the growth of comparative studies, especially in history and philology, were all part of a trend that included the study of myth.

The relevance of Indo-European studies to an understanding of Greek and Roman mythology was carried to an extreme in the work of Friedrich Max Müller, a German Orientalist who moved to Britain and undertook important research on comparative linguistics. In his view, expressed in such works as *Comparative Mythology* (1856), the mythology of the original Indo-European peoples had consisted of allegorical stories about the workings of nature, in particular such features as the sky, the Sun, and the dawn. In the course of time, though, these original meanings had been lost (through, in Müller's notorious phrasing, a "disease of language"), so that the myths no longer told in a "rationally intelligible" way of phenomena in the natural world but instead appeared to describe the "irrational" activities of gods, heroes, nymphs, and others. For instance, one Greek myth related the pursuit of the nymph Daphne by the god Phoebus Apollo. Since—in Müller's interpretation of the evidence of comparative linguistics—"Daphne" originally meant "dawn," and "Phoibos" meant "morning sun," the original story was rationally intelligible as "the dawn is put to flight by the morning sun." One of the problems with this view is, of course, that it fails to account for the fact that the Greeks continued to tell this and similar stories long after their supposed meanings had been forgotten; and they did so,

Müller's study of myth and linguistics

moreover, in the manifest belief that the stories referred, not to nature, but precisely to gods, heroes, and other mythical beings.

Interest in myth was greatly stimulated in Germany by Friedrich von Schelling's philosophy of mythology, which argued that myth was a form of expression, characteristic of a particular stage in human development, through which men imagine the Absolute (for Schelling an all-embracing unity in which all differences are reconciled). Scholarly interest in myth has continued into the 20th century. Many scholars have adopted a psychological approach because of interest aroused by the theories of Sigmund Freud. Subsequently, new approaches in sociology and anthropology have continued to encourage the study of myth.

Allegorical. An example of an allegorical interpretation would be that given by an ancient commentator for the *Iliad,* book 20, verse 67. Referring to an episode in which the gods fight each other, the commentator cites critics who have explained the hostilities between the gods allegorically as an opposition between elements—dry against wet, hot against cold, light against heavy. Thus, the gods Apollo, Helios, and Hephaestus represent fire, and the god Poseidon and the river Scamander represent water. Similarly, the goddess Athena is interpreted as wisdom/sense, the god Ares as the absence of that quality, the goddess Aphrodite as desire, and the god Hermes as reason. An allegorical interpretation of a myth could be said to posit a one-to-one correspondence between mythical "clothing" and the ideas being so clothed. This approach tends to limit the meaning of a myth, whereas that meaning may in reality be multiple, operating on several levels.

Romantic. In the late 18th century artists and intellectuals came increasingly to emphasize the role of the emotions in human life and, correspondingly, to play down the importance of reason (which had been regarded as supremely important by thinkers of the Enlightenment). Those involved in the new movement were known as Romantics. The Romantic movement had profound implications for the study of myth. Myths—both the stories from Greek and Roman antiquity and contemporary folktales—were regarded by the Romantics as repositories of experience far more vital and powerful than those obtainable from what was felt to be the artificial art and poetry of the aristocratic civilization of contemporary Europe.

Myths as natural expressions of human experience

This new attitude is illustrated in a work of the German critic and philosopher Johann Gottfried von Herder entitled "Auszug aus einem Briefwechsel über Ossian und die Lieder alter Völker" (1773; "Extract from a Correspondence on Ossian and the Songs of Ancient Peoples"). Ossian is the name of an Irish warrior-poet whose Gaelic songs were supposedly translated and presented to the world by James Macpherson in the 1760s. Although largely the work of Macpherson himself, these songs made a colossal impact when they were published. Herder believed that the more "savage," that is, the more "alive" and "freedom-loving" a people (*ein Volk*) was, the more alive and free its songs would be. In opposition to the culture of the educated, Herder exalted the *Kultur des Volkes* ("culture of the people"). In 1769 Herder abandoned his job as a schoolteacher and took a boat from Riga, on the Baltic, to Nantes, on the Atlantic coast of France. In *Journal meiner Reise im Jahre 1769* (1769; *Journal of My Travels in the Year 1769*), a description of the experience, he wrote:

> In everything [on board ship] there is experience to illuminate the original era of the myths. *Then* [*i.e.,* in antiquity] every man, ignorant of nature, listened for signs and *had* to listen for them . . . . *Then,* Jupiter's lightning was terrifying—as indeed it *is* [*i.e.,* now] on the Ocean . . . . There are a thousand new and more natural explanations of mythology . . . if one reads, say, Orpheus, Homer, Pindar . . . on board ship.

In other words, for Herder ancient myths were the natural expressions of the concerns that would have confronted the ancients; and those concerns were the very ones that, according to Herder, still confronted the *Volk—e.g.,* ordinary sailors—in Herder's own day.

Comparative. Since the Romantic movement, all study of myth has been comparative, although comparative attempts were made earlier. The prevalence of the comparative approach has meant that since the 19th century even the most specialized studies have made generalizations about more than one tradition or at the very least have had to take comparative works by others into account. Indeed, for there to be any philosophical inquiry into the nature and function of myth at all, there must exist a body of data about myths across a range of societies. Such data would not exist without a comparative approach.

Folkloric. The classic folklore approach is that of Wilhelm Mannhardt, a German scholar, who attempted to collect data on the "lower mythology," which he considered to be more or less homogeneous in ancient and popular peasant traditions and basic to all formation of myth. Mannhardt saw sufficient analogies and similarities between the ancient and modern data to permit use of the latter in interpreting the former. Like Herder, he saw the source of mythology in the traditions passed on among the *Volk.* He collected information not only about popular stories but also about popular customs. He interpreted ancient Greek rituals by relating them to customs of the agricultural peoples of northern Europe, proposing this link in his book *Antike Wald- und Feldkulte* (1877; "Ancient Wood and Field Cults"). Other people who examined myth from the folklore standpoint included Sir James Frazer, the British anthropologist, the brothers Grimm (Jacob, who influenced Mannhardt, and Wilhelm), who are well-known for their collections of folklore, and Stith Thompson, who is notable for his classification of folk literature, particularly his massive *Motif-Index of Folk-Literature* (1955). The Grimms shared Herder's passion for the poetry and stories of the *Volk.* Their importance stems in part from the academic diligence and meticulousness that they brought to the recording and study of popular tradition. In addition to their collection of *Märchen* ("Tales"), they published volumes of *Deutsche Sagen* ("German Legends"). These were tales that purported to record actual events and that were ostensibly set in a specific place and period, as opposed to the "once-upon-a-time-in-the-forest" setting characteristic of the *Märchen.* Collecting and classifying mythological themes have remained the principal activities of the folklore approach.

Myth as a folk tradition

Functionalist. One of the leading exponents of the functionalist approach to myth was the French sociologist Marcel Mauss, who used the phrase "total social facts" in reference to religious symbols and myths and their irreducibility in terms of other functions. In his *Essai sur le don* (1925; *The Gift*), Mauss referred to a system of gift giving to be found in traditional, preindustrial societies. Observing that there was a mass of complex data on the subject, Mauss continued: in these "early" societies, social phenomena

> are not discrete; each phenomenon contains all the threads of which the social fabric is composed. In these *total* social phenomena, as we propose to call them, all kinds of institutions find simultaneous expression: religious, legal, moral, and economic.

In his introduction to the English edition Edward Evans-Pritchard commented on that passage:

> "Total" is the key word of the *Essay.* The exchanges of archaic societies which he examines are total social movements or activities. They are at the same time economic, juridical, moral, aesthetic, religious, mythological . . . phenomena. . . . . Their meaning can therefore only be grasped if they are viewed as a complex concrete reality.

Functionalism is primarily associated with the anthropologists Bronisław Malinowski and A.R. Radcliffe-Brown, however. Both ask not what the origin of any given social behaviour may be but how it contributes to maintaining the system of which it is a part. In this view, in all types of society, every aspect of life—every custom, belief, or idea—makes its own special contribution to the continued effective working of the whole society. Functionalism has had a wide appeal to anthropologists in Britain and the United States, especially as an interpretation of myth as integrated with other aspects of society and as supporting existing social relationships.

Structuralist. Structuralist approaches to myth are based on the analogy of myth to language. Just as a lan-

guage is composed of significant oppositions (*e.g.,* between phonemes, the constituent sounds of the language), so myths are formed out of significant oppositions between certain terms and categories. Structuralist analysis aims at uncovering what it sees as the logic of myth. It is argued that supposedly primitive thought is logically consistent but that the terms of this logic are not those with which modern Western culture is familiar. Instead they are terms related to items of the everyday world in which the "primitive" culture exists. This logic is usually based on empirical categories (*e.g.,* raw/cooked, upstream/downstream, bush/village) or empirical objects (*e.g.,* buffalo, river, gold, eagle). Some structuralists, such as the French anthropologist Claude Lévi-Strauss, have emphasized the presence of the same logical patterns in myths throughout the world.

The logic of myth

In earlier anthropology, "primitive mentality" was characterized by the inability to make distinctions, by a sense of "mystic participation" or identity between man, his cosmos, and all other beings. Beginning with complex kinship systems and later exploring other taxonomies, structuralists argue to the opposite conclusion: the supposedly primitive man is, if anything, obsessed with the making of distinctions; his taxonomies reveal a complexity and sophistication that rival those of modern man.

Formalist. In contrast to the structuralists' search for the underlying structure of myths, the 20th-century Russian folklorist Vladimir Propp investigated folktales by dividing the surface of their narratives into a number of basic elements. These elements correspond to different types of action that, in Propp's analysis, always occur in the same sequence. Examples of the types of action isolated by Propp are "An interdiction is addressed to the hero"; "The interdiction is violated"; "The false hero or villain is exposed"; and "The hero is married and ascends the throne."

An important development of Propp's approach was made in the late 20th century by the German historian of religion Walter Burkert. Burkert detected certain recurrent patterns in the actions described in Greek myths, and he related these patterns (and their counterparts in Greek ritual) to basic biologic or cultural "programs of action." An example of this relation is given in Burkert's *Structure and History in Greek Mythology and Ritual* (1979). Burkert shows how certain Greek myths have a recurring pattern that he calls "the girl's tragedy." According to this pattern, a girl first leaves home; after a period of seclusion, she is raped by a god; there follows a time of tribulation, during which she is threatened by parents or relatives; eventually, having given birth to a baby boy, the girl is rescued, and the boy's glorious future is assured. The reason for the frequency and persistence of this pattern is, in Burkert's view, the fact that it reflects a basic biologic sequence or "program of action"; puberty, defloration, pregnancy, delivery. Another pattern Burkert explains in a similar way is found in myths about the driving out of the scapegoat. This pattern, Burkert argues, stems from a real situation that must often have occurred in early human or primate history; a group of men, or a group of apes, when pursued by carnivores, were able to save themselves through the sacrifice of one member of the group. The persistence of these patterns through time is explained, according to Burkert, by the fact that they are grounded in basic human needs—above all, the need to survive.

FUNCTIONS OF MYTH AND MYTHOLOGY

Explanation. The most obvious function of myths is the explanation of facts, whether natural or cultural. One North American Indian (Abnaki [Wabanaki]) myth, for example, explains the origin of corn (maize): a lonely man meets a beautiful woman with long, fair hair; she promises to remain with him if he follows her instructions; she tells him in detail how to make a fire and, after he has done so, she orders him to drag her over the burned ground; as a result of these actions, he will see her silken hair (viz., the cornstalk) reappear, and thereafter he will have corn seeds for his use. Henceforth, whenever Abnaki Indians see corn (the woman's hair), they know that she remembers them. Obviously, a myth such as this one functions as an explanation, but the narrative form distinguishes it from a straightforward answer to an intellectual question about causes. The function of explanation and the narrative form go together, since the imaginative power of the myth lends credibility to the explanation and crystallizes it into a memorable and enduring form. Hence myths play an important part in many traditional systems of education.

Justification or validation. Many myths explain ritual and cultic customs. According to myths from the island of Ceram (in Indonesia), in the beginning life was not complete, or not yet "human": vegetation and animals did not exist, and there was neither death nor sexuality. In a mysterious manner Hainuwele, a girl with extraordinary gift-bestowing powers, appeared. The people killed her at the end of their great annual celebration, and her dismembered body was planted in the earth. Among the species that sprang up after this act of planting were tubers—the staple diet of the people telling the myth. With a certain circularity frequent in mythology, the myth validates the very cultic celebration mentioned in the myth. The cult can be understood as a commemoration of those first events. Hence, the myth can be said to validate life itself together with the cultic celebration. Comparable myths are told in a number of societies where the main means of food production is the cultivation of root crops; the myths reflect the fact that tubers must be cut up and buried in the earth for propagation to take place.

Cultic or ritual validation

Ritual sacrifices are typical of traditional peasant cultures. In most cases such customs are related to mythical events. Among important themes are the necessity of death (*e.g.,* the grain "dies" and is buried, only to yield a subsequent harvest), a society's cyclic renewal of itself (*e.g.,* New Year's celebrations), and the significance of women and sexuality. New Year's celebrations, often accompanied by a temporary abandonment of all rules, may be related to or justified by mythical themes concerning a return to chaos and a return of the dead.

In every mythological tradition one myth or cluster of myths tends to be central. The subject of the central mythology is often cosmogony (origin of the cosmos). In many of those ceremonies that each society has developed as a symbol of what is necessary to its well-being, references are made to the beginning of the world. Examples include the enthronements of kings, which in some traditions (as in Fiji or ancient India) are associated with a creation or re-creation of the world. Analogously, in ancient Mesopotamia the creation epic *Enuma elish,* which was read each New Year at Babylon, celebrated the progress of the cosmos from initial anarchy to government by the kingship of Marduk; hence the authority of earthly rulers, and of earthly monarchy in general, was implicitly supported and justified.

Ruling families in ancient civilizations frequently justified their position by invoking myths—for example, that they had divine origins. Examples are known from Imperial China, pharaonic Egypt, the Hittite Empire, Polynesia, the Inca Empire, and India. Elites have also based their claims to privilege on myths. The French historian of ancient religion Georges Dumézil was the pioneer in suggesting that the priestly, warrior, and producing classes in ancient Indo-European societies regarded themselves as having been ordained to particular tasks by virtue of their mythological origins. And in every known cultural tradition there exists some mythological foundation that is referred to when defending marriage and funerary customs.

Description. Inasmuch as myths deal with the origin of the world, the end of the world, or a paradisiacal state, they are capable of describing what people can never "see for themselves" however rational and observant they are. It may be that the educational value of myths is even more bound up with the descriptions they provide than with the explanations. In traditional, preindustrial societies myths form perhaps the most important available model of instruction, since no separate philosophical system of inquiry exists.

Instruction through myths

Healing, renewal, and inspiration. Creation myths play a significant role in healing the sick; they are recited (*e.g.,* among the Navajo Indians of North America) when an individual's world—that is to say, his life—is in jeopardy.

Thus, healing through recitation of a cosmogony is one example of the use of myth as a magical incantation. Another example is the case of Icelandic poets, who, in singing of the episode in old Norse mythology in which the god Odin wins for gods and men the "mead of song" (a drink containing the power of poetic inspiration), can be said to be celebrating the origins of their own art and hence renewing it.

The poetic aspect of myths in archaic and primitive traditions is considerable. Societies in which artistic endeavour is not yet specialized tend to rely on mythical themes and images as a source of all self-expression. Mythology has also exerted an aesthetic influence in more modern societies. An example is the prevalence of themes from Greek and Roman classical mythology in Western painting, sculpture, and literature.

MYTH IN CULTURE

Myth and psychology. One of the most celebrated writers about myth from a psychological standpoint was Sigmund Freud. In his *Die Traumdeutung* (1899; *The Interpretation of Dreams*) he posited a phenomenon called the Oedipus complex, that is, the male child's repressed desire for his mother and a corresponding wish to supplant his father. (The equivalent for girls was the Electra complex.) According to Freud, this phenomenon was detectable in dreams and myths, fairy tales, folktales—even jokes. Later, in *Totem und Tabu* (1913; *Totem and Taboo*), Freud suggested that myth was the distorted wish-dreams of entire peoples. More than that, however, he saw the Oedipus complex as a memory of a real episode that had occurred in what he termed the "primal horde," when sons oppressed by their father had revolted, had driven out or killed him, and had taken his wives for themselves. That subsequent generations refrained from doing so was, Freud suggested, due to a collective bad conscience. The relevance of Freud's investigations to the study of myth lies in his view that the formation of mythic concepts does not depend on cultural history. Instead, Freud's analysis of the psyche posited an independent, trans-historical mechanism, based on a highly personal biologic conception of man. His anthropological theories have since been refuted (*e.g.,* totemic [symbolic animal] sacrifice as the earliest ritual custom, which he related to the first parricide), but his analysis is still regarded with interest by some reputable social scientists. Criticism, however, has been leveled against the explanation of myths in terms of only one theme and in terms of the "repression" of conscious ideas.

Freud's creation of a trans-historical method

Another theorist preoccupied with psychological aspects of myth was the Swiss psychoanalyst Carl Jung, who, like Freud, was stimulated by a theory that no longer has much support—*i.e.,* the theory of Lucien Lévy-Bruhl, a French philosopher, associating myth with prelogical mentality. This, according to Lévy-Bruhl, was a type of thought that had been common to archaic mankind, that was still common to primitives, and in which people supposedly experienced some form of "mystical participation" with the objects of their thought, rather than a separation of subject and object. Jung's theory of the "collective unconscious," which bears a certain resemblance to Lévy-Bruhl's theory, enabled him to regard the foundation of mythical images as positive and creative, in contrast with Freud's more negative view of mythology. Jung evolved a theory of archetypes. Broadly similar images and symbols occur in myths, fairy tales, and dreams because the human psyche has an inbuilt tendency to dwell on certain inherited motifs (archetypes), the basic pattern of which persists, however much details may vary. But critics of Jung have hesitated to accept his theory of archetypes as an account of mythology. Among objections raised, two may be mentioned. First, the archetypal symbols identified by Jung are static, representing personal types that conflate aspects of the personality: they do not help to illuminate—in the way that the analyses of Propp and Burkert do—the patterns of action that myths narrate. Second, Jungian analysis is essentially aimed at relating myth to the individual psyche, whereas myth is above all a social phenomenon, embedded in society and requiring explanation with reference to social structures and social functions.

Myth and science. Attention has sometimes focused on changes occurring in the way the real world is apprehended by different peoples and how these changes in "reality" are reflected in myths. This reality changes continually throughout history, and these changes have especially occupied philosophers and historians of science, for a sense of reality in a culture is basic to any scientific pursuit by that culture, beginning with the earliest philosophical inquiries into the nature of the world. Though it would perhaps be going too far to identify the images and concepts that make up a culture's scientific sense of reality with myth, parallels between science and myth, as well as the presence of a mythological dimension to science, are generally reckoned to exist.

The function of models in physics, biology, medicine, and other sciences resembles that of myths as paradigms, or patterns, of the human world. In medicine, for instance, the human body is sometimes likened to a machine or the human brain to a computer, and such models are easily understood. Once a model has gained acceptance, it is difficult to replace, and in this respect it resembles myth, while at the same time, just as in myth, there may be a great variety of interpretations. In the 17th century it was assumed that the universe could be explained entirely in terms of minute corpuscles, their motion and interaction, and that no entities of any other sort existed. To the extent that many models in the history of science have partaken of this somewhat absolutist character, science can be said to resemble myth. There are, however, important differences. Despite the relative infrequency with which models in science have been replaced, replacement does occur, and a strong awareness of the limitations of models has developed in modern science. In contrast, a myth is not as a rule regarded by the community in which it functions as open to replacement, although an outside observer might record changes and even the substitution of a new myth for an old one. Moreover, in spite of the broad cultural impact of theories and models such as those of Newton and Einstein, it is in general true to say that models in science have their principal value for the scientists concerned. Hence, they function most strongly for a relatively small segment of society, even though, for instance, a medical theory held in academic circles in one century can filter down into folk medicine in the next. As a rule, myth has a much wider impact.

Scientific models as paradigms

Modern science did not evolve in its entirety as a rebellion against myth, nor at its birth did it suddenly throw off the shackles of myth. In ancient Greece the naturalists of Ionia (western Asia Minor), long regarded as the originators of science, developed views of the universe that were in fact very close to the creation myths of their time. Those who laid the foundations of modern science, such as Nicholas of Cusa, Johannes Kepler, Sir Isaac Newton, and Gottfried Leibniz, were absorbed by metaphysical problems of which the traditional, indeed mythological, character is evident. Among these problems were the nature of infinity and the question of the omnipotence of God. The influence of mythological views is seen in the English physician William Harvey's association of the circulation of the blood with the planetary movements and Darwin's explanation of woman's menstrual cycles by the tides of the ocean.

Several thinkers (*e.g.,* the theologian Paul Tillich and the philosopher Karl Jaspers) have argued convincingly for a mythological dimension to all science. Myth, in this view, is that which is taken for granted when thought begins. It is at the same time the limit reached in the course of scientific analysis, when it is found that no further progress in definition can be made after certain fundamental principles have been reached. In recent scientific researches, especially in astronomy and biology, questions of teleology (final ends) have gained in importance, as distinct from earlier concerns with questions of origin. These recent concerns stimulate discussion about the limits of what can be scientifically explained, and they reveal anew a mythological dimension to human knowledge.

Myth and religion. The place of myth in various religious traditions differs.

Ritual and other practices. The idea that the principal

function of a myth is to provide a justification for a ritual was adopted without any great attempt to make a case for it. At the beginning of the 20th century many scholars thought of myths in their earliest forms as accounts of social customs and values. According to Sir James Frazer, myths and rituals together provided evidence for man's earliest preoccupation, namely, fertility. Human society developed in stages—from the magical through the religious to the scientific—and myths and rituals (which survived even into the scientific stage) bore witness to archaic modes of thought that were otherwise difficult to reconstruct. As for the relationship between myth and ritual, Frazer argued that myths were intended to explain otherwise unintelligible rituals. Thus, in *Adonis, Attis, Osiris* (1906) he stated that the mythical story of Attis' self-castration was designed to explain the fact that the priests of Attis' cult castrated themselves at his festival.

The Myth and Ritual school

In a much more articulate way, biblical scholars stressed the necessity to look for the situation in life and custom (the "Sitz im Leben") that mythical texts originally possessed. A number of scholars, mainly in Britain and the Scandinavian countries and usually referred to as the Myth and Ritual school (of which the best-known member is the British biblical scholar S.H. Hooke), have concentrated on the ritual purposes of myths. Their work has centred on the philological study of the ancient Middle East both before and since the rise of Islām and has focused almost exclusively on rituals connected with sacred kingship and New Year's celebrations. Of particular importance was the discovery that the creation epic *Enuma elish* was recited at the Babylonian New Year's festival: the myth was, it was argued, expressing in language that which the ritual was enacting through action. Classical scholars have subsequently investigated the relations between myth and ritual in ancient Greece. Particularly influential has been the study of sacrifice by Walter Burkert entitled *Homo Necans: The Anthropology of Ancient Greek Sacrificial Ritual and Myth* (1983).

Connections between myths and cult behaviour certainly exist, but there is no solid ground for the suggestion, following Frazer, that, in general, ritual came first and myth was then formulated as a subsequent explanation. If it is only the subsequent myth that has made the sense of the earlier ritual explicit, the meaning of the ritual may remain a riddle. There is in fact no unanimous opinion about which originated first. Modern scholars are inclined to turn away from the question of temporal priority and to concentrate instead on the diversity of the relationship between myth and ritual. While it is clear that some myths are linked to rituals, so that it makes sense to say that the myth is expressing in the language of narrative that which the ritual expresses through the symbolism of action, in the case of other myths no such ritual exists.

The content of important myths concerning the origin of the world usually reflects the dominant cultural form of a tradition. The myths of hunter-gatherer societies tell of the origin of game animals and hunting customs; agricultural civilizations tend to give weight to agricultural practices in their myths; pastoral cultures to pastoral practices; and so on. Thus, many myths present models of acts and organizations central to the society's way of life and relate these to primordial times. Myths in specific traditions deal with matters such as harvest customs, initiation ceremonies, and the customs of secret societies.

Religious symbolism and iconography. Sacred objects are found in all religious traditions, and sacred images in most. They are the material counterparts of myth inasmuch as they represent sacred realities of figures, as myths do in narrative form. Representing does not entail faithful copying of natural or human forms, and in this respect religious symbolism is again like myth in that both depict the extraordinary rather than the ordinary. Many symbolic representations have their sources in myths. Representations in human form, especially "natural" human form, are rare. The sculptures of divine figures in classical Greece (by sculptors such as Phidias and Praxiteles) are the exception. Usually the degree of representation occurring in cult practices and the depiction of mythical themes has been considerably less humanistic. An example is the way geometric and animal figures abound in the history of religions. Another example is the use of sacred masks, as in the mysteries of Dionysus, an ecstatic cult in the Aegean world of classical antiquity, and the indigenous traditions of Australia, America, prehistoric Europe, and elsewhere.

Sacred texts. The Old Testament is usually regarded as embodying much material that anthropologists would regard as containing mythical themes in just the same way as the practices of the ancient Greeks, Chinese, or Abnaki Indians are bound up with myths. Yet the religion of Israel was in many respects critical of myths (in the sense of noncanonical, approved narratives). Similarly, it rejected any representation of God in natural forms. Anti-mythological tendencies exist in the religions that have their roots in Israel. The New Testament of Christianity in some instances derogates myths by describing them as "godless" and "silly." Islām's emphasis on the transcendence of God, as attested in the Qur'ān, similarly allows little room for mythological stories. The activities of the supernatural beings known as *jinn,* however, are acknowledged even by official Islām, besides being prominent in popular belief (as in *The Thousand and One Nights*); and other mythological themes, for example motifs relating to the end of time (eschatology), also figure in Islāmic religion, above all in its Shī'ite form. Orthodox Shī'ite Muslims believe in the existence of 12 *imāms,* semidivine descendants of the Prophet Muḥammad through his son-in-law 'Alī. Toward the end of time, according to the beliefs of Shī'ism, the 12th *imām* will return to bring truth and justice to mankind.

Biblical and Qur'ānic criticism of myth

Other traditions with sacred scriptures are more tolerant of myth, for example Hinduism and Buddhism. Running through certain central texts of the Hindu sacred tradition is the theme of the contrast between the One and the Many. Thus, the philosophical poem known as the *Bhagavadgītā* contrasts the person who sees Infinity within the ordinary finite world with the person who merely sees the diversity of appearances. Yet this ascetic and abstract view by no means excludes a rich and extraordinarily diverse mythology, which is reflected in the tremendous variety of Indian religious statuary and which mirrors the religious complexity of Indian society. A justification for the coexistence of an ideal of unity with a pluralistic reality is found in the *Rigveda,* where it is written that although God is One the sages give him many names. Buddhism also finds room for exuberant mythology as well as for the plainer truths of sacred doctrine. Buddhism embraces not only the teachings of the Buddha about the pursuit of the path to Enlightenment and Nirvāṇa but also the exotic mythical figures of Yamantaka, who wears a necklace of skulls, and the grossly fat god of wealth Jambhala.

Myth and the arts. *Oral traditions and written literature.* Myths in ancient civilizations are known only by virtue of the fact that they became part of a written tradition. In the case of Greece, virtually all myths are "literature" in the form in which they have survived, the oldest source being the works ascribed to the Greek poets Homer and Hesiod (usually dated, in written form, to the 8th century BC). Literary forms such as the epic have frequently served as vehicles for transmitting myths inasmuch as they present an authoritative account. The Homeric epics were both an example and an exploration of heroic values, and the poems became the basis of education in classical Greece. The great epics of India (*Mahābhārata* and *Rāmāyaṇa*) came to function as encyclopaedias of knowledge and provided models for all human existence.

Visual arts. In principle, the sort of relationship that exists between myth and literature exists also with respect to the other arts. In the case of architecture and sculpture, archaeological discoveries confirm the primacy of mythical representations. Among the earliest known three-dimensional objects built by man are prehistoric megalithic and sepulchral structures. Mythological details cannot actually be discerned, but it is generally believed that such structures express mythological concerns and that mythical images dictated the shape. An especially intriguing example is the stone circle at Stonehenge in southern England. Axes of this construction are aligned with significant risings and settings of the Sun and Moon, but the idea that

Mythological aspects of architecture

the circle was built for a religious purpose must remain likely rather than certain.

Grave monuments of rulers are among the most important remains of ancient civilizations (*e.g.,* the Egyptian pyramids; and the sepulchral structures of Chinese rulers since the Chou period, *c.* 1111–255 BC). There is worldwide evidence that in archaic cultures man considered the points of the compass to have mythological affiliations (*e.g.,* the West and death or the East and a new beginning). Mythological views even influenced building activity. One architectural feature that can have mythological significance is the column. In a number of popular traditions the sky is believed to be supported by one or more columns. The relatively strict separation between religious and civil architecture that modern man is perhaps inclined to take for granted has not existed in most cultures and periods and perhaps is not universal even in modern times.

Even when art ceases to represent mythological matters outright, it is still usually far from representational. That art has ceased to represent mythology is challenged by some theorists, who argue that what seems to be abandonment of mythological forms is really only a change in mythology. The opposing arguments are analogous to the favourable or unfavourable attitudes toward myth that religions have developed.

Myth as a source of the drama and the dance

Performing arts. Myth is one of the principal roots of drama. This is particularly obvious in the earliest Western drama, the tragedies of classical Greece, not only because of the many mythological subjects treated and the plays' performance at the festival of Dionysus but also because of the playwrights' mythlike presentation of events and facts. An example of such presentation is the story pattern, notably the way retribution follows transgression. Another feature of Greek drama that is relevant to the subject of myth is the fact that the role of the chorus was taken by a group of ordinary citizens. In Greek tragedy the heroic past was presented and explored by a chorus of nonheroic individuals; hence the meaning of the inherited myths was examined by a collectivity that can be seen as standing for the wider collectivity (more than 10,000 in number) that constituted the audience at the plays. In its songs the chorus frequently had recourse to expressions of a proverbial kind, using the distilled wisdom of the community to account for the strange and often disturbing events represented in the plays. The origins of drama are obscure, but Theodor Gaster, an American historian of religion, has suggested that in the ancient eastern Mediterranean world the interrelationship of myth and ritual created drama. Elsewhere, dramatic presentations (as in Japanese Nō plays and the Javanese *wayang*) are similarly rooted in myth.

Dance has been a medium for the expression of mythological themes throughout the world and in all periods for which there is evidence. Especially common are dances aimed at ensuring the continuity of fertility or the success of hunting, at curing the sick, or at achieving shamanistic trance states. An aspect of the decay of ritual in the modern West is the tendency for dance to lose its close and direct connection with the life of the community. A further consequence is that the role of dance in embodying and exploring a community's myths has often been overlooked, and dance may have become further removed from myth than any other form of art in the Western world. There are important and significant exceptions, however. One of the most notable is the work of the American choreographer Martha Graham, who frequently used mythical themes—often drawn from Greek antiquity—as the inspiration for her ballets.

Music. Myth and music are linked in many cultures and in various ways. For example, numerous stories ascribe the origins of music to a figure, usually divine, who lived in the mythical past. Thus, in ancient Greece the lyre was said to have been invented by the god Hermes, who handed it on to his brother Apollo as part of a bargain. From then on Apollo played the lyre at the banquets of the gods, while the Muses sang to his accompaniment. An ancient Chinese myth tells of the discovery of the "foundation tone," which, in addition to being a musical note of specific pitch, also had political implications, since each dynasty was thought to have its own "proper pitch." The foundation tone was produced when Ling Lun, a scholar, went to the western mountain area of China and cut a bamboo pipe in such a way that it produced the correct sound.

Throughout the world music is played at religious ceremonies to increase the efficacy and appeal of prayers, hymns, and invocations to divinities. The power of music to charm the gods is movingly expressed in the Greek story of Orpheus. This mythical figure goes to the underworld to try to have his dead wife, Eurydice, restored to life. By means of his lyre playing and singing he is able to win over even the god of death, so that Eurydice is allowed to leave the underworld. The continuing potency of the myth (including its tragic conclusion—Orpheus is forbidden to look back at his wife but does so and thus loses her again) is shown by the fact that it has been retold in Europe by numerous composers of opera since the early 17th century.

Lévi-Strauss's view of myth and music

That a particularly close connection exists between myth and music has been argued by Claude Lévi-Strauss. In an analysis of the myths of certain South American Indians (*Le Cru et le cuit,* 1964; *The Raw and the Cooked*) he explains that his procedure is "to treat the sequences of each myth, and the myths themselves in respect of their reciprocal interrelations, like the instrumental parts of a musical work and to study them as one studies a symphony." His treatment is divided into such subsections as "The 'Good Manners' Sonata," "Fugue of the Five Senses," and "The Opossum's Cantata." In *Myth and Meaning* (1978) Lévi-Strauss returned to the link between myth and music, which had proved difficult for his readers to understand. To make his point clearer Lévi-Strauss took the example of a theme from an opera by Richard Wagner. Each time the theme is repeated its overall meaning grows clearer, as each instance is superimposed on the others in the series, so that it becomes possible to see what the different occurrences of the theme have in common. Analogously, the meaning of a myth is found not simply by reading its narrative in sequence, but by superimposing upon one another similar mythical events from one narrative and boiling down each resulting "bundle" to a common denominator. It is the relationship between these bundles that constitutes the logic of the myth.

The use of music for religious ends has declined in modern Western societies, but mythical themes (*e.g.* in opera and oratorio) are still used with genuine artistic effect. The repertoires of late 20th-century opera companies may include, for example, Giacomo Puccini's *Turandot,* about a princess who asks her suitors three riddles and beheads them if they fail to answer correctly and a prince who will die if his name is discovered; Richard Strauss's *Die Frau ohne Schatten* ("The Woman Without a Shadow"), about a princess who must gain a shadow or her husband will be turned to stone; and Wagner's *Tannhäuser, Lohengrin, Der Ring des Nibelungen,* and *Parsifal,* all loosely based on tales from medieval Germanic mythology.

Myth and history. Myth and history represent alternative ways of looking at the past. Defining history is hardly easier than defining myth, but a historical approach necessarily involves both establishing a chronological framework for events and comparing and contrasting rival traditions in order to produce a coherent account. The latter process, in particular, requires the presence of writing in order that conflicting versions of the past may be recorded and evaluated. Where writing is absent, or where literacy is restricted, traditions embedded in myths through oral transmission may constitute the principal sources of authority for the past. Hence, myths may be cited when a situation in the present is materially affected by what version of the past is accepted. For instance, if a dispute arises among the Iatmul of Papua New Guinea over the rights of different clans to possess land, the contending parties take part in oral contests involving the recitation of long lists of mythological names and other details from the myths. Since each clan's view of the mythic past has implications for the ownership of estates by persons living in the present, victory in these contests is a matter of direct practical importance to the participants.

Myth, history, and tradition

Even in societies where literacy is widespread and where

a considerable body of professional historians is at work, it may still be the case that a majority of the population form their views of the past on the basis of inherited mythlike traditions. Examples from the 20th century in Europe would be the polarized communities (Protestant and Roman Catholic) of Northern Ireland, or pro- and anti-Communist sympathizers in Greece. In the former case, the two communities have different and irreconcilable pictures of the events related to the partition of Ireland. In the latter case, the course of the civil war (after the end of World War II) is viewed quite differently by the two groups. These rival traditions may be described as mythlike because they are narratives with a strong validating function—the function of justifying current enmities and current loyalties—and they are believed with a quasi-religious faith against which objective historical testing is all but powerless.

Finally, similarities to myths may be present even in the work of those who are justifiably described as historians. A clear instance of this is the ancient Greek writer Herodotus, the so-called "father of history." He had the radically original idea of writing an account of the struggle between the Greek world and its "barbarian" neighbours during the Persian Wars, an account that combined and evaluated a range of disparate and often conflicting pieces of information. On these grounds he should certainly be described as a historian. Yet, his work is full of themes and story patterns that also occur in Greek myths—for example, transgression against the gods leads to retribution; again, people who live at the margins of the Greek world are imagined as having customs that are the exact inverse of their Greek equivalents. In the work of Herodotus there is no incompatibility between myth and history; both historical events and the patterns into which such happenings are perceived as falling form part of his overall enterprise: namely, to conduct an inquiry (the meaning of the Greek word *historia*) into the past. As with the distinction between myth and science, then, that between myth and history is by no means a straightforward one.

MAJOR TYPES OF MYTH

Myths of origin. Cosmogony and creation myth are used as synonyms, yet properly speaking, cosmogony is a preferable term because it refers to the origin of the world in a neutral fashion, whereas "creation myth" implies a creator and something created, an implication unsuited to a number of myths that, for example, speak of the origin of the world as a growth or emanation, rather than an act. Even the term origin should be used with caution for cosmogonic events (as well as for other myths purporting to describe the beginning of things), because the origin of the world hardly ever seems the focal point of a mythological narrative—as a mythological narrative is not a matter of inquiry into the first cause of things. Instead, cosmogonic myths are concerned with origins in the sense of the foundation or validity of the world as it is. Creation stories in both primitive and advanced cultures frequently speak of the act of creation as a fashioning of the earth out of raw material that was already present. In African cosmogonies, especially, the earth is preexistent. A creation out of nothing occurs as a theme much less frequently, for all that such creation myths are more satisfying to the philosophical mind. Philosophical questions, however, are less important in the justificatory systems set up by myth.

Water, though important everywhere as a source of life and image of endless potentiality, has a special role in Asia and North America, where the creator (often an animal) is assisted by another figure, who dives for earth in the primordial ocean. The earth-diver helper sometimes develops into an opponent, or Satan-like character, in other areas—*e.g.*, those touched by Zoroastrianism, an ancient Persian dualistic religion. Though hardly an explanation in the ordinary sense of the word, the theme accounts for the fact that evil is constitutive of the cosmos without holding the creator responsible for it. Other widely diffused motifs are: the cosmogonic egg, found in the Pacific world, parts of Europe and southern Asia (*e.g.*, in Hinduism); the world parents (usually in the image of sky and earth); and creation through sacrifice or through a primordial battle. Creation through the word of the creator also occurs outside the Old Testament account (in Polynesia).

Cosmogony sets the pattern for everything else in most traditions; other myths are related to it or derived from it. Because man's inhabitable world, the cosmos, is the crucial issue, no matter how various the contents may be and how different from one period to another, cosmogony probably is the clearest expression of man's basic mythological propensity. All cosmogonic accounts have certain formal features in common. They speak of irreconcilable opposites (*e.g.*, heaven and earth, darkness and light) and, at the same time, of events or things totally outside the common range of perception and reason (*e.g.*, a "time" in which heaven and earth were not yet separated and darkness and light intermingled). In other words, the basic ingredients of man's world and orientation are presupposed yet are realized, constituted, or brought about anew in the narration. The narrative can arrive at such a reconstitution only by transcending the limits of ordinary perception and reason.

Common features in cosmogonic and creation myths

The origin of man is usually linked immediately to the cosmogony. Man, for instance, is placed on the earth by God, or in some other way his origin is from heaven. Nevertheless, it is only in mythologies influenced by philosophical reflections that the place of man becomes the conspicuous centre of the cosmogony (*e.g.*, Pythagoreanism, a Greek mystical philosophical system; Orphism, a Greek mystical religious movement; Gnosticism, a Christian dualistic and esoteric movement; and Tantrism, a Hindu and Buddhist esoteric meditation system). Man is sometimes said to have ascended from the depths of the earth (as with the Zuni, an American Indian people) or from a certain rock or tree of cultic significance. These images are often related to the idea of a realm of ancestors as the origin of newborn children. Man is also said to be fashioned from the dust of the ground (as in Genesis) or from a mixture of clay and blood (as in the Babylonian creation myth). In all cases, however, man has a particular place (because of his duties to the gods, because of his limitations, or even because of his gifts), even though—especially in many hunters' civilizations (*e.g.*, the African San peoples and many North American Indian tribes)—the harmony of man and other forms of nature is emphasized.

In most cosmogonic traditions the final or culminating act is the creation of man. The condition of the cosmos prior to man's arrival is viewed as separate and distinct from the alterations that result from the beginning of the human cultural world. Creation is thus seen as a process of periods or stages, frequently in a three-stage model. The first stage consists of the world of gods or primordial beings; the second stage is the world of the ancestors of man; and the third stage is the world of man. The three stages are sometimes seen as interrelated; for example, the gods may be the creators of man or the ancestors of man, or ancestors may undergo a transformation to become men.

Among innumerable tales of origin, one of the most common types is related to the origins of institutions. Certain initiation ceremonies or ritual acts are said to have originated in the beginning, in mythical times, this primeval moment of inception constituting their validity.

Myths of eschatology and destruction. Myths of eschatology deal with "the end." The end is conceived of as the opposite of the cosmogony; it means first and foremost the origin of death but also, in a wider sense, the end of the world. Special forms of eschatology are prevalent in messianism (belief in a future salvation figure) and millenarianism (belief in a 1,000-year reign of the elect).

Myths about the origin of death, for which an added explanation has to be found in the sense that death is not seen as automatically the end of life, are probably as widely diffused as creation stories. One of the most common types of such myths speaks of a primordial time in which death did not exist and explains that it arose as the result of an error, as a punishment, or simply because the creator decided the earth would get too crowded otherwise. One example of a myth about the origin of death may be regarded as characteristic; it occurs, with variations, in many parts of the world. Among the Zulus the story is told that the supreme being Unkulunkulu instructed the

The origin of death

chameleon to take a message to mankind, saying that they would be immortal. But the chameleon moved slowly, since he stopped to have something to eat (or, according to a variant, basked in the sun and fell asleep). In due course the supreme being changed his mind and sent a lizard to men, telling them that they would die. The lizard arrived and delivered his message. When the chameleon eventually arrived, his message conflicted with what mankind had already been told by the lizard. The chameleon was not believed, and men were mortal from then on.

Expectations of a cataclysmic end of the world are also expressed by myths. A universal conflagration with a final battle and defeat of the gods is part of Germanic mythology and has parallels in other examples of Indo-European eschatological imagery. In many "primitive" religions specific expectations about the end of the world do occur, but until recently they have not received much scholarly attention. An example of such a belief about the end of the world is found among the Pawnee Indians. In their view, there will come a time when everything will disappear and the star of death will govern the world. The Moon will turn red, the Sun will be extinguished, and men will be turned into stars flying along the route to heaven now taken by the dead.

Messianic and millenarian myths. The hope of a new world surges up from time to time in many civilizations. Many such religious movements have flourished in the 20th century in Melanesia, Africa, South America, and Siberia. Christian elements are usually detectable, but the basic element in virtually all cases is indigenous. These cults and movements centre on prophetic leaders, often emphasize the return of the dead at the renewal to come, and are convinced of a catastrophic end of the present world. In many cases, the culture hero is expected to return and lead believers in battle against the evil forces. In the history of Judaism and Christianity, as in many primitive millenarian and messianic movements, there is an expectation of a new heaven and a new earth.

Myths of culture heroes and soteriological myths. A great many nonliterate traditions have myths about a culture hero (most notably one who brings new techniques or technology to mankind—*e.g.,* Prometheus, who supplies fire to mankind in Greek mythology). A culture hero is generally not the person responsible for the creation but the one who completes the world and makes it fit for human life; in short, he creates culture. Another example of a culture hero is Maui in Polynesia, who brought islands to the surface from the bottom of the sea, captured and harnessed the Sun, lifted the sky to allow man more room, and, like Prometheus, gave fire to mankind.

The bringer of culture is often also the bringer of health. Thus, the culture hero of the Woodlands and Plains Indians in North America is at the same time related to the foundation of the medicine society. A comparable figure occurs in many traditions of classical antiquity or the Mediterranean basin generally as the "good son"—*e.g.,* Horus, the son of the god Osiris in Egypt, or the figure of the king in the Psalms. Health and (spiritual) salvation are synonymous, and this is implied in the Greek word *sōtēr,* which can mean both "saviour" and "preserver from ill health." Related to soteriological myths in many cases is the hope for a final and total salvation in which the "good" powers will triumph, such as through Saoshyant, the saviour in Zoroastrianism. In fact, Zoroastrianism shared with the Judeo-Christian tradition the notion of a Last Judgment followed by the ultimate salvation of the world. According to Zoroastrian belief, as the end approached heroes from the past would come to life and help in the struggle of good against evil. Saviours, the Saoshyants, would work toward the triumph of virtue and the spreading of heavenly light over all creation.

Myths of time and eternity. The apparent regularity of the heavenly bodies long impressed every society. The sky was seized as the very image of transcendence, and what seemed to be the orderly course of Sun, Moon, and stars suggested a time that transcended man's—in short, eternity. Many myths and mythological images concern themselves with the relationship between eternity and time on earth. The number four for the number of world ages figures most frequently. The Zoroastrians of ancient Persia knew of a complete world age of 12,000 years, divided into four periods of 3,000 each, at the end of which Ormazd (Wise Lord) would conquer Ahriman (Destructive Spirit). Similarly, the Book of Daniel (in the Old Testament) mentions four kingdoms—of gold, silver, bronze, and a mixture of iron and clay, respectively—after which God will establish an everlasting kingdom. The notion of four world ages, sometimes associated with metals, occurs also in the works of classical writers and in later speculative writings on human history. Judaism developed the view of a 1,000-year period between the four world ages and the everlasting kingdom (hence the words millennium and millenarian). Although other numbers occur (three, six, seven, 12, and 72), four is dominant. In ancient Mexico this world was held to be preceded by four other worlds. India, in both Hindu and Buddhist texts, has developed the most complex system of world ages and worlds that arise and come to an end. Here, too, the number four is important—*e.g.,* the four ages (*yugas*) of decreasing length and increasing evil. Many writings, often with large numbers, reflect exact astronomical observations and calculations. Some mythologies—*e.g.,* those of the Maya in Central America—have developed sophisticated views interrelating time and space. Mythological accounts of repetitions of worlds after their destruction occur not only in India but also elsewhere, such as in Orphism and in the Stoic philosophy that flourished in classical antiquity.

The ages of the world

Myths of providence and destiny. In attitudes to the idea of a link between human activity and the stars, the most familiar example of which is probably astrology, there is a broad range of mythical motifs between astrological calculations (in the sense of an attempt at an intellectualized account of what is happening) and devotional self-surrender. There are many occasions at which a man may be filled with doubt about his own fate or the fate of his community. In some myths divine supremacy is marked by a god's mastery over fate. Marduk, the patron god of Babylon, acquires the "tablets of fate" in his primordial battle preceding the creation. There is no doubt about Zeus's supremacy in the Greek poet Hesiod's genealogical account of the gods, yet in the works of Homer, Zeus is powerless to defy fate and save the life of his son Sarpedon. Mythological views of providence, destiny, or fate are given precise shades of meaning vis-à-vis dominant views in a tradition concerning justice and divine law, the philosophical problem of determinism, the theological problems of theodicy (justification of a good god with observable facts of evil), and predestination. An important difference in mythological accounts of providence exists between those traditions that speak of the creation of the world as a result of God's will (as in Judaism, Christianity, and Islām) and those that attribute worldly phenomena to causation by a lesser being (as Buddhism does).

Myths of rebirth and renewal. Myths of archaic traditions generally imply a conception of the world, nature, and man in terms of cyclic time. According to Australian Aboriginal myth, man is reincarnated into profane life at the moment of his birth. At his initiation he reenters sacred time, and through his burial ceremony he returns to his original "spirit" state. Similar beliefs are held by many tribal peoples, and their myths are expressed in terms of cosmic cycles. Special myths are narrated in many places in preparation for initiation procedures. In agricultural societies, in addition to the themes of cosmic renewal, renewal through birth, and rebirth through initiation ceremonies at the attainment of manhood and womanhood, the theme of seasonal renewal is of great importance. The cyclic concept of time in all these traditions is present in many of the great religious and philosophical systems, such as Brahmanism (a Hindu system), Buddhism, and Platonism, and to some extent it is at variance with the idea of linear time typical of Judaism, Christianity, and Islām. But no culture, not even that of Jews, Christians, or Muslims, completely disregards the cyclic patterns of the seasons, work, festivities, or existence. Such patterns seem to be engraved on man's perception of the world.

Cyclic time

Myths of memory and forgetting. Some of the North American medicine men claim to remember their prena-

tal existence. Such memory, according to their mythology, is lost in ordinary people. Similar myths of memory and forgetting are related to the hierarchy that exists in all archaic societies. The fundamental knowledge of the world, transcending ordinary consciousness, is not equally attainable by everyone. Myths of memory can take the form of collective nostalgia. In South America the Yaruros, whose material existence was so simple that they lacked the skills of the agricultural and pastoral life, were one of the many tribes that in the face of modern Western cultural expansion gave up the struggle for their own social and cultural identity, becoming assimilated into a more complex society. As the Yaruros ceased to struggle for the preservation of their tribal identity, they expressed a yearning to return to the Great Mother ruling the land of the dead and awaiting them in her paradise. Mythologies of memory and forgetting have a role in many traditions. They are of great significance in traditions where the idea of rebirth or reincarnation exists. Some people have claimed to remember previous existences, and a few (among them the Buddha) the very first. The veil of *māyā* ("illusion") in many Indian stories prevents a man from remembering his true origin and goal. In Gnosticism there is talk of a similar forgetfulness, which must be resisted. In ancient Greek myth, Mnemosyne (Memory), the mother of the Muses, is said to know everything, past, present, and future. She is the Memory that is the basis of all life and creativity. Forgetting the true order and origin of things is often tantamount to death (as in the case of Lethe, the river of death in Greek mythology, which destroys memory). Anamnesis, "commemoration" or "recollection," is one of the crucial parts of the Christian celebration of the Communion. Through the anamnesis, the passion and death of the Lord is "applied" to the congregation. In philosophy, the imagery of forgetting and remembering occurs in the thought of Śaṅkara, a medieval Indian philosopher, and of Plato in connection with the paramount calling of the thinker and the difficulty of living up to that calling.

Myths of high beings and celestial gods. Supreme celestial deities occur in many mythologies, with various qualities and attributes, in many shapes, and with great diversity in cultic significance. A cardinal distinction exists between the supreme being in many archaic or polytheistic traditions and the God of the great monotheistic systems (Judaism, Christianity, and Islām). Even though certain qualities seem alike in many cases (*e.g.,* transcendence, omniscience), the God of the latter arose historically in a reaction to polytheistic views and practices and demonstrates his supremacy accordingly, whereas the more archaic types of supreme beings nowhere show that aggressive aspect in their mythologies. The exalted status of archaic supreme beings and celestial gods does not necessarily involve exclusion of other supreme beings. Outstanding examples are Vishnu, Śiva, and the great goddess in Hindu literature, who are each described as supreme yet do not reduce the "reality" of the others. "Supremacy" is not as unambiguous and general a term as it seems, and in Hinduism it refers first and foremost to the *perfection* (*i.e.,* the idea that a deity is supremely perfect) of a deity in himself.

Distinction between high gods and one unique God

The sky seen as a sacred entity is an all but universal belief. It is often related to or identical with the highest divinity. Nevertheless, supreme beings are always more than what can be explained from celestial phenomena alone, for they are often called creators of the world, founders of the order of the world, and protectors of law; and they are praised for their eternity and goodness. Often, the supreme being that created the world does not—or has ceased to—receive attention in the cult, although he may still be invoked in moments of great crisis. In a good many ancient agricultural societies, the idea of a great goddess prevailed instead of a male creator-god. The great goddess (as in the ancient Middle East and India) is venerated principally because of her omnipotence, especially her power over life. The sky god-creator sometimes cedes to a divinity who is also related to the sky but apparently is experienced more concretely because of his activity. Such a divinity (especially in pastoral cultures) can be a god of atmospheric phenomena (storm, rain, thunder, or lightning), whose power for the good of the people is extolled. In spite of his power, however, he is one of several gods, and in some cases (Yahweh in ancient Israel and Allāh in Islām) one such god retains the full creative function of early creator gods, and in him all "true" divinity is concentrated. In addition, a divinity related to the Sun rather than the heavens can assume preeminence; this has happened in some ancient imperial traditions (*e.g.,* Egypt, Inca Empire). Among sky gods who remained important in the mythologies of ancient civilizations are Zeus in Greece, Jupiter in Rome, and T'ien in China.

Myths concerning founders of religions and other religious figures. Although the founders of great religions (Confucius, Zoroaster, the Buddha, Moses, Jesus, Mani, Muḥammad) are generally conceded to have had actual existence, information about them is couched in legendary terms that have many mythological features. The same is true of many other religious figures (prophets, saints, or gurus [Hindu spiritual teachers]). Those traditions that have preserved the memory of their founders have, as a rule, carefully emphasized the elements that function most mythologically, in the sense that they state categorically realities that could not be known in any ordinary fashion or that raise the founder above ordinary historical conditions. Examples are the account of Jesus' prayer in Gethsemane, which no one heard according to the text itself, his statement that he was before Abraham, and his prophecies. Buddhist texts state that the Buddha not merely surpassed all yogis in knowledge of previous existences but, in fact, had conquered time. Well known too are his predictions concerning the course and decline of Buddhism and (in Mahāyāna texts) his promises as to the future spiritual attainments of the bodhisattvas. Other examples are Muḥammad's eschatological teachings in the Qur'ān and those of Zoroaster.

Mythological features in records of historical figures

Myths of kings and ascetics. Genuine myths concerning kings are found only in traditions that know a form of sacred kingship. Temple records from ancient Babylon mention offerings to kings who were considered divine. Hymns addressed to them make references to the king's union with a goddess—*i.e.,* the mythological motif of the "sacred marriage." One of the epithets for the king in ancient Egypt was "endowed with life" or "imparting life." The twofold meaning of the epithet is significant and can serve to make the mythology of sacred kingship understandable in other places as well, because the function of the king is in fact double. He mediates between the divine world and the world of man, representing each to the other. Hence, in Egypt a sacrifice by an individual was understood as offered to the king and at the same time by the king. The king's role of mediator and protector brings royal mythologies close to myths of culture heroes. Solemn procedures in which kings become divinities occur relatively late in history. An early and most conspicuous case of such an apotheosis (becoming divine) is that of Alexander the Great, who was called a god in his lifetime. Later, apotheosis took place for Roman emperors, although there are no cases of an emperor being accorded divine honours in his lifetime. A great many legends have accumulated around the figures of kings (*e.g.,* around King Aśoka of India and King Arthur in Britain). Stories about the Holy Roman emperor Frederick I Barbarossa and Charlemagne have a somewhat eschatological mythical flavour, because they are said to dwell each in his mountain (in the Kyffhäuser and the Untersberg, respectively) until they appear again to act as saviours in a crisis.

Most narratives about great ascetics, as well as other saints, could be regarded as legends rather than myths. There are, however, instances of saints or ascetics who are presented as a more than worldly model, so that a case can be made for the mythological function of their legends (*e.g.,* al-Ḥallāj in Islām and St. Francis in Christianity). In the case of traditions that have asceticism as an integral part, certain figures and the legends around them do indeed function as exemplars.

Myths of transformation. Countless stories exist concerning the origin of peculiar rocks, properties of animals, plants, stars, or other features in the world. In addition to such etiologic tales there are several myths that speak

of cosmic changes brought about at the end of primordial times. An altogether different and extensive mythology exists concerning initiation rites and other "rites of passage" that involve transformation of man's being.

Cosmic transformation may concern an original world, without proper human means of existence and without death, that was transformed through a certain event (*e.g.,* the death of Hainuwele, a type of primal being known as a dema, or ancestral, deity) into the world known to mankind, a truly inhabitable world with vegetation, animals, and other features that had not existed before.

On a wider scale are myths that could be appendages to cosmogonic myths but that have not turned into mere etiologies. Many myths akin to the type of the dema deity (like Hainuwele) and to the culture-hero type (like Prometheus) account for events—such as the invention of agriculture, domestication of animals, and the use of fire—that have transformed the world for the benefit of man. Many others are just as closely related to cosmogonic accounts but tell of "setbacks" in primordial times. In agricultural societies, for example, myths have been collected that ascribe the unevenness of land or the formation of mountains to an ancient mishap or evil force.

Realization of the contents of myths

In rites of passage (*e.g.,* rites accompanying birth, attainment of maturity, marriage, death) the contents of myths are acted out. In each case the intention behind the rites is that man's mode of being be affected, indeed transformed. Through the birth ceremony the child "becomes" a person, and through initiation an adolescent "becomes" an adult, a member of a sodality, or a warrior. There is a great variety of customs in different communities and traditions, but everywhere these rites dramatize graphically the cosmic processes and realities expressed in language in myths. In many traditions the myths of the community are conveyed to the novice at the time of his initiation. Even in the major world religions rites of passage are still performed, as evidenced in such ceremonies as circumcision, Baptism, weddings, and mortuary rites. In all instances, the rites derive their meaning from the core of the tradition, and for that reason man's existence is regarded as transformed. In some cases the transformation derived from the dominant myth is far-reaching. The initiated shaman is able to transcend the ordinary human condition and overcome dangers that would cause the death of a noninitiate. Through his initiation he is believed to have gone through death and thus conquered it. In certain Hermetic (an occult magical tradition) and Gnostic texts the certainty of attaining divine being is clearly expressed.

MYTH IN MODERN SOCIETY

Secularization of myth and mythology. Deciding the extent to which there has actually been any secularization of myth involves a problem of definition. If myth is seen as the product of a past era, it is difficult to determine at what actual moment that era ended. Thus, it is virtually impossible to state precisely when a certain mythical theme becomes a mere literary theme or to determine in general when myths are no longer being created. It is more fruitful to recognize that symbols, myths, and rituals are all subject to change over time. Nor is secularization an irreversible process. It is instead a process that takes place time and again. Secularization movements and movements toward "mythification" of a phenomenon, narrative, or idea are aspects of the same historical processes. There have also been many types of secularization; the one brought about in Western society since the Middle Ages is only a single example. Another instance was the development in archaic and classical Greece (sometimes referred to—with great oversimplification—as a movement "from myth to reason") whereby fundamental questions about the nature of the universe came increasingly to receive answers in terms of philosophical, as opposed to mythical, reasoning.

On the other hand, although the secularization of modern times is not a unique phenomenon, it is a new and complex type, to which many factors have contributed. Scientific, particularly astronomical, discoveries of the late medieval and Renaissance periods were accompanied by a new trust in cosmic laws and an increasingly abstract notion of God. More or less Euhemeristic historical accounts that were common in the Middle Ages and were a symptom of a certain secularization process themselves gave way to history writing, focusing on psychological, social, and economic facts. In philosophy, naturalism of various sorts opposed notions of transcendence that earlier systems had taken for granted. The most common tendency in modern society has been to regard the characters and events in mythical accounts as not real or as by-products of realities that are not transcendent but rather immanent.

Secularization with mythification

This secularization in modern society, like earlier secularization processes, is accompanied by a process whereby new myths are formed (see below *Political and social uses of myth*).

Demythologization of major religious traditions. Demythologization should be distinguished from secularization. Every living mythology must come to terms with the world in which it is transmitted and to that extent inevitably goes through processes of secularization. Demythologization, however, refers to the conscious efforts people make to purify a religious tradition of its mythological elements. The term demythologization (*Entmythologisierung*) was coined by Rudolf Bultmann, a German theologian and New Testament scholar. In the strict sense of the word, demythologizing efforts have been limited to theological discussions in 20th-century Christianity.

Even after secularization has taken place a certain mythological residue may persist. Edward B. Tylor, one of the founders of anthropology as an academic discipline in the 19th century, coined the use of the word survival for customs and beliefs that continued to be adhered to long after the context in which they had had their meaning had ceased to exist. Because such customs and beliefs may be regarded as mere superstitions, the word survival usually has a slightly derogatory overtone. There are many survivals of myth in this sense. The myth of "the noble savage," well-known from the 18th-century writer Jean-Jacques Rousseau, can be understood as a survival of a paradisiacal mythology: Western man expecting to find evidence of paradise on earth.

The secularization process in modern times has affected symbolic behaviour (cult, ritual, liturgy) and symbolic objects (sacred places) more than myth, however. Nevertheless, commonly accepted forms of mythology in modern society do not permeate all parts of society or fulfill all needs. (In all likelihood, no society has ever been perfectly homogeneous in its myths.) At the same time there exist profound mythological needs in modern society, and some are filled by myths borrowed from submerged or alien traditions. Modern society's neglect of cosmic symbolism (which in contrast was widespread in archaic tradition) has provoked certain reactions, such as the continuing interest in astrology, which may even be seen as an attempt to present a coherent account of the cosmos. And the huge scientific advances of the 20th century have given rise to a literature, science fiction, that resembles myth, even down to an eschatological element.

Political and social uses of myth. In the industrialized Western society of the 20th century, myths and related types of tales continue to be told. Urban folklorists collect stories that have much in common with the tales collected by the Grimm brothers, except that in the modern narratives the lone traveler is likely to be threatened, not by a werewolf, but by a phantom hitchhiker, and the location of his danger may be a freeway rather than a forest. Computer games use sophisticated technology to represent quests involving dragons to be slain and princesses to be saved and married. The myth of Superman, the superhuman hero who saves the world and preserves "the American way," is a notable image embodying modern Americans' confidence in the moral values that their culture espouses. Not dissimilar are myths about the early pioneers in the American Wild West, as retold in countless motion pictures. Such stories often reinforce stereotypical attitudes about the moral superiority of the settlers to the native Indians, although sometimes such attitudes are called into question in other movies that attempt to demythologize the Wild West.

A particular illustration of the power that myths continue to exert was provided as late as the 1940s by the belief

in the existence of an Aryan racial group, separate from and superior to the Semitic group. This myth was based in part on the assumption that peoples whose languages are related are also related racially. The fact that this assumption is spurious did not prevent the Aryan myth from gaining wide acceptance in Europe from the 18th century onward, and it was eventually to provide a supposed intellectual justification for the persecution of the Semitic Jews by their Aryan Germanic "superiors" during the period of Nazi domination. This episode suggests that, in politics, a myth will take hold if it serves the interests and focuses the aspirations of a particular group; the truth or falsity of the myth is irrelevant. In a sense, of course, this function is merely an extension of its more general role in religion, where a myth, as well as addressing questions such as a society's place in the cosmos, may serve to justify a particular kind of governmental organization.

Myths and ideologies

Although politics is often regarded as having taken over the role once played by religion or myth in Western society, the situation is more complex than such a generalization would imply. Just as myth has always had a strong social and political element, so political movements and theories have mythical dimensions. For instance, a mythological component has always been important in keeping political units together, from villages to nations. Recently, however, this mythical dimension has gained prominence with the rise of competing mythlike ideologies such as capitalism and communism; the word ideology might indeed be replaced, in much contemporary discussion about politics, by the term mythology. Finally, crucial terms in modern sociopolitical discussion, such as freedom and equality, although they have a long and complex philosophical history, are often posited in a manner analogous to the function of myth presenting its own authority.

(K.W.Bo./R.G.A.B.)

Animals and plants in myth

Relationships between man, animals, and plants

Animals and plants have played important roles in the oral traditions and the recorded myths of the peoples of the world, both ancient and modern. This section of the article is concerned with the variety of relationships noted between man and animals and plants in myths and popular folk traditions and in so-called primitive and popular systems of classification.

Man has always been intrigued by the problem of boundaries: what distinguishes him from another man; what marks off his culture from another; what the dividing lines are between man and plants, man and animals, or man and his gods. At times he has maintained a rigid sense of separation and viewed the breaking of distinctions as transgression. At other times he has sought to cross the boundaries in order to gain power or knowledge. In some myths, he has glorified an age when distinct categories had not yet come into existence, and he has yearned for a return to this paradisiacal condition. In other traditions, he has viewed with horror the monsters that result when different spheres of being are mixed.

According to a view prevalent in many traditional societies, man was formed by the gods. His history is given in the myths of the primordial establishment of things, and his solemn responsibility, along with every other living thing, is to fit himself within this given world. This does not mean that people living in such traditional societies lack distinctions. Among the African Lele, for example, animals are distinguished from man by their lack of manners, their immense fecundity, and by their sticking to their own sphere and avoiding contact with humans. Animals that violate this third characteristic are understood to be human-animals, the product of sorcery or metempsychosis (transmigration of souls).

Man's relationship to nature and the divine

The Great Chain of Being that dominated Western thought throughout the Middle Ages made man both the highest of the animals and the lowest of the gods. Man's body was like that of the animals: corporeal, sensate, and mortal. Man's spirit or intellect resembled the gods: incorporeal, rational, and immortal. The great surge of ethnological and biologic data and theories from the 16th century on tended to undermine this point of view. New forms of men were encountered (*e.g.*, the "savage") who seemed to their first describers closely akin to the brute; new biologies were proposed that placed man wholly within the animal kingdom, merely as one species among many, and postulated man's descent from animals. More recently, psychology and ethology have emphasized the irrational (or brutish) elements in man and suggested close analogies between animal and human behaviour. Since the 18th century man has been defined in a new, nonbiological way: as a cultural being rather than as the inhabitant of a natural realm. There have been many forms of this dichotomy: man is the only being who has a language, uses symbols, employs tools, freely plays, is self-conscious, or possesses a history. Man, in short, creates himself as a cultural being in distinction to the animal or plant, which is created by its environment or heredity. These questions of man's identity and the way he resembles or differs from other sentient beings may be found in every culture and during every age.

Man is a creature who tends to draw boundaries, both conceptually and practically. Not only does his being demand that he find a position in a complex system of relationships but also his social life and his biologic survival depend on the making of distinctions. To speak with the gods, have relations with another human, take possession of another's territory, or eat this or that plant or animal involves man in a host of decisions upon which his existence depends. One of his chief resources for answering such questions is that of the myths and legends mapping the world in which he dwells.

Myths and legends concerning animals and plants employ a wide variety of motifs but express a limited number of relationships. Man, animals, and plants may stand in a relationship of (1) opposition or difference, (2) descent, (3) mixture, (4) transformation, (5) identity, or (6) similarity. These are determined by and expressive of the total worldview of a people. The hunter, for example, has a different understanding of the animal from that of the agriculturalist or pastoralist; the tuber planter has a different view of plants from that of the cultivator of grains. Even within these broad categories sharp differences occur. The Kalahari San of southern Africa, who, alone, naked, and crawling on the ground, blends in with his environment in order to kill an animal for food, reveals a way of looking at man's relation to nature different from that of the Masai tribesman of eastern Africa, who, costumed and walking upright as part of a line of chanting hunters in order to slay a lion as a symbol of his manhood, stands forth visibly as the ruler of the world through which he moves. The Cretan bull dancer of ancient Mediterranean culture, playing with the animal by somersaulting over his back, expresses a conception of man's relation to this powerful animal and the forces of fecundity and death that it symbolizes different from that of the Spanish bullfighter who slays the beast.

RELATIONSHIPS OF OPPOSITION OR DIFFERENCE

The fundamental religious boundary is that between the sacred and the profane, the sacred being conceived of as a sphere of power superior to or opposed to the mundane. That which is sacred may be either creatively or chaotically powerful. If the former, it is primarily expressed in creation myths; if the latter, in demonic traditions.

Cosmogonies. The notion of a creator deity in animal or plant form is comparatively rare. There are stories of animals, birds, or insects creating the world and of creators with animal attributes or animal companions, but these are isolated traditions. Even in the widespread motif of the birth of the world from a cosmic egg there is rarely the notion of a bird laying or incubating the egg (the most notable exception is the world egg laid by a beautiful bird in the beginning of the *Kalevala,* the national epic of Finland). There are, however, a number of cosmogonic (origin of the world) motifs that employ a fundamental animal or plant symbolism: the cosmic tree that supports and nourishes the world; the earth surrounded by a serpent or supported on a turtle or on some other animal's back; the features of the present world created by the actions of some primeval animal—*e.g.,* lakes and rivers caused by

the digging of an animal or hills raised by the flapping wings of a bird. Sacrificial motifs abound, such as the world being formed from the cut-up parts of an animal or restored by its primordial sacrifice.

Animals in opposition to creation

A number of important traditions associated with animals occur in dualistic creation accounts in which animals oppose creation, acting as a foil to the creator, or creation is accomplished by combat between the creator and animal monsters representative of chaos who must be slain or bound before the world can be established. The widely distributed earth-diver myth is the most familiar example of dualistic creation (see above *Myths of origin*).

Other oppositions occur with respect to the creation of man (see below *Relationships of descent*). Perhaps the most frequent myth of the origin of death is that of the "perverted message" or "two messengers." In one, an animal is sent with a message from the creator that man is immortal, but the animal alters the message to state that man must die. In the other, two animals are sent, one with the word that man is immortal, one with the message that man will die. A mishap occurs to the first, and only the fatal message reaches man.

Union of disparate features expressing a creative totality

In some traditions, there is a union of disparate features or opposites in a given mythic being. This does not express a chaotic hybrid but rather a creative totality (the "coincidence of opposites"). Though most frequently expressed by androgyny (having both male and female characteristics), either in traditions of an androgynous creator or first man, the theme is present in some animal and plant traditions as well (*e.g.,* the emergence of man from the androgynous *rīvās* plant in Iranian mythology). Although it occurs in cosmogonic settings (*e.g.,* the tree that unites heaven and earth), motifs of the reconciliation of animal and plant opposites more usually occur in paradisiacal imagery that promises the harmonious mingling of realms (*e.g.,* the "peaceable kingdom" of Isaiah 11:6–8 or Virgil's Eclogue IV).

Animal and plant deities. Belief in sacred plants or animals is widespread. Common to all of these is the notion that the plant or animal is a manifestation of the sacred and thus possesses the dual attributes of beneficence (in healing, hunting, or agricultural magic) or danger (as expressed in taboos against their destruction or consumption). More rarely, gods are believed to have animal (theriomorphic) or plant (phytomorphic) forms. Influenced by ancient Greek disparagement of contemporary Egyptian religion and Judeo-Christian antipathy to "idolatry," Western scholars have tended to speak of such traditions as "animal worship," although it is usually not the animal itself but rather the sacred power revealed by the animal that is being revered. Other deities possess animal or plant attributes or are incarnations associated with particular animals or plants. Here the animals or plants possess a symbolic function. Certain qualities are associated with certain species (*e.g.,* wisdom with the owl, strength with the lion, immortality with the eagle, inspiration with the grape), and the god's possession of these qualities is indicated by his being identified with the appropriate animal or plant. In other traditions, natural phenomena are associated with the actions of certain species (*e.g.,* wind as a bird, lightning as a snake), and the god who controls such phenomena is identified with the species. At times, the animal or plant achieves a divine identity of its own—*e.g.,* the thunderbird or the earthquake monster.

Western attitudes toward animals and plants as manifestations of the sacred

Hunting and agricultural deities. In the traditions of archaic hunting peoples there is frequently a figure whom scholars term the master of the animals or the protector of game. He is the ruler of the forest, of all animal species, or of only one particular species (usually a large game animal—*e.g.,* the northern master of the caribou). The master controls all game animals (frequently by penning them up). He dispenses a certain number to man as food and can be invoked by a shaman when he withholds game. He guides the hunter and, in some traditions, avenges the spirits of slain animals, whose souls return to his enclosures when they die. He is sometimes pictured in human form, on occasion having animal attributes or riding an animal; in other traditions, he is a giant animal or can assume animal form.

In a related complex, a deity in animal form demonstrates to man the art of hunting, serving as the first victim (a motif found in some of the American Indian bear mother or buffalo woman tales). Or the deity appears among men as an animal who must be slain and eaten so that he may return to his heavenly home (*e.g.,* the Ainu Iyomante feast in Japan).

A similar pattern is found among archaic agricultural peoples. An ancestral (*dema*) goddess, at times in plant form, produces food asexually from her body. She is slain by the tribe, and from the dismembered portions of her body crops appear.

The archaic pattern of the *dema* deity needs to be distinguished from the widespread tradition among technically more sophisticated agricultural peoples of the bountiful mother earth or the god or goddess of vegetation or special crops. In the latter case, the deity, frequently depicted or associated with the appropriate animal and vegetative characteristics, is the principle of inexhaustible vitality. The god frequently has a human consort who participates in a sacred marriage in order to gain fecundity for man (this happens in ancient Mesopotamian religions, for instance).

The functions of the culture hero

Culture heroes. The master of the animals or corn mother is frequently found in association with animal culture heroes. An animal or trickster who can assume animal form secures for man the various attributes of culture (acting either in consort with or opposition to the gods). These traditions are found in etiologic stories about how man first learned to hunt, discovered tobacco, and accomplished other things. The most frequent motif is that of the animal who stole fire from the gods for man. Frequently, such traditions lie behind etiologies of specific animal or plant characteristics; *e.g.,* the bat is black and blind because it stole fire and was singed by the flames and blinded by the smoke. In other tales, the animals oppose the acquisition of culture by man and must be overcome by a human culture hero.

A closely related theme is the myth of a life-giving tree or other healing magical plant, growing in paradise or some other inaccessible place, to which the culture hero must travel in order to gain a boon for mankind. He is frequently assisted by or has to overcome supernatural animals. This is an especially widespread type of myth, with numerous instances found throughout the world.

Demonic plants and animals. Opposed to these positive conceptions of the creative powers of plants and animals is the notion that their sacred power is chaotic or demonic. Rather than aiding man, they are destructive. The most common examples are monstrous plants and animals, which figure especially in heroic quests as guardians of boons or threats to be overcome; mythical animals associated with destructive natural phenomena, such as the earthquake monster or the monster who according to some traditions causes eclipses by devouring the Sun or Moon; and personifications of evil powers such as death or disease (*e.g.,* the hound of hell) or chaos beasts (such as dragons) whose release marks the end of the world or who will be slain in a final battle by a saviour deity. A universal phenomenon is the association of certain species of animals with sorcerers and witches. The most frequent form of this belief is that of the familiar—an animal whose soul is bound up with that of the sorcerer, whose form the sorcerer can assume, and who may be commanded to serve his evil master.

Dragons and familiars

Some species (*e.g.,* animals such as the serpent and various narcotic plants) exhibit the ambivalence of the sacred—they are conceived as being both beneficent and dangerous. This reflects a crucial aspect of the sacred—that it is a region of power. As was stated above this power is ambivalent—*i.e.,* it can act for mankind's benefit or detriment—and is perceived therefore as the location either of creativity or of chaos.

RELATIONSHIPS OF DESCENT

One of the major ways man has of organizing his world is through genealogy or relations of descent. In theogonies, or tales of the origin of gods (*e.g.,* that by Hesiod), or in legendary lists of human offspring (such as the genealogies

in the Old Testament), relations of descent and the association of characteristics, territories, and spheres of influence with descendants provide a means of mapping the cosmos and the human world. In traditions concerning animals and plants, relations of descent are most prominent in myths of the origin of man and in totemic (animal-clan relational) materials. Central to both is the figure of the plant or animal ancestor.

Creation of man from plants or animals. A widespread motif, especially among archaic peoples, concerns man's supposed descent from plants or animals. These descent traditions usually name a particular species as man's ancestor, and the tribe frequently takes its name from the plant or animal.

In some myths, an asexual mode of creation is implied; a child, for example, appears from the bud of a tree or from a split fruit, or man is a featherless bird sent from the sky. Even the motif of the birth of man from an egg is predominantly an asexual motif inasmuch as no preliminary coition is mentioned. Other traditions, particularly agricultural ones, see man as the product of the mating of a plant or animal species. In some myths, fabrication rather than descent is emphasized. Man is fashioned from a plant or animal by the gods, or his parts are modeled after other species. In these descent traditions, the primal man who results is usually the progenitor of a particular people. Other peoples are created from different or less favourable species. These traditions persist in folkloric accounts of the birth of individuals from plants or animals. Such myths express a close relationship between man and the animal and plant world. Man does not represent a new type of being but rather a new manifestation or form.

The widely distributed notion of animal or plant ancestors places considerable emphasis on transformation (see below *Relationships of transformation*). The ancestral myths describe a primeval time of creation (or successive creations) followed by a decisive alteration in the conditions of life in the shift from the ancestral to the present human mode of being. Compared with the "fixed" characteristics of the present period, the ancestral era is represented as having been one of flux, lacking definite boundaries. In it animals, plants, and men are much the same: they can speak with each other, have sexual relations with each other, and engage in other relationships. The ancestors are polymorphic (many formed) and are frequently depicted as emerging from the ground. In such cases their movement toward the surface is represented as an increasing differentiation, away from compound hybrids and toward forms somewhat resembling present species. But even on the surface, the ancestors remain relatively fluid; some resemble plants, others animals or men, and all have shared characteristics and the power to change their form at will.

The ancestral era

The ancestors are depicted as primordially powerful beings, but due to a variety of causes their world becomes transformed, and the present order of things comes into existence. Human culture and the decisive features of the world as man now knows it are established during the transformation: man's labour, sexuality, and death are due to some action of the ancestors; the topography of the land is the "tracks" left by the ancestors; men, animals, and plants are depicted as having received their present form after the ancestral age.

Totemism. The relations to an animal or plant ancestor are frequently associated with the complex phenomenon of totemism. Totemism is primarily a social relationship. It expresses the belief that there is a connection between a group of persons, on the one hand, and a species of animal or plant, on the other. The relationship to the totem (animal or plant symbol) occurs in a variety of forms; associated phenomena (*e.g.*, exogamy, or marriage outside the clan, and taboos against killing the totem species) may or may not be present. The myths associated with such traditions narrate the origin of a social group and the discovery of its totem. It was commonly believed in the 19th century that there was a stage in the development of human thought that could be called "totemic," a stage at which primitive peoples perceived a mystical connection between particular social groups and the animals or plants that were their totems. Totemism apparently covered a bewilderingly wide range of phenomena: the list of totems among the Nuer, for instance, includes lion, waterbuck, tortoise, papyrus, rafters, and certain diseases. Utilitarian explanations for the choices of totems—"good to eat," "useful," etc.—do not fit the ethnographic data, and to say that the totems are chosen because they have some special mystical significance is merely to rephrase the problem, without identifying why only certain items have mystical significance. In *Le Totémisme aujourd'hui* (1962; *Totemism*) Lévi-Strauss advocated a different approach. He suggested that totemism, far from being a special stage in human development, was merely an instance of the use, within so-called primitive systems of classification, of objects and categories from the world of everyday experience to divide and order that experience.

A phenomenon that has, at times, been confused with the social relations of totemism is that of the individual guardian. It involves a relationship between a particular person and a particular species, usually revealed to the individual in a vision, such as in the vision quests among the North American Plains Indians. These guardians become a source of knowledge and good fortune for the individual. To these traditions, other folkloric motifs may be related, such as the birth of various individuals from intercourse between humans and animals or plants; the animal wife; animal nurses; or the ability of certain persons to understand or converse with animals or plants.

Hierarchy. The fluidity of boundaries characteristic of relations of descent raises important questions as to the status of man or of culture in relation to nature. Are animals and plants more like men than not? Is the human world superior to or inferior to the natural sphere? Such questions lie behind a variety of motifs associated with descent traditions: that the first men were undeveloped, amorphous, or resembled animals; that animals resisted the creation of man; and that the primordial man is the ruler of the natural world. The characteristic fluidity of the descent traditions persists in traditions such as the wild man and in relations of transformation and identity (see below).

The status of man and culture in relation to nature

RELATIONSHIPS OF MIXTURE

For some societies boundaries and the maintenance of distinctions guarantee the continued existence of the cosmos as an integrated totality. There are rituals that periodically reenact the original process whereby the cosmos was divided up and established in its present form. In such cases a new beginning, for example New Year's celebrations as carried out in modern Western society, re-create the original beginnings of things as they are today. Other rituals foster remembrance of the decisive deeds of the ancestors in fixing the present state of things; ritualized social structures (such as the caste structure of India) maintain a complex system of distinctions; and religious ideologies (such as astrology) foster the notion of spheres of power that control all members of a class, be they gods, planets, animals, plants, minerals, or men. In such societies, to be real is to affirm and repeat the structures of the cosmos. Each being is called upon to dwell in a limited world in which everything has its given place and role to fulfill. To be sacred is to remain in place. To break out, to cross boundaries, is to open the world to the threat of chaos, to commit transgression. Associated with this worldview is the notion that the mixing of realms is the result of evil influence and leads to monsters, hybrids, and uncleanliness. An alternative view in the history of religions sees positive sacred power to be gained from the violation of the given boundaries of the world. Each being, in such a view, is called upon to challenge its limits; to break them and to create new possibilities for existence, to achieve freedom. Associated with this view is either the necessity for a periodic loosening of restraint or the celebration of gods or sacred persons who have achieved freedom. Religiously expressed, for the one view, the sacred is the ordinary, that which remains in place; for the other, the sacred is the extraordinary, that which is not restricted to its allotted place.

These two points of view—*i.e.*, that power comes from

conformity to class or freedom from class—may be illustrated by the widespread category of taboo. Research in the second half of the 20th century has led to the conclusion that taboo is primarily a taxonomic (classificatory) system.

Proscriptions against crossing boundaries

Those things that are forbidden involve the crossing of boundaries or are beings that fall between classes. Thus, one may not with impunity enter other spheres (*e.g.,* the realms of the gods) or touch sacred objects, transport an object from one realm to another, cross sexual or class lines, or have relations with a being not of one's class. Many food taboos have been shown to reflect taxonomic anomalies. An animal such as the bat is tabooed because it has fur like a mammal but flies like a bird; it has wings like a bird but has fur rather than feathers—and therefore is neither mammal nor bird and must be shunned. On the other hand, the consumption of forbidden foods or engaging in forbidden sexual practices (including homosexuality and bestiality) is part of the ritual of transcendence in many cultures. If an individual can survive the crossing of boundaries, he will obtain extraordinary sacred power (*e.g.,* adherents of Tantrism, a system of esoteric practices performed in both Buddhism and Hinduism, who violate both eating and sexual taboos; the Jewish magicians mentioned in the Old Testament Book of Isaiah, chapter 65, who eat the forbidden swine and say ". . . do not come near me, for I am holy").

From the earliest times man has shown a readiness to be fascinated by monsters. Monsters are chaos beasts, lurking at the interstices of order, be they conceived as mythical creatures who preceded creation, survivals from an archaic era, creatures who dwell in dangerous lands remote from human habitation, or beings who appear in nightmares. Though the forms and types of monsters are numberless, a single principle holds good for the majority of them: a monster is out of place, conforming to no class or violating existing classes. This is most frequently expressed by the monster's having hybrid form (the result of a mixture of species, attributes, sexes, and other categories), being the result of a transformation, or having dislocated or superfluous parts. Because modes of locomotion and other bodily characteristics are prime modes of classification, the superfluity or lack of organs removes the monster from the ordinary taxonomic divisions. The dragon, for example—perhaps the most widespread monster in myth and folklore—is born through a mixture of species: it is a serpent born asexually from a rooster's egg incubated in manure; by the transformation of an animal; or by the joint generation of a man or worm and a metal. Its form is a compound of species: the body of a serpent or crocodile with the scales of a fish; feet, wings, and occasionally the head of a bird; the forelimbs and occasionally the head of a lion; or, in another dominant type, the ears of an ox, the feet of a tiger, the claws of an eagle, the horns of a deer, the head of a camel, the eyes of a demon, the neck of a snake, the belly of a mollusk, and the scales of a fish. In other types of dragons, organs or attributes of the snake, lizard, fish, mollusk, toad, elephant, horse, pig, ram, deer, eagle, falcon, octopus, or whale predominate. In many traditions, the dragon has the power to transform itself at will. Its possession of superfluous organs is most frequently expressed by its being many headed, and it has both subterranean and aerial characteristics and habits.

Generation of the dragon

The most common hybrid monster generally mixes differing species—*e.g.,* the Centaur (horse-man), the Minotaur (bull-man), Echidna (snake-woman), Pegasus (horse-bird), Sphinx (woman-lion-bird), Siren (bird-woman), and Empusa (animal-metal) of Greek mythology and the griffin (lion-eagle), mermaid (woman-fish), vegetable lamb (plant-animal), barnacle goose (mollusk-bird), and mandrake (plant-man). In other instances, the characteristics are juxtapositions of different species—*e.g.,* the tree that bears human heads as fruit; horses born from eggs; flesh-eating mares; milk-producing birds.

The most extreme form of the fluidity that is characteristic of monsters is the Protean figure who can change into any form or combination of forms at will. In all of these monstrous forms, the central notion appears to be the danger associated with beings that are out of place or are fluid. But some contemporary anthropologists have argued the opposite conclusion; *i.e.,* rather than being threats to the classificatory system, monsters, through their startling combinations and juxtapositions, force men to think more clearly about and distinguish more sharply between the different boundaries of their world. In this interpretation, the monsters are ultimately supportive of order rather than a destructive threat to it.

RELATIONSHIPS OF TRANSFORMATION

One of the largest groups of animal and plant traditions in folklore and religious material is that of transformation. Familiar stories—such as Beauty and the Beast; the transformation of a man into an ass in the *Metamorphoses* by Apulcius, a Roman writer of the 2nd century AD; the frog king or the swan maiden, as well as such well-known traditions as that of the werewolf, the vampire, or leopard man—testify to the wide dissemination of this theme. Every permutation and combination exists: man into mammal, bird, fish, insect, reptile, amphibian, or plant; animal into man or plant; animal into another species of animal; or plant into animal. There are also partial transformations resulting in hybrid forms as well as alternating transformations—*e.g.,* animal, man, or tree by day and the reverse at night. Another great series of transformations concerns the dead, who either transmigrate into or return in animal and plant forms.

The power to compel another to change form, or to cross boundaries oneself at will, may be judged good or evil depending on the assessment of order in the worldview of the particular culture. In the majority of instances of transformation of another, the transformation is considered to be the result of evil magical powers, and most tales conclude with the disenchantment of the subject, his release from the evil power, and his return to his original form. Many of the instances of self-transformation are for the positive purpose of transcendence.

Several of the motifs present in the folklore of transformation suggest cultic procedures (*e.g.,* transformation into an animal by putting on its skin). Cultic practices probably lie behind and lend credibility to many such tales.

Ritualized moments of transition

In many societies, ritual change involves a transition period in which boundaries are broken and chaos rules, only to be overcome as order is restored. This is common in festivals in which the social order is temporarily suspended or reversed (as in the ancient Roman Saturnalia and the carnival celebrated in many Roman Catholic countries) and in rites of passage (such as initiation). Animal and plant transformations play a significant role in such ceremonies, both as negative symbols of chaos (*e.g.,* return of the dead in animal form to mingle with the living; ritualized combats against the primordial dragon) and as positive symbols of the breaking through of bounds and the release of the forces of life (*e.g.,* the presence in many of these ceremonies of young males dressed as animals who engage in sacred sexual intercourse). Prominent in such Saturnalian traditions are deities such as the Greek god Dionysus, who can assume vegetable, animal, or human forms at will, who is a god of sudden, dramatic epiphanies (manifestations) and license, and whose devotees, through orgiastic rituals, participate in his freedom to break all bounds in order to recover the boundless vitality and fecundity of primordial chaos. A new life for the cosmos, society, and the individual is supposedly obtained through the abolition of the order of the old.

Initiation ceremonies make use of transformations to a somewhat different end. The initiant receives new birth by the dying of his old self after a series of ordeals. Antagonists, frequently in masked animal form, torment him, and his "death" and rebirth are analogous to the hero's successful fight against monsters. Alternatively, the culmination of initiation is frequently the narration of the myths of the ancestors and the vision of them. Masked men, in mixed animal and plant forms, appear to the initiant to remind him of his true origin as opposed to his biologic origin as a product of his parents. (Other ritual uses of masks achieve the same effect: the ritual transformation of the "actor" into the sacred animal, plant, or deity.)

Frequently, although the nomenclature for plants and animals is learned by a child from birth, the logic of the

system is revealed only at initiation, at which point the initiant, as an adult, becomes responsible for the proper observance of all the boundaries required by his society (*e.g.,* among the Senufo of Africa, 58 figurines are presented to the initiant in a carefully prescribed order that provides an inventory of the basic classes of animals, men and human activities, and social distinctions).

The role of the shaman

Within many cultures there are religious specialists in the breaking of bounds. Perhaps the most widespread example is that of the shaman who is deemed able to journey at will to heaven or the underworld, mingling with both the gods and the dead. His journey occurs through magical flight (frequently in the form of a bird) with animal psychopomps (soul conductors) or guardians or by ascending the sacred tree that connects heaven and earth. The shaman may transform himself into an animal and know how to converse with animals. Another similar phenomenon is the existence of leopard societies in Africa. In these a practitioner is believed to be able to transform himself into an animal frequently considered to be his incarnate "second self."

RELATIONSHIPS OF IDENTITY

Works on the supposedly primitive mentality published in the 19th and early 20th century usually presumed that primitive man could not distinguish between plants, animals, and men. This "hazy vision," as it was often called, was believed to lie at the root of religious phenomena such as animism (belief that inanimate objects and natural phenomena have souls) and totemism. More recent studies have demonstrated the presence of complex taxonomies among peoples sometimes described as "primitive," although they do not usually employ the criteria of a modern biologist. Relations of identity, when compared with the other forms of relationship already described, are comparatively rare, occurring most frequently in traditions about the soul. Relations of similarity are more common, usually in literary settings, such as plant or animal fables. The most common expression of identity relates the soul of man to that of animals or plants.

Soul-stuff. Although man tends to associate the soul with personal survival or continuity after death, there is an equally ancient view that emphasizes the continuity of life. This view, to which the Dutch anthropologist Albertus Christiaan Kruyt gave the term soul-stuff (a term he contrasted with the postmortem soul), is chiefly found among the rice cultivators of the Indonesian culture area, although it is also witnessed elsewhere. Central to this belief is the circulation of vitality throughout different levels of existence. The soul-stuff is created by the deity as an indestructible reservoir of life. It is eternally reborn—either by returning to its creator, who will redistribute it, or by transmigrating into an embryonic human, animal, or plant. Whatever form it assumes, the same "stuff" is common to all beings.

Death, or postmortem, soul. The majority of traditions concerns the postmortem soul, which leaves the body or comes into existence only after death. A number of motifs reflecting different assessments of the nature of life and death occur. The soul may assume an animal or plant form or there may be animal psychopomps, most frequently a winged creature such as a bird or butterfly. The soul may transmigrate into or be reincarnated as an animal or plant. These traditions need to be distinguished from those concerning spirits of the dead who reappear in animal form. Related to these are traditions about the separable soul, which is capable of removing itself or being removed from a person while still living. This most usually occurs in sleep. While detached it may be placed in or assume the form of an animal or, more rarely, a plant. In general, where the notion of soul-stuff predominates, relations of identity are prevalent; where the notion of a death soul is present, the traditions are more closely akin to relations of transformation (see above).

Psychic interrelations

Plural souls. A more complex pattern, of wide distribution, is that of the plurality of souls. Man's vitality and personality are viewed as the result of a complex set of psychic interrelations. A classic example is that of the Apapocuva-Guaraní of Brazil, as described by the anthropologist Curt Nimuendajú: a gentle vegetable soul comes, fully formed, from the dwelling place of the gods and joins with the infant at the moment of birth. To this is joined, shortly after birth, a vigorous animal soul. The type of animal decisively influences the recipient's personality: a gentle person has received a butterfly's soul; a cruel and violent man, that of a jaguar. Upon death, the vegetable soul enters paradise; the animal soul becomes a fierce ghost that plagues the living. The plurality of souls provides a complex taxonomy accounting for and relating the distinctive character traits of plants, animals, and men.

The alter ego, or life index. Other religious and folkloric traditions view the life of man as bound up with that of a plant or animal: if one is destroyed the other dies as well. In some traditions, this is confined to the familiar or guardian of a witch or shaman; in others, it is an individual relationship possible for any man. An example of the latter relationship is nagualism, a phenomenon found among the Indians of Guatemala and Honduras in Central America. Nagualism is the belief that there exists a nagual—an object or, more often, an animal—that stands in a parallel relationship to a person. If a man's nagual suffers harm or death, the man suffers harm or death as well. According to one story, during the initial hostile encounters between the Indians and the Spaniards, the Indians' naguals fought on their side against the invaders. When the nagual of the Indian chief—which was in the form of a bird—was speared and killed by the Spanish general, the Indian chief died at the same moment.

Nagualism relates the life of each individual to the life of an animal or other object. More rarely, there is a relation between an entire tribe and a particular plant or animal. In some societies, a ritual of identification is performed, usually at birth (*e.g.,* planting a tree or burying the placenta at the roots of a tree). In others, an individual has a vision or undertakes a vision quest to identify his alter ego.

RELATIONSHIPS OF SIMILARITY

Relations of similarity between human beings and plants or animals usually depend upon the perception of an attribute or aggregate of attributes that they have in common. This process is apparent in colloquial expressions such as when someone is called a "cool cat," a "bitch," a "clumsy ox," a "greedy pig," or "foxy." A similar process appears to lie behind many of the so-called totemic names or theriophoric or phytophoric personal names (*e.g.,* Swift Deer, Bold Eagle) and is concealed in a number of familiar Western names (*e.g.,* Leo, "the lion"; Deborah, "the bee"; and Jonah, "the dove"). The reverse process, the giving of human names to plants or animals, also depends in a majority of instances on the discernment of character similarities. Care must be used, however, in the interpretation of proper names. Every plant or animal name does not necessarily reveal the perception of similarity. For example, the Seminole Indians combine a character name with a shape and animal name in an arbitrary fashion that appears to pay no attention to their meaning, resulting in unusual combinations such as that of a well-known Seminole medicine man whose name translates as "crazy, spherical puma."

Function of fables

The same process is at work in the universal literary form of plant and animal fables. The fable depends for its point upon the association made by the reader or listener between himself and one of a limited number of characteristics possessed by each animal or plant. More complex forms, verging on allegories, such as the beast epic and the debates between various plants and animals as to which are superior, also exist. The popular *Physiologus* ("Naturalist"), a Greek work from the 2nd century AD, and the medieval bestiary traditions draw morals particularly from monstrous or wondrous animals and plants. Both the fable and the bestiary traditions contributed to the formation of the stereotyped bird, beast, and flower emblems that figure in heraldry and religious iconography.

The process of discovering similarities of personality between plants and animals, on the one hand, and human beings, on the other, also plays a significant role in certain archaic sciences. Physiognomy, which claims to find correspondences between bodily features and psycholog-

ical characteristics, often makes use of such supposed similarities. The earliest Western systematic treatise, the Aristotelian *Physiognomonica,* maintains that people with facial characteristics resembling certain animals have the temperaments ascribed to those animals (*e.g.,* persons who have noses with slight notches resemble the crow and are impudent just as the crow is). These views persist in popular figures of speech, such as "bulldog jaw." The same structure underlies the use of plants and animals in archaic healing practices, alchemy, and astrological tables in which animals, plants, and minerals, as well as human personality traits, are associated with the birth signs of the zodiac or planets.

(J.Z.S./R.G.A.B.)

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Names

A name is a word or group of words used to refer to an individual entity (real or imaginary); the name singles out this entity by directly pointing to it, not by specifying it as a member of a class. For instance, it is possible to refer to the same entity, in this case a river, in two distinct ways: (1) "The Colorado is a beautiful river," and (2) "The river that flows through Austin is beautiful." Because there is only one river that flows through Austin, Texas, the subject of sentence 2 is unambiguously identified, and the reference of the sentence is fully individual. The subject of sentence 2, however, is not a name but rather a nominal (noun) phrase that specifies one member of the whole class of rivers by indicating a unique property of it. The word Colorado in sentence 1, on the other hand, is a name, because it directly points to the specific river. The fact that there is more than one river called Colorado, and that more specific information is sometimes needed to identify the one being discussed (*e.g.,* "I prefer the Texan Colorado to the California one"), does not change the status of "Colorado" as a name, because each of the two rivers is referred to in the way required by the definition.

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NAMES AND APPELLATIVES

A general appellative (*i.e.,* a common noun) capable of being used in reference to a whole class of entities can also be used with an individual reference. For instance, if an inhabitant of Austin, Texas, says, "Let's go swimming today, not in the pool but in the river," there is no doubt that the word river has a unique, individual reference to one single river, namely, the Colorado. This fact, however, does not make a name out of it; "river" is here a common noun, but its reference is specified by the extralinguistic context of the situation in which the sentence was said. Some names seem to belong more to the category of appellatives than to the category of names like Colorado in "the Colorado River." For example, names like Big River, Red River, Stony Brook, and Cedar Hill may have their origin in a specific use of a general noun. If a sentence like "After five days of marching, we had to cross a river, the big one, not one of the smaller ones" is used very often, the name Big River may result. Such names are more frequently given as directly descriptive names. The similarity of names of this type with expressions like those exemplified in sentence 2 above is deceptive. There is, after all, more than one big river, so that the specification "the big river" is not complete. The full identification of one single river as the reference is given by the context. Therefore, apart from certain special expressions (like "the big one, not one of the smaller ones"), names like Big River, Red River, and so on have the same status as names like Colorado.

In some languages, a name is differentiated from an appellative (common noun) by formal means. The difference is sometimes indicated by the script; *e.g.,* languages using alphabets such as the Latin, Greek, Cyrillic, Armenian, and Georgian use a capital letter at the beginning of a name. (But, on the contrary, in German all nouns, not only names, are written with an initial capital.) There are examples of a purely grammatical differentiation of names as well, such as the usual absence of the articles "a" or "an" in English; *e.g.,* "Yesterday I saw an archer practicing his art" and "Yesterday I saw (Bill) Archer practicing his art."

Formal means for marking names

The distinction between names and appellatives (common nouns) is generally clear: names are used in individual reference, appellatives can be used in reference to all members of a class or to any number of them (*e.g.,* river, hill, man, girl, car, table, virtue, and so on). Nevertheless, there are some borderline cases. For instance, a nation can be conceived as an individualized entity, so that "Americans," "Englishmen," and "Spaniards" are names; on the other hand, it is clear that other groups of people are not conceived in this way, so that expressions like "soldiers," "sailors," and "clergy" are not names. It is difficult to decide on the status of expressions like the "Baptists," "Adventists," and "spiritists." In a similar way, if all vehicles produced by Henry Ford are Fords and if one can buy an individual Ford as well, is "Ford" a name? It probably is, or approaches that status; but names of this type frequently lose the character of names and develop into common nouns. Expressions like "the Roman Catholic Church," "the Ministry of Education" (of a specific state) also have a dubious position as to their status as real names. The uncertainty in this respect is indicated by the vacillation in the use of capital letters in various languages. This overlapping has a long history and is reflected in modern terminology. The Greeks used the term noun (*onoma*) for both the common noun and the name; when they wished to make a distinction, they specified the name as a proper noun (*onoma kyrion*). It is in this tradition that the term proper noun, or proper name, is used for a name, and noun, general noun, or common noun, for an appellative.

THE SCIENCE OF ONOMASTICS

Categories of names. The science that studies names in all their aspects is called onomastics (or onomatology—an obsolete word). The subject of this science is broad because almost everything can have a name and because the study of names theoretically encompasses all languages, all geographical and cultural regions, and all historical epochs. For practical purposes, some divisions of the subject are necessary; *e.g.,* by language (as the study of Kiowa or Provençal names) or by geographical, historical, or similar partitions (the study of the names in India, of the Levant at the time of the Crusades, and so forth). Another division (usually combined with the preceding ones) is given by the character of the names themselves; in a very broad categorization, names of persons, or personal names, are discerned on the one hand, and names of places, or place-names, on the other. In the most precise terminology, a set of personal names is called anthroponymy and their study is called anthroponomastics. A set of place-names is called toponymy, and their study is called toponomastics. In a looser usage, however, the term onomastics is used for personal names and their study, and the term toponymy is used for place-names and their study. The term toponymy itself can be understood in two ways, even in the exact terminology: either it is taken in the broadest possible way as including inhabited places, buildings, roads, countries, mountains, rivers, lakes, oceans, stars, and so on, or it is restricted to inhabited places (cities, towns, villages, hamlets). If the latter alternative is the understanding of the term toponymy, then the uninhabited places (*e.g.,* fields, small parts of forests) are called microtoponymy; names of streets, roads, and the like are

Divisions within onomastics

called hodonymy; names of bodies of water, hydronymy; names of mountains, oronymy. Additional terms are not generally used (though one occasionally hears words like chrematonymy—names of things).

In any case, different categories of names frequently must be studied together, because there are transitions. For instance, many place-names are derived from personal names (*e.g.,* Washington), many names of planets and stars are derived from the names of mythological characters (*e.g.,* Venus, Mars, Alpha Centauri), and many personal names are derived from place-names, names of nations, and other such names (*e.g.,* Austerlitz, Napoleon's battlefield; French; Scott). There is also a division of names into primary and secondary ones. Neptune is primarily the name of a Roman god; transferred to the name of a planet, it is a secondary name.

Forms of personal names. There are many subdivisions and terms within the category of personal names. Originally, one name was given to a person at an early period of life—in Europe (and later in America), normally at Baptism. This is called either simply the name, the baptismal or Christian name, or the forename; in the United States and Canada it is usually called the first or given name. Because many people received the same name (given name), they were differentiated by surnames (for example, John Redhead, John Hunter, John Scott). Many of these surnames became fixed and hereditary in individual families. These are called either surnames or family names, and in the United States and Canada they are frequently known as last names. Thus the basic pattern is given name + family name, together called the name or the personal name. There are exceptions concerning this sequence. Among the Chinese and Hungarians, for example, the family name precedes the given name: Mao Tse-tung, Nagy István. The Hungarians usually switch the order when they write English; thus, Nagy István becomes István (or Stephen) Nagy. The Chinese, however, maintain the order of family name first.

Surnames and family names

There are variations in the basic pattern. In the United States and Canada the usual practice is to insert another name (frequently expressed in writing only by the initial letter) between the given and the family name. This is the second, or middle, name. It may be the original family name of a married woman inserted between her first name and the last name of her husband, the maiden name of one's mother, as well as other names. In Europe, such a second name is less common and is usually acquired at Baptism (or, eventually, at Confirmation). In most European countries, the first baptismal name is the important one, and the second one (third, and so forth) can be omitted. In German usage, however, the baptismal name immediately preceding the family name is the most important one. For example, if one of the baptismal names in Johann Sebastian Bach or Johann Wolfgang von Goethe is to be omitted, it would be Johann. (But in a sequence like Johann Nepomucenus Nestroy, the shorter form is Johann Nestroy, because Nepomucenus is only an attribute discerning one of the numerous saints who had the name Johann.) British usage varies in this respect, but sometimes follows the German pattern—*e.g.,* W. Sidney Allen.

In a few areas, particularly among East Slavs, the so-called patronymic (*i.e.,* a name derived from the given name of the father) is inserted between the given and the family name. In Russian, if the father's name is Ivan Krylov, then the son's name, for example, will be Pyotr (given) Ivanovich (patronymic) Krylov (family), and the daughter's name will be, for example, Varvara Ivanovna Krylova. The usual form of address in Russian—among acquaintances, neighbours, colleagues at work, and inclusive superiors—is by the given name and the patronymic. In Iceland the given name is used with the patronymic, the use of family names being discouraged. In Spain the family name of an individual consists of the family names of father and mother, the first being the most important one.

The terms maiden name and girl's name are sometimes used for the original family name of a married woman. Nickname is used in reference to surnames (which have not developed into family names), mainly of the jocose type—*e.g.,* a thickish Mr. John Smith is called Fatty. A surname, also called a byname or to-name (obsolete), can be used to differentiate persons with the same family names if they belong to different families and if given names are not used among them. In a village, there may be several families with the name Jones; if they are not called or referred to by first names, they may be known as Jones at the Pond, Jones the Redhead, and so forth. Hypocoristic forms of names are those that are used in familiar, friendly, or intimate situations (usually shortened or otherwise modified)—*e.g.,* Tom for Thomas, Jim for James. Some of these forms are also used as given names, particularly in the United States.

THE NAMING PROCESS

One of the most important elements of the naming process concerns the meaning and associations of the name. In this case the term meaning is radically different from that in the case of common nouns, in which the "meaning" is their ability to be used in reference to a class of entities, to denote or designate them. As was noted above, the absence of this ability to refer to a class of entities is typical of a name. If the meaning of a typical common noun, such as automobile, is considered, it can be seen that it denotes a certain type of vehicle. On the other hand, if the word automobile itself is considered, one can see that it consists of a Greek element, *auto* "self," and a Latin one, *mobilis* "movable," so that the sum of the meanings of the constituent parts of the word suggests a gloss like "self-movable," "self-mover." The meaning of a name involves that which the constituent parts suggest. In this sense, the meaning of a name like Red River is obvious. To get a meaning of a name like Philip, however, one must go back to its original Greek version, Philippos, which means "lover of horses." This meaning of names frequently gets lost, however. There are several causes for this, one being that the name may be accepted into another language, as were the Indian place-names in America (*e.g.,* Oshkosh, Chicago, Kankakee), and the Greek and other names transferred to Europe and America via Christianity. In addition, names may cease to be understood as a result of language change; *e.g.,* the place-name Birmingham was understandable in Old English as "habitation of Biorma's people," and the originally Germanic name Gerard was once understood as "strong spear" (*Ger-hardo*). Names also changed by shortening (*e.g.,* Los Angeles, from El Pueblo de la Reyna de los Angeles, "Town of the Queen of the Angels," the town named in honour of the Virgin Mary) and by scribal error (*e.g.,* Pria in France, a misread medieval abbreviation of Pradaria, "meadow"). Another cause of the loss of meaning in names is that the meaning simply fades out by constant use of the word as a name. No one thinks of the meaning "ford for oxen" when speaking about Oxford, and no one realizes a discrepancy if Mr. White has a dark complexion. Finally, it sometimes happens that a name has no particular meaning from the beginning. For instance, the place-name Tonolo and the family name Bréal were created from random sequences of sounds.

Loss of original meaning of names

Choice of personal names. Names that have no meaning (above all not for the person who chooses the name) still can have associations. Although "Mary" and "John" may have no specific meaning, they were the names of important persons in the Christian religion and therefore have been used very frequently. An association may be so strong that it overwhelms the meaning of a name, even a disagreeable meaning; *e.g.,* the association with the cult of St. Demetrios made the name Demetrios one of the most popular in the Greek Orthodox Church, though its meaning is "belonging to [the pagan goddess] Demeter." On the other hand, such an association may more or less completely fade out and be combined with or replaced by other associations, such as a national tradition (Patrick in Ireland, Yves in Brittany, István in Hungary, Ivan in Russia) or with a family tradition (Louis in the Bourbon family, Wilhelm among the Hohenzollerns, Henry in the Ford family). On a less elevated level, there is the example of a rich uncle making a given name more than eligible. A name can be associated, correctly or not, with various

prestige factors, or its choice may be influenced simply by fashion. Another source of names, often extraordinary ones, was the occasional habit in Roman Catholic countries of giving a child the name of the patron saint whose day of celebration coincides with the child's day of birth (or Baptism); many names like Hyacinthus X, or Narcissus Y, were produced in this way.

"Good" and "bad" names

In the majority of cases, children are given "good," likable, and propitious names. In some cultures (*e.g.,* in some parts of sub-Saharan Africa, formerly in China, and sporadically in ancient Greece), however, the children are (or were) sometimes given "bad" names with meanings like "ugly," "disagreeable," or "crippled." The purpose of such names, which are called apotropaic names, is to make the child undesirable to demons.

The choosing of a given name is a highly private and individual matter. All the circumstances just mentioned can be motives for the choice, in addition to many other personal reasons, such as a consideration for the relatives' names or a simple liking of the phonetic shape of a given name. This wish to give a likable name may go so far that a sequence of sounds is chosen that sounds pleasant to the person who makes the choice but that has no relation to the existing stock of names or to the words of the language; *e.g.,* "Golly" was invented as a name of a girl and has no "meaning" or associations. This phenomenon is relatively common in the United States.

Choice of place-names. Place-names are less personal, less intimate, and a matter of public concern. The usual pattern is that the national Ministry of the Interior (or its equivalent) keeps an official list of place-names, particularly of place-names that form administrative units, together with lists of districts, counties, and the like. This function may also be performed by the ministry or agency that supervises the postal service. Bodies endowed with authority provide or choose new place-names if there is a need to create them on a greater scale—*e.g.,* the U.S. Board on Geographic Names.

International cooperation (performed above all by the Universal Postal Union) is necessary because names of identical places may vary from language to language. Particularly difficult are place-names originally written in scripts other than the Latin (Roman) one (the official script of the Universal Postal Union), such as Arabic, Chinese, Cyrillic, and the Indic writing systems. But, even within the Latin script, there are two basic types of difficulties. First, one place can have different names (or modifications of a name) in various languages—*e.g.,* French Nice and Italian Nizza; German München, English and French Munich, and Italian Monaco. A very difficult situation arises when a place is generally better known by its international name than by its original one; *e.g.,* Dublin is Baile Átha Cliath in Irish. Confusion may also be caused by names that are translated; *e.g.,* the Rocky Mountains are in German Felsengebirge and in Russian Skalistye Gory. There are also names with the same written form but with varying pronunciations; *e.g.,* for Paris, the accent, pronunciation of vowels, and pronunciation of consonants change from French to German to English.

The second difficulty involves the actual printing of all the letters with diacritical marks that are necessary for different alphabets of the Latin script. Because many printing firms lack the various marks, some possibly confusing omissions or modifications can hardly be avoided; *e.g.,* the dot over the *I* in Turkish İstanbul and the bar through the *l* in Polish Kołobrzeg are frequently omitted. International cooperation is also necessary and is developing in connection with the choice of place-names in outer space, particularly on the surface of the Moon.

HISTORICAL AND CROSS-CULTURAL DEVELOPMENT OF NAMES

Legal aspects of naming. While place-names are considered a public matter, personal names also seem to be getting more regimented by various laws and regulations. The United Kingdom and the United States are practically the only countries that adhere to the principle of Roman law that a person has the right to use and change his name as he pleases, except for fraudulent purposes. The first important regulation concerning given names was the decision of the Council of Trent (1563), which specified that the Roman Catholic priest administering Baptism should make certain that children are given names of Catholic saints; if the parents were to insist on another name, the priest should administer Baptism in that name but add the name of a saint as the second baptismal name. This regulation, still a valid part of Canon Law, was directed against the Protestant custom (spreading at that time) of giving children names of important persons from the Old Testament otherwise unconnected with Christianity (*e.g.,* Abraham, Samuel, Rachel). In this respect the regulation was successful in Catholic countries, but it did not succeed in stopping the use of given (baptismal) names like Cesare in Italy (from Latin Caesar).

Naming regulations of the Council of Trent

The next important law was passed in France. The French Revolution first gave complete freedom in naming; the result was some very fanciful given names like Mort aux Aristocrates, Racine de la Liberté, or even Café Billard. To stop this, a law was passed in 1803 that restricted given names to "names of persons known from ancient history" and "names used in various calendars." Again, the law was successful in its main intention; in addition, it prevented the spread of controversial given names such as Marat and Robespierre and of literary names such as Aramis, d'Artagnan, and Romeo. Very reasonably, the law never was interpreted too narrowly, so that feminine given names such as Jeanette and Henriette, for example, have been admitted, though they were not legal because no calendar contains them. This law is still valid in France.

Similar laws were passed, at various times, in eastern European countries and in certain neighbouring central Asian states, where the given name can be chosen only from names known and established as such, the exact formulation varying from country to country. One of the results of this legislation is that the repertoire of Russian given names today is more or less exactly the same as that of the pre-Soviet period, when the Orthodox Church was paramount. Catholic names are commonplace in Lithuania, whereas Muslim and other names are used in Uzbekistan and Tajikistan, sometimes without any ecclesiastical association whatsoever. In the Caucasus there are given names such as Soslan and Dzerassa, drawn from Caucasian mythology.

In regard to family names, the most important regulation was made at the Council of Trent (1563); it was decreed that every parish must keep complete registers of Baptisms, with the names of the child and those of his parents and grandparents. This had been done before but not so systematically. The new practice (soon followed in Protestant parishes) helped to establish the family names. There is not much legislation concerning family names, because two basic assumptions are made: that the bride will accept the bridegroom's family name by marriage and that their children will automatically have the family name of the parents.

Parish registers

Combined names—as under the German law permitting the bride to add her original family name to her new one in a hyphenated form (Inka Schmidt, when married to Karl Neumann, may become Inka Neumann-Schmidt) or the practice in outstanding British families of combining the family names of the married couple in a hyphenated form (Beatrix Curzon and Frederic Cholmondeley become Beatrix and Frederic Cholmondeley-Curzon)—are rare.

In the majority of cases, the law is concerned with family names mainly in cases of divorce, adoption, and illegitimacy. After a divorce, the wife is usually eventually allowed to reassume her maiden name and in Germany, for example, can be forced to do so if she is judged to be the guilty party and her former husband so desires. In adoption procedures, either the family name of the adopting persons is accepted or a hyphenated form is created. A child born out of wedlock usually receives the family name of its mother.

In many parts of Europe, legislation or habit have changed the basic assumptions concerning the family name, and a different situation has developed. When a Czech woman, Anna Klímová, for example, marries a Josef Novák, both may retain their original family names, or the wife may

become Anna Nováková or, more remarkably, the husband may become Josef Klíma, accepting the wife's family name. This must be decided by mutual agreement, and their children's names also are agreed upon in this way. The purported reason for this legislation is the full equality of women. (There is, however, one loophole in the system, namely, the Russian patronymic: this is automatically derived from the father's name, whereas equality understood in this way would demand a choice between the father's or the mother's name.) In Spain the married woman normally retains her maiden name.

Personal names. *European patterns of naming.* The development of personal names was complicated. In the old Indo-European system, a person had one name, which could be one of two types: a compound or a noncompound substantive. Noncompound names may originally have been given to inferior members of the tribe and their children. The compound names frequently associated the bearer with a god (they are called theophoric names) or attested to his virtues, abilities, skills, possessions, and so forth. The association of the meanings of the parts of the compound was sometimes only loose, as is particularly observable in German anthroponymy (see below). Examples of compound names include the Sanskrit Viṣṇuputra "son of Vishnu," Devadatta "given by god," Devarāja "godking." From Iran come the Avestan name Hōrmizāfrid "benediction of Ahura Mazdā" and the Old Persian name Mithradates "given by Mithra" (two Iranian gods).

Compound and noncompound names

Among Greek names there are also many theophoric names, such as Herodotos "given by Hera," Isidoros "given by Isis" (modern Isidore), or Theodoros (modern Theodore) and Dorotheos (modern only in the feminine form, Dorothy), both "given by god." There are many other similar Greek names; *e.g.,* Astyanax "lord of the city," Pericles "very famous," and Demosthenes "strength of the people." Plato "broad (in shoulders)" is a noncompound Greek name.

The compound names of the Celts include Vercingetorix "great king of warriors," Orgetorix "king of killers," Rextugenos "son of justice." Noncompound Celtic names included, for example, Artos "bear" and Galba "big." Examples of Germanic compound names include Heriberhto "army + resplendent" (modern Herbert), Huguberhto "resplendent by thought" (modern Hubert), Godofrido "divine peace" (modern Gottfried and Geoffrey), Frideriko "peace + powerful" (modern Frederic and Friedrich), and Theodobaldo "people + valiant." Among the noncompound Germanic names is Karl (or Charles), in the Latin form Carolus, meaning "man."

Typical Slavic compound names are Vladimir "governs the world," Vladislav "rule + glory," and Miroslav "world + glory."

The Latin system of personal names was quite different and probably developed under Etruscan influence. In the earliest times the Romans seemingly had only one name; *e.g.,* Romulus, Remus, Manius. From the beginning of historical times, however, the Roman personal name consisted of a praenomen (given name, forename) and a nomen (or *nomen gentile*). Only intimates used the praenomen, and its choice was restricted to fewer than 20 names, among them Gaius, Gnaeus, Marcus, Quintus, Publius, Tiberius, and Titus. The nomen that followed was hereditary in each gens (a related group of families, like the Scottish clan); examples include Antonius, Aurelius, Claudius, Cornelius, Fabius, Horatius, Julius, Lucius, Maccius, Tullius, and some others. Because the choice of both the praenomen and the nomen was restricted, the patrician families and later all families started using a hereditary name, called a cognomen.

These cognomina developed from original surnames; *e.g.,* Cicero "bean," Pictor "painter," Plautus "flat foot," Tacitus "silent." Thus the Roman name eventually consisted of three parts: Marcus Tullius Cicero, Gaius Julius Caesar. In addition, a person might acquire an individual surname, called an agnomen: Publius Cornelius Scipio Africanus was so named because of his successful war in Africa.

This system of naming was used during the whole republican period and later in the empire. Toward the end of the empire, however, the naming pattern began to change and subsequently was lost. One reason was that more persons used names lacking any real relation to themselves. For instance, a slave (and then his children) used the praenomen and the nomen of the master who set him free; *e.g.,* had Marcus Tullius Cicero freed a Syrian slave, the name of the latter might have been Marcus Tullius Syrus.

The number of freed slaves grew constantly, particularly after the victory of the Christian religion. Also, a free inhabitant of the empire who was granted Roman citizenship acquired the praenomen and nomen of the magistrate who made him a citizen, and in AD 212, when all free noncitizens were given citizenship by the emperor Caracalla, hundreds of thousands of persons prefixed Marcus Aurelius to their names, whether Greek, Syrian, African, or any other. In this way, Roman names lost their significance.

Another change was introduced by the Christians, who belonged to social classes that were not particularly concerned with the habits of the Roman higher class and who preferred names connected with their own religion; *e.g.,* from its founders (Petrus, Paulus, Joannes, Maria, Timotheus) or from the new martyrs, frequently persons with simple Latin or Greek surname-like names such as Stephanos "wreath" (modern Stephen), Laurentius "laurel" (modern Lawrence), and Sidonius "coming from Sidon [in Phoenicia]" (modern Sidney). Simple names like these were sometimes called *signum.* The Christians, however, soon started creating their own names; *e.g.,* Benedictus "blessed," Desiderius "desiring [salvation]," Renatus "reborn [by Baptism]," (modern René).

Christian names

With the spread of Christianity, this stock of names spread into territories that did not belong to the Roman Empire, but the diffusion was slow. In both the Germanic and the Slavic sphere (half of which came under the influence of the Eastern Church), the use of many of the original non-Christian names was continued, partly by tradition and partly because some of the bearers of these names became saints themselves. In this way, the repertory of given names was set, in general, somewhere around the 12th century. A notable addition to it was the influx of Old Testament names brought by the Reformation (Adlai, Benjamin, and so on). Certain names have left no trace of their ephemeral existence—*e.g.,* Puritan names such as Humility, Be Faithful, Kill Sin; French revolutionary names; and Russian postrevolutionary names such as Mels (an acronym containing the initial letters of Marx, Engels, Lenin, and Stalin). American fanciful given names for girls, such as Claretta, Elizene, Gwyned, and Marilla, are also relatively insignificant in impact, though the group is growing.

Christian and non-Christian given names

Family names. Family names came into use in the later Middle Ages (beginning roughly in the 11th century); the process was completed by the end of the 16th century. The use of family names seems to have originated in aristocratic families and in big cities, where they developed from original individual surnames when the latter became hereditary. Whereas a surname varies from father to son, and can even be changed within the life span of a person, a hereditary surname that develops into a family name better preserves the continuation of the family, be it for prestige or for the easier handling of official property records and other matters. Family names frequently developed (via surnames) from hypocoristic forms of given names; *e.g.,* from Henry came Harry, Harris, Hal, Halkin; from Gilbert came Gibbs, Gibbons, Gibbin, Gipps, Gilbye, Gilpin; and from Gregory there developed Gregg, Grigg, Greggs, Griggs, Greig. Other sources of family names are original nicknames—Biggs, Little, Grant (grand, large), Greathead, Cruikshank, Beaver, Hogg, Partridge; occupations—Archer, Clark, Clerk, Clarkson (son of a clerk), Bond, Bonds, Bound, Bundy (bondman); and place-names—Wallace (man from Wales), Allington, Murray, Hardes, Whitney (places in England), Fields, Holmes, Brookes, Woods (from microtoponyms).

A great number of family names come from patronymic surnames; in English, they are usually formed by the suffixation of "-son." Patronymic surnames can be formed from the father's given name or from any of its variants. Therefore, there is not only the form Richardson, but

also Dickson, Dixon, Dickinson; and Henryson, Harrison, Henderson; Gilbertson, Gibson; and Gregson, Grigson. Some English patronymics, particularly in old families, are formed with a prefixed "Fitz-" (*e.g.,* Fitzgerald), which goes back to Norman French *fits* "son." In contradistinction to English, the Scottish patronymics are formed by a prefixed "Mac" or "Mc" (McGregor), the Irish with "O" (O'Brien) or "Mc" or "Mac," and the Welsh with "P-" (Powell "son of Howel"). In Modern Greek, patronymics are formed by suffixation; *e.g.,* Dimitriopoulos "son of Dimitrios."

French family names

The development of family names is similar in all of Europe. For example, French names such as Jaquet, Jacquot, Jacotot, Jacotin, Cottet, Cottin, Cotin, Jacquin, Jacquinet, Jacquinot, Jacquart, Jacquier all derive from Jacques; Davignon, Decaen, Derennes, and Beauvais developed from the place-names Avignon, Caen, and so forth; Breton, Lebreton, Lenormand come from the names of districts; Clerk, Leclerc, Duclerc, Auclerk, Clergue (*cf.* English Clark), Boucher, Boulanger, Masson designate professions ("butcher," "baker," "mason"); and Roux, Leroux, Rousset, Rousseau, Lerouge, Roujon are all variants of "red" (*i.e.,* red hair). Roughly the same scheme exists everywhere in Europe. Some family names can be traced to nicknames that must have their origin in incidents and attitudes that cannot be understood now; *e.g.,* Czech family names such as Nejezchleba "Don't eat bread!" and Skočdopole "Jump into the field!"

The development is slighty different among Jews. While living in ghettos, they used only given names. After the end of the 18th and the beginning of the 19th century, they chose or were given family names. Many of these names (which vary in the individual languages) are derived from religious vocations: Cantor, Canterini, Kantorowicz (lower priest); Kohn, Cohen, Cahen, Kaan, Kahane (priest); Levi, Halévy, Löwy (name of the tribe of priests). Many are derived from place-names—Morpurgo (Marburg)—or from nicknames—Hirsch ("deer" in German). Frequently, particularly in Austria, the Jews were given derisory family names, such as Eberstark "strong as boar," Rosenduft "fragrance of roses," and Hitzig "hot," from Itzick, a mocking form of Isaac.

The only outstanding exception to this European pattern of naming occurs with the names of kings, who use one of their given names. Some royal families have what could be called family names; *e.g.,* the Hohenzollerns (more correctly, Hohenzollers) of Prussia. The British royal family accepted the name Windsor only in 1917 (this was changed to Mountbatten-Windsor for the future members of the family who will not enjoy princely status). The pope of the Roman Catholic Church abandons his personal name after his election and chooses a single name, sometimes associated with his intentions; *e.g.,* Pope Paul VI chose the name Paulus because of St. Paul's missionary activities and travels.

Other patterns of naming. Names and naming practices in other cultural areas show a strong similarity in the basic trends. Among the ancient Assyrian and Babylonian names are theophoric designations such as Ashurbanipal, meaning "Ashur [a god] created son," and Nabukudurriusur (Nebuchadrezzar of the Bible), translated as "Nabu [a god] protected the estate." The Phoenician (Carthaginian) name Hannibal means "grace of Baal" (a god).

Theophoric names

The Hebrew Yehonatan, Yonatan (*i.e.,* Jonathan) means "God gave"; Rafa'el (Rafael) is translated as "God cured." There are also nontheophoric names such as Laban (from Hebrew *lavan* "white"). The Aramaic surname of the fisherman Simon, Kepha, meaning "stone," became famous in the New Testament as Petros (Peter), the Greek translation of the name (*petra* "rock, stone").

The more complicated structure of Arabic society brought an independent development similar to the European one. Given names such as Muḥammad, Ibrāhīm (= Abraham), Manṣur "victor," ʿAlī "exalted," ʿAbd Allāh "slave of Allāh" are differentiated by surnames such as Ibn ʿAbbās "son of ʿAbbās," al-Baghdādī "from Baghdad," al-Ghazālī "the spinner." The Caucasian (*e.g.,* Ossetic) personal name consists of a given name preceded by the name of the tribe (gens) in the genitive plural; the name of the father may be inserted, thus giving Gaglojty Soslany fyrt Nafi "Nafi, son of Soslan, of [the gens of] Gaglo." Chinese society has had the institution of hereditary family names since the 4th century BC, but the number of these names has been reduced to some 200. Examples include Chan, Mao, and Lu. The choice of the given name was formerly much freer, but legislation seems to have restricted it. In a similar way, there are not more than 300 Korean family names, but only three of them—Kim, Pak, and Yi—belong to the great majority of families in Korea. The given name is chosen, but its choice is limited by the practice that one of the two syllables of the name should be identical within a family for a generation; the whole given name should have an auspicious meaning.

By the 20th century, the originally European pattern of given name + family name had been introduced practically everywhere. Black Africa (*e.g.,* among the Yoruba) now has the "normal" pattern of personal names, but both the given and the family names are of vernacular stock. There are given names such as Olúsolá "god [non-Christian] made greatness," Òṣunbùnmi "Òṣun [a river] gave me," and Adeyẹmi "crown befits me," and family names like Ajólore "who [is] a kind doer." Among the American Indians there are, surprisingly, practically no theophoric names. Instead, the Indians used names related to the totem, to animals indicated by omens or dreams, and to successful incidents in life. Those North American Indians who did not accept English names now use the English translation of their names as last names (which sometimes are not hereditary); *e.g.,* John Sleeping Owl, Mary Little Bear.

Types of place-names

Place-names. *Descriptive and commemorative place-names.* If the "meanings" of place-names and the motives for their choice are examined, several broad types may be discerned. Descriptive names indicate a characteristic feature of the entity; *e.g.,* Rocky Mountains, North Sea, Newcastle. The chosen feature is sometimes only illusory or observed by chance, as in the case of the Pacific Ocean (only a small part of it was calm, or pacific, when seen and named). Honorific and commemorative names are another broad category. Examples include Constantinople (formerly called Byzantium, renamed Konstantinoupolis "city of Constantine" because that emperor made it the capital of the Roman Empire); Aphrodisias "[the town of] Aphrodite" (in Asia Minor), changed into Stauropolis "city of the cross" with the advent of Christianity; Cartagena, transferred to Colombia (South America) in commemoration of Cartagena in Spain (Cartagena in Spain was in turn developed from Latin Carthago Nova, a translation of the name given to the town by the Phoenician settlers in commemoration of Carthage, the Phoenician rival of Rome); Nieuw-Amsterdam, commemorative of the Dutch capital, changed to New York (honorific for the Duke of York). Among the numerous benedictory, wishful names are the Russian Vladivostok "govern the East!" (founded and named by Russians as their main base on the Pacific coast), Cape of Good Hope (a renaming of a more descriptive Cape of Tempests), and Greek Pontus Euxinus (now the Black Sea) "hospitable sea" (a renaming of Pontus Axeinos "inhospitable sea"). In most cases, however, place-names do not have a "meaning" at all, particularly not for the general user.

Place-names reflecting historical influences. Place-names are frequently accepted into the language of a new population. The toponymy of the United States illustrates this well. Spanish names are numerous in the South and Southwest; *e.g.,* Florida, San Antonio, Santa Fe, and San Diego, all of which are Spanish names of Roman Catholic saints or holidays. French names occur frequently in the Southeast and the central United States (*e.g.,* La Nouvelle Orléans, changed into New Orleans; Baton Rouge; St. Louis; Louisiana); Dutch names are found in the East (Haarlem changed into Harlem); Indian names are interspersed everywhere; and, finally, English names are superimposed over all the rest. An examination of all these names, which are now used by a mostly English-speaking population, could not fail to yield some information about the colonization of the United States, even if the history were not known.

In the same way, the place-names of Britain reflect its

history. Above all, there are Celtic names—*e.g.,* Eboracum (named for a tree), partly translated as Eoforwic, which changed into York. Roman names are also numerous; *e.g.,* Castra "military camp," changed into Chester, and Lindum Colonia "Colony Lindum" (which itself is Celtic, *linne* + *dunom* "town at the lake") is now Lincoln. There are, in addition, Anglo-Saxon names (*e.g.,* Whittingham "habitation of Hwita's people"), Scandinavian names (*e.g.,* Badby, in which *-by* is the Scandinavian element instead of English *-bury* "castle"), and Norman names (*e.g.,* Richmond, from a personal name consisting of *rīkī* "rich, powerful" + *mond* "world").

Changes in place-names

Any country's toponymy consists of various layers. In France there are Celtic names such as Lucodunos "shining town" that became Latinized into Lugdunum and changed into the modern form Lyon; Greek names such as Agathe (Tyche) "good (luck)," which has become Agde; Roman names such as Forum Julii "marketplace of Julius," modern Fréjus; and old Germanic names such as Clarbec "clear brook" (*klar* + *Bach* in German). Most important is the fact that place-names can be used as a source of information themselves, even if other forms of evidence are lacking; for instance, because Moskva (= Moscow) is a Finnish name (Finnish *kva* "water") and because other Finnish toponyms are present in Russia, the prehistoric presence of Finnish tribes in that location can be presumed. Names of rivers are particularly important for this purpose, because they are very conservative and usually are taken over by a new population. A considerable number of river names in western and central Europe show remarkable similarity (*e.g.,* Esera in Spain, Isère in France, Yser in Belgium, Isar in Bavaria, Jizera in the Czech Republic) and are the only evidence of a pre-Celtic Indo-European population of those regions.

In a similar way, names are also indicative of cultural and political trends. Singapore (Sanskrit Siṃhapura "castle of lions"), for example, testifies to the cultural influence of India in the area. Particularly significant in this respect are deliberate changes of names caused by changes in political power, ideology, and so forth. Changes such as Nieuw-Amsterdam becoming New York, or Léopoldville (named after the king of Belgium who acquired the Congo) becoming Kinshasa, are very common. Some cases of renaming do not lack humour: La Roche-sur-Yon in France was rebuilt by Napoleon and renamed Napoléon-Vendée, which was changed to Bourbon-Vendée under the Restoration; during the 100 days of Napoleon's return from Elba and in the subsequent second Restoration, the cycle was repeated once more, and only the Third Republic restored the old name. Renaming also shows examples of cynicism: Lyon, which had rebelled against the revolutionary covenant, was punished by systematic demolition and a massacre of its inhabitants; the ruins of the city were renamed Commune-Affranchie "Liberated Commune." Changes of place-names are sometimes made systematically; when the territory called Alto Adige in Italian and Südtirol (South Tirol) in German became part of Italy after World War I, for instance, a systematic effort was made to give or to return to these territories the Italian character in both place-names and personal names. The Russian Revolution brought a change of names that were reminiscent of the old regime and ideology; *e.g.,* St. Petersburg (changed into a more Slavic Petrograd by the tsar during the war) became Leningrad (and then St. Petersburg again in 1991); Tsaritsyn (from *tsar* "emperor") became Stalingrad (and then Volgograd in the late 1950s); and Yekaterinodar (from Yekaterina [= Catherine], an empress) became Krasnodar (from *krasny* "red"). However, most of the pre-Revolution names were reinstated after the collapse of the Soviet Union in 1991.

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(L.Zg.)

Nanking (Nanjing)

Nanking (Wade-Giles romanization: Nan-ching; Pinyin: Nanjing), capital of Kiangsu Province in central eastern China, is a port on the Yangtze River and a major industrial and commercial centre. Rich in history, it served seven times as the capital of regional empires, twice as the seat of revolutionary governments, once (during World War II) as the site of a puppet regime, and twice as the capital of a united China (the second time from 1928 to 1937). The name Nanking ("Southern Capital") was introduced in 1421 during the Ming dynasty (1368–1644).

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Physical and human geography

THE LANDSCAPE

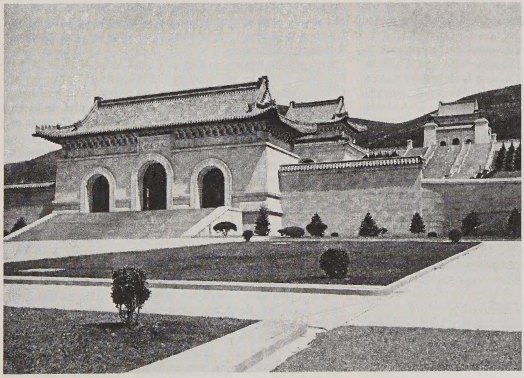
The city site. Nanking is situated on the southeastern bank of the Yangtze, some 160 miles (260 kilometres) from Shanghai (215 miles by water, 193 miles by rail). The city proper comprises the area encircled by a gigantic wall constructed during the Ming period and adjacent suburbs. The city wall—of which about two-thirds is still standing—is 21 miles long, has an average height of 40 feet (12 metres), and contains 13 gates. The municipality (*shih*) of Nanking includes territory extending to the border of Anhwei Province on the north, west, and south and to the borders of Yang-chou and Cheng-chiang municipalities on the east. Included in the municipality, which has an area of about 2,516 square miles (6,516 square kilometres), are counties on either side of the Yangtze and both urban and rural districts. The city wall

Climate. The four seasons are clearly distinguishable. The hot summer months are from July to September, while winter lasts from December until March. Spring and autumn are both mild and pleasant. January and July mean temperatures are about 37° F (3° C) and 82° F (28° C), respectively. The average annual rainfall is 39 inches (990 millimetres), the bulk of it falling between June and August.

The city layout. The city of Nanking, encircled by hills and rivers, resembles a gourd, with its tip pointing northwest, toward suburban Hsia-kuan, on the south bank of the Yangtze. Hsia-kuan and P'u-k'ou, which is opposite it on the north bank, house the harbour facilities of the huge Nanking River Port. On the west and south Nanking is bordered by the Ch'in-huai River, which runs along the outside of the city wall and is a tributary of the Yangtze. On the east are the foothills of the Tzu-chin ("Purple-Gold") Mountains, and at the city's southern tip is Chin-liang ("Quite-Cool") Mountain. Outside of the city wall to the northeast is the extensive Hsüan-wu Hu ("Mystic Martial Lake"), containing five islets linked by embankments, and on the other side of the Ch'in-huai to the southwest is Mo-ch'ou Hu ("Lake of No Sorrow"); both lake areas are city parks. The skyline suggests spaciousness and grandeur. Blue-glazed tiles adorning the old city gates, parklike scenery along the boulevards, lotus blossoms and tea pavilions on the lakes, and temples half hidden in the green hills are all characteristic sights in Nanking.

The city comprises four districts. The north district, from I-chiang Men (a city gate) to the Ku Lou (Drum Tower; built in 1382), traversed by Chung-shan Avenue as its axis, contains such landmarks as Pei-chi Ko ("North Pole Pavilion") and Chi-ming Ssu ("Cockcrow Temple"), as well as government offices, Nanking University (founded in The city's four districts

Ewing Galloway



Sun Yat-sen Mausoleum at Nanking.

1902), and modern residential quarters. The central district, surrounding Hsin Chieh-k'ou ("New Crossroads"), is the business centre of the city, and to the south is situated the populous old city—traditionally famous for entertainment. The east district, a centre of culture, contains the ruins of the former Ming palace as well as the Nanking Museum, with its exhibits on Chinese history, and scientific institutions.

Forming an integral part of the life of the city are its immediate outskirts. To the south is the Yü-hua T'ai ("Terrace of the Rain of Flowers"), noted for its five-colour pebbles and a Communist martyrs' memorial. In the eastern outskirts, on the magnificent forested Tzu-chin range, are the Ming emperor Hung-wu's mausoleum, its approach noted for pairs of large stone animals; the blue-tile-roofed mausoleum of Sun Yat-sen; the Ling-ko Ssu ("Temple of the Valley of Spirits") and the nearby 200-foot-high pagoda; and the Tzu-chin Mountains Astronomical Observatory. Other scenic spots include Yen-tzu Chi ("Swallow's Bluff") in the north and Ch'i-hsia Shan ("Abode of Clouds Mountain") farther to the northeast. Two industrial districts extend northeastward and southwestward from the city.

THE PEOPLE

Despite much industrial growth, the city of Nanking retains a traditional feature—the existence of a substantial rural population within the boundaries of the municipality. The people speak Mandarin with a marked local accent. The city has small communities of Christians, Buddhists, and Muslims.

THE ECONOMY

Agriculture. Much of the land in the municipality's rural districts is under cultivation; the major agricultural products are rice, wheat, peanuts (groundnuts), and fruits and vegetables. In and around the many lakes and ponds *pai-ho* (lily bulbs), water chestnuts, lotus roots, and other aquatic plants are grown. Both freshwater fishery and pig farming are important. Along the canals and creeks, farmers raise large flocks of ducks; the Nanking duck, preserved in salt and pressed, is one of China's food delicacies.

Industry. Before 1949, Nanking was noted chiefly for its traditional handicraft products, such as satins, velvets, and brocades. The city's major industrial expansion has taken place since then, and Nanking has become an important industrial centre. Major manufactures include automobiles, petrochemicals, electronics, machinery, textiles, consumer goods, pharmaceuticals, and high-technology products. Industrial parks, economic development zones, foreign investment, and international joint ventures play major roles in the economy. Nanking is an important commercial port in the Yangtze River delta, second only to Shanghai, and serves as a hub for trade between the north and south.

Major industries

Transportation. Nanking's major avenue of commerce is the Yangtze, which connects the city with the Yangtze delta and with central China. Nanking is linked by rail to Shanghai and to major Chinese cities to the north. Another railroad leading south extends to T'ung-ling in Anhwei province; a loop line through the eastern suburbs links it with the Shanghai-Nanking line. In 1968 the rail ferry between P'u-k'ou and Hsia-kuan was replaced by the Yangtze bridge, more than 20,000 feet in length, with a double-track railroad on its lower deck and a four-lane highway on the upper deck.

Buses, taxis, automobiles, and bicycles are the city's primary means of transport. Highways link Nanking to Shanghai and other cities in Kiangsu, Chekiang, and Anhwei provinces. Nanking Lu-k'ou International Airport, which opened in 1997 and is located in a southern suburb, has flights to domestic and overseas destinations.

ADMINISTRATION AND SOCIAL CONDITIONS

Government. Nanking's municipal government is part of the hierarchical structure of the Chinese government that extends from the national organization, through the provincial apparatus, to the municipal and, ultimately, neighbourhood levels. Paralleling this structure is that of the Chinese Communist Party (CCP). As in all of China, real power in Nanking is held by the local CCP, but local government institutions perform various formal functions. The Nanking Municipal People's Congress, the formal governmental decision-making body, follows the guidance of the local CCP in issuing administrative orders, collecting taxes, determining the budget, and implementing economic plans. Under the direction of the local CCP, a standing committee of the Municipal People's Congress recommends policy decisions and oversees the operation of municipal government. Executive authority is formally assigned to the Nanking People's Government, the officers of which are elected by the congress. The local government consists of a mayor, vice mayors, and numerous bureaus in charge of public security, the judicial system, and other civil, economic, social, and cultural affairs.

Administratively, the city is divided into districts (*ch'ü*). Below the district, police substations supervise the population, while subdistrict or neighbourhood offices handle civil affairs in their areas. Residents' committees help mediate disputes, carry out literacy campaigns, and promote sanitation, welfare, and family planning.

Health. Nanking made great progress in public health and medicine during the Nationalist period. Health conditions have continued to improve under the Communist government, which has placed great emphasis on public health education. There are many general and specialized hospitals in Nanking, and clinics and health stations are maintained by neighbourhood associations, factories, and schools. Nanking is also a noted centre for training doctors in traditional Chinese medicine.

Education. Nanking inherited from Nationalist days an excellent school system that in 1949 included 300 primary and middle schools and some of the best universities and colleges in China. Since the 1950s there has been a considerable increase in the number of primary, middle, and technical secondary schools.

In addition, much attention has been given to adult education, and many spare-time schools, university extensions, and other institutions that provide training in technical fields have been established. Nanking University and Nanking Institute of Technology are among the leading institutions of higher education in the country, and colleges of hydraulic engineering, aeronautical engineering, and meteorology are also of national significance.

Adult and higher education

CULTURAL LIFE

Nanking's long history as a cultural centre is reflected in its many surviving monuments and buildings of historical significance. The Nanking Museum, Museum of the Heavenly Kingdom of Great Peace (Taiping Museum), and the Kiangsu Provincial Museum are all housed in buildings constructed in traditional Chinese style. Among the city's numerous research agencies and scientific societies is the Kiangsu Academy of Science, a branch of the Chinese Academy of Sciences.

Some of the leading artists of China have worked in the Kiangsu College of Traditional Painting. Troupes of Peking opera and various Kiangsu operas give performances of both traditional theatrical pieces and modern plays in the city. Sports grounds are found in all parts of Nanking and its suburbs. The well-equipped Wu-t'ai Shan Stadium, in the centre of the city, is used for major sports events. The public at large, however, finds its recreation in the many beautiful parks and resorts.

History

THE EARLY EMPIRES

Nanking's recorded history dates to the Spring and Autumn (770–476 BC) and the Warring States (475–221 BC) periods, when a castle near Yü-hua T'ai was constructed by the Yüeh state in 472 BC. After the Yüeh territory was taken over by the Ch'u state, another castle under the name of Chin-ling was built on Chin-liang Mountain to control the traffic between the Yangtze and the Ch'in-huai. Under the Ch'in (221–206 BC) and Han (206 BC–AD 220) dynasties, Nanking was successively under the jurisdiction of Mo-ling County (*hsien*) and Tan-yan County.

Nanking—under the name of Chien-yeh—emerged as the political and cultural centre of Southeast China during the period of the Three Kingdoms, when Sun Chien and his son Sun Ch'üan made it the capital of the kingdom of Wu from 229 to 280. In 317 the Eastern Chin dynasty (317–420), fleeing foreign invaders in North China, again chose the city as a capital. Renamed Chien-k'ang, Nanking became a haven for northern families in exile. After the fall of the Eastern Chin, Nanking, under four successive dynasties—Liu-Sung (420–479); Southern Ch'i (479–502); Southern Liang (502–557); and Southern Ch'en (557–589)—was the seat of government of the regional empires south of the Yangtze.

These regimes were dominated by military men whose rivalries weakened the government. But in Nanking progress was made in areas other than politics, and its population grew to 1,000,000 during the Southern Liang. Bountiful harvests, coupled with tea, silk, papermaking, and pottery industries, supported a booming economy. Culturally, the Six Dynasties—as the dynasties that ruled from 220 to 589 are called—produced a galaxy of scholars, poets, artists, and philosophers. The works of Wang Hsi-chih and Ku K'ai-chih set the canons of calligraphy and painting, respectively. The publication of *Wen hsüan* ("Literary Selections") and of *Wen-hsin tiao-lung* (a classic in literary criticism), the evolution of what has come to be known as the Six Dynasties essay style (a blending of poetry and prose), and the formal recognition and systematization by Shen-yüeh (a 6th-century courtier) of the four tones of the Chinese language were achievements of this period. In philosophy, the so-called *ch'ing-t'an* ("pure discourse") movement, spiritually akin to a form of Taoism, found many adherents who held themselves aloof from politics. Hundreds of Buddhist temples were built. Voluminous Buddhist scriptures were edited and transcribed, and thousands, including the emperor Wu Ti, founder of the Southern Liang dynasty, took monastic vows.

The Six Dynasties

From 581 to 1368, under the successive unified empires of the Sui, T'ang, Sung, and Yüan dynasties, Nanking reverted to the status of a prefectural city. Various names were given the city: Chiang-chou and Tan-yang under the Sui; Chiang-chou, Chin-ling, and Pai-hsia in early T'ang; Sheng-chou in late T'ang; and Chin-ling again under the Five Dynasties in the 10th century; Chien-k'ang under the Sung; and Chi-ch'ing under the Yüan. When the Southern T'ang briefly maintained a regional regime in the city from 937 to 975, Nanking enjoyed much intellectual creativity (the ruler Hou-chu himself being a poet of consummate skill) and was the scene of new construction, notably the octagonal stone pagoda of the Ch'i-hsia Temple and the crosstown channel of the Ch'in-huai Ho. Another period of prominence occurred during the Southern Sung dynasty (1127–1279), when Yüeh Fei used the city as his base for resistance against the Juchen in North China.

In 1368 the emperor Hung-wu, founder of the Ming dynasty, made Nanking the capital of a united China. Naming the city Ying-t'ien-fu ("Responding to Heaven"), he built a grand Imperial palace and the city wall. In addition, earth ramparts were prepared to form the basis for a larger outer wall. In 1421, however, Hung-wu's son, the Yung-lo emperor, moved the capital to Peking. The city became a subsidiary capital and was renamed Nanking.

The growth of trade and industry, however, brought new wealth to Nanking, especially to Hsia-kuan. Weaving, pottery, printing, and brocade making were the leading industries. Oceangoing vessels used by Cheng Ho in his famous 15th-century expeditions to the South Seas were built in the shipyards to the northwest of the city. An Imperial college—the Kuo-tzu chien—attracted students from throughout the empire, as well as from Japan, Korea, Okinawa, and Thailand. The scholars of this college helped compile the *Yung-lo ta-tien* ("Yung-lo Emperor's Encyclopaedia"); its printing plant issued fine editions of many classics, as well as such works as *Pen-ts'ao kang-mu* ("Great Pharmacopoeia") by Li Shih-chen and *Yüan-shih* ("History of the Yüan Dynasty") by Sung Lien.

In the Ch'ing (Manchu) dynasty (1644–1911/12), Nanking, renamed Chiang-ning, became the government seat of the viceroy of Kiang-nan (who governed the provinces of Kiangsu, Kiangsi, and Anhwei). In 1842 the treaty ending the Opium War was signed there. A decade later, in 1853, the city was taken by the Taiping revolutionary forces under the leadership of Hung Hsiu-ch'üan. As the capital of T'ai-p'ing T'ien-kuo (Heavenly Kingdom of Great Peace), Nanking became a commune practicing universal brotherhood, equality of the sexes, and communal ownership of property. Numerous palaces for Hung and his lieutenants were built. When the Taipings were overthrown in 1864, there was widespread destruction of public buildings, of temples, and of the city wall by Ch'ing troops, and the city was left nearly prostrate.

The Taiping capital

THE MODERN CITY

Recovery took decades. Although foreign trade was sanctioned by the treaties of Tientsin concluded with France in 1858, it did not begin until 1899. By that time, modern industry and communication had reached the city. In 1908 the Shanghai-Nanking railroad was opened, followed four years later by a railroad from the port city of Tientsin in Hopeh province to P'u-k'ou. Such economic growth, however, was overshadowed by the revolution of 1911. After the uprising had begun upstream at Wu-ch'ang in Hupeh province, the revolutionary leaders proclaimed Nanking the seat of the provisional government of the Republic of China, and the democratic constitution of 1912 was adopted there before the first president, Yüan Shih-k'ai, moved the capital to Peking.

Under the infant Republic of China, Nanking was governed by warlords for more than a decade. Sun Yat-sen, leader of the Kuomintang (Nationalist Party), embittered by politicians' intrigues centred in Peking, vowed to make Nanking the Nationalist capital. Accordingly, when his follower Chiang Kai-shek achieved unified control of the country in 1928, the Nationalist government made Nanking once more the capital of a united China. Progress was made in developing communications, industries, and natural resources. Physically, too, the city acquired a new look; modern boulevards and government buildings were constructed; new railroad stations and airfields were built; and the Sun Yat-sen Mausoleum was erected.

Such achievements were, however, cut short by the war against Japan. Nanking fell in 1937. In the sack of the city that followed, between 100,000 and 300,000 civilians were slaughtered. The city was then ruled by puppet governments until Japan's defeat in 1945. From 1946 to 1949 Nanking resumed its status as the capital of Chiang Kai-shek's Nationalist government, but Chinese Communist forces took the city in 1949. When the People's Republic of China was proclaimed on Oct. 1, 1949, Nanking was once again abandoned in favour of Peking as the national capital. In 1952 it was made the provincial capital of Kiangsu. Nanking was transformed into a modern industrialized city. Lives were lost and hardships suffered during the Great Leap Forward (1958–60) and the Cultural Revolution (1966–76). During the latter, many cultural and historical relics were damaged. Since then the city has generally prospered and has become a major tourist destination.

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Naples

Naples (Italian: Napoli) lies on the west coast of the Italian Peninsula, 120 miles (190 kilometres) southeast of Rome, in the fertile region of Campania. On its celebrated bay—flanked to the west by the smaller Gulf of Pozzuoli and to the southeast by the more extended indentation of the Gulf of Salerno—the city is situated between two areas of volcanic activity: Mount Vesuvius to the east and the Campi Flegrei (Phlegraean Fields) to the northwest. The most recent eruption of Vesuvius occurred in 1944. In 1980 an earthquake damaged Naples and its outlying towns, and since then Pozzuoli to the west has been seriously afflicted by bradyseism (a phenomenon involving a fall or rise of land).

Naples is located near the midpoint of the arc of hills that, commencing in the north at the promontory of Posillipo and terminating in the south with the Sorrentine peninsula, form the central focus of the Bay of Naples. To the south of the bay's entrance to the Tyrrhenian Sea, the island of Capri forms a partial breakwater, visible from the city in clear weather and at times of impending storm but increasingly screened by polluted air from the industrial zone developed, since World War II, between central Naples and the Vesuvian slopes. Pollution also afflicts the waters of the port, obliging the more scrupulous practitioners of the immemorial Neapolitan fishing industry to withdraw ever farther from their native shore.

While Naples' importance as the principal port of southern Italy is at last in decline, the city remains the centre of the nation's meridional commerce and culture, beset by inveterate difficulties, and distinguished by an adroit and original spirit that retains many suggestions of the classical past and of assimilated historical experience. Of all the cities of southern Italy with Greek origins, Naples presents the most striking example of a lively continuity. It is also perhaps the last great metropolis of western Europe whose monuments, albeit often in decay, may still be seen in their popular context, without distractions of tourism or self-conscious commercialism.

Since World War II, during which Naples suffered severe bombardment, modernization has increasingly altered the city's setting and character; and a measure of long-deferred but often speculative prosperity is reflected in new suburbs now proliferating in once-rural surroundings. However, Naples remains arcane and compelling, a city whose richness requires from the visitor time, accessibility, and some knowledge of the Neapolitan past.

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Physical and human geography

THE LANDSCAPE

Description and climate. Generations of observers have described Naples as a vast popular theatre, a designation applying as much to the city's aspect of a tiered arena as to its animated street life. It may also be characterized as an immense *presepio,* in evocation of the populous scene of the traditional Neapolitan Christmas crèche—the expansive natural setting being countered, within the town itself, by a congested vitality. In the shadow of Vesuvius, within the sweep of the bay, the Neapolitan decor is still predominantly one of moldering palaces in red or ochre and ancient churches in stone or stucco. Although the narrow old streets, teeming and traffic-ridden, clamber up hillsides topped by new constructions, few buildings in central Naples as yet rise more than 10 stories. Three fortified castles—two of them on the seafront and one on a central eminence—still define the city's heart. At the picturesque, pale Castel dell'Ovo, the shoreline divides into two natural crescents.

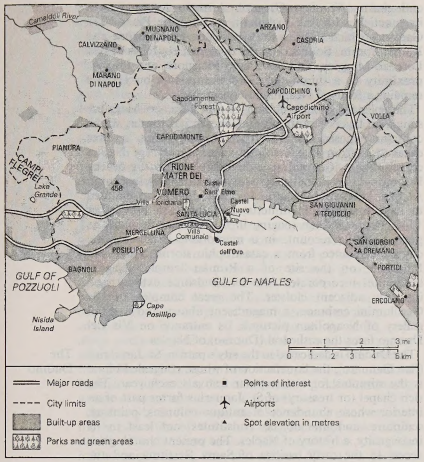
The blond, volcanic tuff, or tufa, of the region is much used in construction, as is the dark Vesuvian lava that paves the older streets. Magisterial use was also made, in past centuries, of the dark southern stone *piperno,* seen at its most imposing at the Castel Nuovo. The city's aspect of southern colours interspersed with evergreen groves of ilex, palm, camellia, and umbrella pine reflects a climate in which balconies are in use most of the year. High temperatures in July and August often exceed 90° F (32° C), while the damp, chilly winter is alleviated by many brilliant days. Winter temperatures rarely fall to freezing, and the snow occasionally appearing on Vesuvius is seldom seen in the town itself. The south wind, the sand-laden sirocco, intermittently brings a burdensome humidity, terminating in rain. Temperatures

Layout and architecture. Suburban Naples incorporates the headland of Posillipo, which joins the city at the yachting port of Mergellina—signaled by the church of Santa Maria del Parto. The nearby church of Santa Maria di Piedigrotta, centre of a now-diminished popular festival, is steeply overlooked by a small park encompassing the entrance to the Roman grotto called the Crypta Neapolitana. This poignant place also contains the Roman columbarium known as the Tomb of Virgil, and the sepulchre of the Romantic poet Giacomo Leopardi, who died at Naples in 1837.

From Mergellina, the seaside sweep of Via Francesco Caracciolo is flanked by the long, public park called Villa Comunale, sheltering the Zoological Station and the Aquarium (the oldest in Europe), both founded in 1872. Along the inland border of the park runs the Riviera di Chiaia, marking what was once the shoreline. (The name Chiaia probably derives from *ghiaia,* denoting a shingle.) Still for the most part lined with handsome old palazzi, the Riviera di Chiaia was a favourite residential area for foreign visitors in the 18th and 19th centuries. The Neoclassical Villa Pignatelli, constructed for Sir Ferdinand Acton in the 1820s, is now, with its period furnishings, a museum. Recessed in contiguous streets, the churches of Santa Maria in Portico and the Ascensione a Chiaia contain works of the prolific 17th- and 18th-century Neapolitan painters.

Above this busy littoral, the panoramic Corso Vittorio Emanuele unfurls northeastward around the lower slopes of the town, toward the labyrinthine zone of Rione Mater Dei. Higher still, the prosperous Vomero district is served, like other upper areas of the city, by spiraling roads and a funicular railway. Among the modern blocks of the Vomero, the early 19th-century Villa Floridiana—housing the national museum Duca di Martina, with a fine collection of European and Oriental porcelain and ceramics—is easily distinguished in its extensive park.

Piazza della Vittoria—whose titular church commemorates the Battle of Lepanto (1571)—closes the sweep of Villa Comunale and leads inland to the fashionable shops of Piazza dei Martiri, Via Chiaia, and Via dei Mille. The



Naples and surrounding area.

waterfront road, becoming Via Partenope, passes along the ancient quarter of Santa Lucia—much altered since the late 19th century by land reclamation and monotonous construction and bordered on the seafront by some of the city's best hotels. Beneath the spur of the Pizzofalcone quarter—the remaining fragment of the defunct volcano Echia and once the site of a villa of the Roman general Lucius Licinius Lucullus—a brief causeway leads to the seagirt Castel dell'Ovo, its ancient origins incorporated in a medieval fortress. On the bay's second crescent, the eastbound road passes below the long, red flank of the Royal Palace and arrives at the foot of the mighty Castel Nuovo, which, with its round towers, dominates the main port on the one hand and, on the other, the large Piazza del Municipio.

The Castel Nuovo

The Castel Nuovo, so called to distinguish it from the older Castel dell'Ovo, was founded in 1279 by Charles I of Naples (Charles of Anjou). One of many Neapolitan landmarks to bear interchangeable names, it is known locally as the Maschio Angioino, in reference to Charles' Angevin origins and from the southern Italian convention that a show of power is necessarily male. There, in the 14th century, the brilliant court of King Robert welcomed Petrarch and Boccaccio, and Giotto was summoned to execute frescoes (now lost). The castle was embellished by Alfonso V of Aragon (Alfonso I of Naples), whose triumphal entry into Naples in 1443 supplies the theme of magnificent Renaissance sculptures over the west entrance. The castle, containing important late medieval and Renaissance decoration, now houses municipal bodies and an institute of Neapolitan history with an important library. At the west end of Piazza del Municipio, the Naples city hall incorporates, in a handsome structure of the 1820s, a 16th-century church.

The waterfront road continues past docklands, skirting on its inner side the popular church of Santa Maria del Carmine. The nearby Piazza del Mercato, a lively scene of morning markets, was also, in past centuries, a place of execution. Bombardment of the port of Naples during World War II obliterated much of the character of this section of shoreline, and the road itself diverges in the industrial zone of San Giovanni a Teduccio (a name that possibly recalls that of Theodosius). Visible history resumes in the approach to Portici and the Vesuvian shore.

Inland above Piazza del Municipio, the San Martino Hill is surmounted by a former Carthusian monastery—now an important museum of paintings and objects concerned with the history of Naples—and by the massive abutment of Castel Sant'Elmo. Both are of Angevin origins. The castle, founded in 1329 by Robert of Anjou, was recreated in the 16th century, under the Spanish viceroys, in the form of a six-pointed star. Within the complex of the former San Martino monastery, the church itself is rich in paintings and marble decoration of the Neapolitan Baroque. From the adjoining museum, one passes to a terraced garden with an incomparable panorama of Naples and the bay.

South of Piazza del Municipio, beyond the Castel Nuovo, stands the red complex of the Royal Palace, whose northeast wing, set in a small park, houses the great collections of the National Library of Naples. The main facade of the Royal Palace grandly faces, southwest across the vast Piazza del Plebiscito, the basilica of San Francesco di Paola, which—erected in royal thanksgiving for the restoration of Bourbon rule (1815)—is modeled on the Pantheon of Rome. The palace, created by Domenico Fontana early in the 17th century, now houses government offices and a notable picture gallery. Above San Francesco di Paola to the southwest, the rise of Monte di Dio is crowned by two important churches: the 17th-century Santa Maria degli Angeli and the 18th-century Nunziatella.

Adjacent to the palace on the north is the San Carlo opera house, which has heard and inspired many of the great artists of bel canto. Although the prodigious musical creativity of 18th-century Naples has no modern parallel, the San Carlo remains an important element of Europe's musical life. Across the busy intersection from the San Carlo, the late 19th-century arcades of the cruciform Galleria Umberto I serve, under their glass cupola, as an ornate meeting place; the arcades were familiar ground to Allied servicemen in the closing phase of World War II—a dramatic period recalled in such writings as John Horne Burns's *The Gallery* (1947), Norman Lewis' *Naples '44* (1978), and the macabre *La pelle* (1949; *The Skin*, by the politically volatile Curzio Malaparte, while early postwar disaffection is portrayed in Raffaele La Capria's *Un giorno d'impazienza* (1952; *A Day of Impatience*). Immediately south, on Piazza Trieste e Trento, the 17th-century church of San Ferdinando has traditionally given the *Stabat Mater* of Giovanni Battista Pergolesi—composed in 1736 for this confraternity—during Easter Week.

Via Toledo

From Piazza Trieste e Trento, the teeming thoroughfare of Via Toledo—named for the Spanish viceroy Don Pedro di Toledo, who laid it out in 1536—passes north into the dense centre of Naples. Its innumerable shops interspersed with grand churches, Via Toledo is banked with 17th- and 18th-century palazzi whose former magnificence has been turned to commercial or municipal use or—as in the case of the mighty Palazzo Maddaloni—has been allowed to lapse into residential decay. On the slope above Via Toledo,

Lee de Wys, Inc./F. Damm



The Bay of Naples with the view south toward Mount Vesuvius.

steep alleys climb toward San Martino through a zone that, preserving its labyrinthine 17th-century structure, is still known as the Spanish Quarter. The lower line of Via Toledo is interrupted at Piazza Carità by structures built during the Fascist and postwar eras.

Debouching into the Neoclassical hemicycle of Piazza Dante, Via Toledo resumes its route under other names, skirting the western flank of the National Archaeological Museum in its ascent toward Capodimonte.

Piazza Dante forms part of the western boundary to the district that, lying along three principal *decumani* (streets of orientation) of the Greek and Roman town, has comprised the city's heart since ancient times. Beyond the picturesque Alba Gate this district is introduced, at the western extreme of Via Tribunali, by the historic Naples Conservatory of Music and its great adjoining Gothic church of San Pietro a Maiella. Via Tribunali, the *decumanus maior* of Greco-Roman Naples, extends east for approximately one mile, terminating at the law courts near the old Capuana Gate. At its western end, the Renaissance Pontano Chapel (in decay) recalls the humanist Giovanni Pontano, who lived in Naples under Aragonese rule, while the older origins of the contiguous Baroque church of Santa Maria Maggiore are apparent in a Romanesque campanile.

Parallel to Via Tribunali, the upper, briefer Via Anticaglia conserves, within subsequent structures, evident remains of Roman public buildings. The lower parallel—the street that, bearing interim names, becomes Via San Biagio dei Librai—delineates the so-called Spaccanápoli ("Split of Naples"), a designation more loosely applied to all of this ancient centre.

From Piazza del Municipio, Spaccanápoli is approached along the north-northwest trajectory formed by Via Medina and Via Monteoliveto—a route that passes, to the east of Via Monteoliveto, the recessed Renaissance and Baroque complex of Santa Maria la Nova; and, to the west, in a small square, the church of Monteoliveto, or Sant'Anna dei Lombardi, supreme in Naples for its abundance and quality of Renaissance sculpture. From Via Monteoliveto, the short slope called Calata Trinità Maggiore rises to Piazza del Gesù Nuovo, a principal means of access to Spaccanápoli.

Overlooked from the west by Palazzo Pignatelli (where the painter Edgar Degas resided while in Naples) and with the 18th-century ornate Neapolitan obelisk Guglia dell'Immacolata at its centre, this square is dominated by the church of Gesù Nuovo, its gem-cut facade masking a sumptuous Baroque interior. Opposite rises the medieval complex of Santa Chiara, erected for the Franciscan order in the 14th century. The vast church, transformed internally in the 18th century and now restored (following tragic bombardment in 1943) to its original Gothic form, houses a damaged splendour of royal tombs and early frescoes. At its rear the large cloister decorated in 18th-century majolica tiles is one of the loveliest in Naples.

Santa Chiara

From this square the line of Spaccanápoli runs due east. The profusion of important monuments there, the mingling of eras, and the exuberance of the human setting are of inexhaustible fascination. Near the Gesù Nuovo, Palazzo Filomarino houses the Italian Institute for Historical Studies, founded by the philosopher Benedetto Croce. (Another celebrated Neapolitan philosopher, Giambattista Vico, was born, two centuries before Croce, in a house also preserved in this street.) Flanked by great palazzi, the basilica of San Domenico Maggiore, its Gothic form merged into the structures of later centuries, is a treasury of painting and sculpture. In 1272–74, St. Thomas Aquinas taught in the adjoining monastery. Where the intersecting Via Mezzocannone turns south toward the University of Naples, the church of Sant'Angelo a Nilo contains a lofty tomb sculptured by Donatello and Michelozzo. The nearby Renaissance Palazzo Santangelo was a stronghold of the once-mighty Carafa family.

In the upward transverse of Via San Gregorio Armeno, the church of this name exemplifies the Neapolitan Rococo. In this street, in slotlike shops, figures are made for the innumerable Neapolitan family crèches—culminating each Christmas in a scene of indescribable liveliness and charm. Via San Gregorio Armeno terminates, at its junction with Via Tribunali, in the little Piazza San Gaetano, which overlies the site of the Greek agora and Roman forum. Bounded by the two great churches of San Lorenzo Maggiore and San Paolo Maggiore, and in close proximity to a third—the Gerolomini—this busy space remains a focus of Neapolitan continuity.

The splendid Gothic church of San Lorenzo Maggiore stands on layers of antiquities. Beneath its cloister, which contains exposed remains from Roman times, a large excavation from the Greek and Roman eras of Naples constitutes—with antiquities discovered below the nearby Duomo—a considerable segment of the ancient city centre. At San Lorenzo Maggiore, in 1334, Boccaccio claimed to have first seen Fiammetta; and there, in November 1345, Petrarch, then lodging in the adjacent monastery, prayed—as he recounts in a memorable letter—for the city's deliverance from a catastrophic storm. San Paolo Maggiore, on the site of a Roman temple, features antiquities incorporated into its handsome exterior and into the adjacent cloister. The great complex of the Gerolomini embraces a magnificent library and a small gallery of Neapolitan pictures. Its entrance on Via del Duomo faces the cathedral (Duomo) of Naples.

The Duomo

The Duomo is dedicated to the city's patron, St. Januarius (San Gennaro), the liquefaction of whose congealed blood is the stimulus for two popular festivals each year. The rich chapel (or treasury) of St. Januarius forms part of an interior whose abundance of antique columns, painting, sculpture, and fine objects constitutes, not least in its incongruity, a history of Naples. The present church gives access to the early basilica of Santa Restituta and the adjoining baptistery, with 5th-century mosaics, of San Giovanni in Fonte. Near the upper (southern) flank of the cathedral, the 14th-century church of Santa Maria Donnaregina is, in its interior decoration, among the most interesting and beautiful medieval monuments of Naples, while the nearby Santi Apostoli, on the site of a Roman temple, provides a prodigious display of 17th-century Neapolitan painting.

To the east, the formidable Castel Capuano—site of law courts since the 16th century—rises near the round towers of the Capuana Gate, which in turn overshadow the Renaissance church of Santa Caterina a Formiello. Renaissance also is the decoration, by Giuliano da Maiano, of the exterior arch of this Aragonese city gate. Beyond the Capuana Gate, the northwest-southeast diagonal of Via Carbonara follows the line of demolished city walls. Marked, on its upper slope, by the monumental church of San Giovanni a Carbonara—containing the statuary tomb of King Ladislas and other capital late Gothic and early Renaissance works—Via Carbonara descends, with a change of name, to Piazza Garibaldi and the railway station.

Toward the end of the 19th century, precipitate change was wrought, from Piazza del Municipio to the railway station, by the slum clearance, or *risanamento,* that, following a calamitous epidemic of cholera in 1884, drove the straight, ugly Corso Umberto I (also called the Rettifilo) through that historic quarter. The stolid Rettifilo conceals, in small recesses, many historic buildings—beginning with the church of San Pietro Martire and concluding, at Piazza Garibaldi, with that of San Pietro ad Aram and its paleo-Christian crypt. Near Piazza Garibaldi, the Aragonese Nolana Gate is an enclave of busy markets.

Museums. Naples possesses two of the world's great museums, both founded under Bourbon rule. The National Archaeological Museum houses unsurpassed collections of Greco-Roman antiquities, comprising many of the finest works—in marble, bronze, mosaic, fresco, and ceramic—from Herculaneum, Pompeii, and other Campanian sites and the Farnese marbles, a Bourbon inheritance. The museum also possesses significant Egyptian antiquities. Overlooking Naples on the north from its handsome park, the National Museum and Gallery of Capodimonte contains, together with important tapestries and porcelain, a splendid collection of paintings, including masterworks by Simone Martini, Masaccio, Botticelli, Colantonio, Lotto, Parmigianino, Correggio, Titian, El Greco, and

Pieter Bruegel the Elder, and fine examples of the Neapolitan 17th- and 18th-century painters. Following the earthquake of 1980, works by Caravaggio and Titian were removed to Capodimonte from their traditional settings in the city.

In addition to museums already noted, the civic Filangieri Museum houses, in a Renaissance building on Via del Duomo, a collection of paintings and objects, many of them related to Neapolitan history. At the nearby State Archives, documents of great historic importance are installed in the former Benedictine monastery of SS. Severo and Sossio—a vast complex including, in the Platano cloister, celebrated frescoes by Antonio Solario.

THE PEOPLE

Travelers in Italy accustomed to grand public squares where visitors may at leisure observe the monuments and manners of the town are often puzzled by Naples' apparent lack of such focal points—not because great piazzas do not exist there, but because they are often used as mere traffic arteries and because the city's life is not so much concentrated in such places as diffused around them. The city's heart will rather be discovered in the small, populous enclaves—animated in the mornings, dormant by afternoon, revived at evening—which, each with distinctive character, make up the town's traditional districts. Intimacy with such a city is necessarily gradual, requiring a state of mind amounting to a revelation.

Naples, which, following the 18th-century discoveries of the buried cities of Vesuvius, long remained essential to cultivated travel, now serves visitors mainly as a wayside halt to neighbouring sites and resorts. Already in decline, tourism at Naples was sharply reduced by the effects of World War II, which left the city a shambles, and by the cessation of regular sea travel, which no longer brought visitors to the port of Naples. Many of the city's monuments were, moreover, embedded in what modern travelers often viewed as uninviting squalor; and random street crime—making it unsafe to carry items of value—compounded the disadvantages. A new touristic emphasis on brevity, velocity, and large numbers imposed, in turn, requirements that Naples could not meet—the city's riches of ancient continuity and of a slowly unfolding charm being unsuited to a hasty or systematic approach.

Decline in tourism

Bypassed by the foreign influx, Naples has thus preserved much authenticity and some skepticism toward modern tenets. Goethe's generalization that Neapolitans "wish even their work to be a recreation" is still valid, however incompatible with economic and administrative realities. While Goethe himself could not resist the northern cliché that Neapolitans are childlike, the tolerant penetration of motive, the graceful absence of envy, belligerence, or nationalism, and above all the civilizing Neapolitan sense of mortality, seem indicative, rather, of a long transmitted comprehension in human affairs.

Intellectual life in Naples, which is mainly centred around scholars concerned with the classical and Neapolitan past, is marked by high distinction and strong animosities and generates an important and varied literature. Despite the growth of a middle class and a notable advance in the status of women, emphatic divisions persist between prosperous and poor, while, in all classes, history has fatally extinguished—with rare exceptions—the flame of civic spirit. Government corruption and neglect are intensified by bureaucratic confusion and by the violent interventions of the Camorra, an illicit Neapolitan association analogous to the Sicilian Mafia. Nevertheless, with infinite adaptation, a sense of identity is maintained. Many festivals have fallen victim to traffic, and the old Neapolitan songs—now electronically diffused—have no successors. But fervour and fireworks still greet saints and soccer players alike. The ironic Neapolitan dialect holds its own. Individuality and family loyalty remain strong, as does a capacity not only for pleasure but for joy.

THE ECONOMY

Industry. Naples is the industrial centre of southern Italy. Under the Bourbons the city had an early start in manufacturing, with foundation of the porcelain factory at the royal palace of Capodimonte in 1740 and the development of silk and other textile production soon thereafter. The textile industry has remained important. Other traditional industries of continuing importance are food processing and winemaking. The first steel mill opened at the end of the 19th century, but the industry did not add significantly to national production until the 1970s. Among the newer industries in the region are electronics manufacturing, petroleum refining, and automobile assembly. The tourist industry continues to be important to the regional economy.

Early economic development

Industrial development was aided considerably after World War II by the concerted action of state planning and fiscal agencies and of companies either owned or controlled by the national government. Local enterprise was associated with the programs. The region's infrastructure was upgraded extensively and its energy production expanded. Nevertheless, Naples and the whole of southern Italy lags well behind the north.

Transportation. In 1818 the first steamboat on the Mediterranean was launched at the royal shipyards in Naples. Remodeling of the ancient harbour and its early medieval additions—now mostly filled in—was begun in 1826. Port facilities were badly damaged during World War II, but the subsequent reconstruction and modernization of its facilities have kept Naples one of the chief Mediterranean ports.

In 1839 Italy's first railway traversed the five miles from Naples to the royal residence of Portici. The first funicular railway on the peninsula was opened to the heights of Vomero in 1880. Naples developed into an important railway centre, being the main junction between Rome and southern Italy. Since World War II the city also has become a major junction point for road and air travel.

History

THE EARLY PERIOD

Naples was founded about 600 BC as Neapolis ("New City"), close to the more ancient Palaepolis, which had itself absorbed the name of the siren Parthenope. Both towns originated as Greek settlements, extensions almost certainly of Greek colonies established, during the 7th and 6th centuries BC, on the nearby island of Pithecusa (now Ischia) and at Cumae on the adjacent mainland, where remarkable Greek ruins may be visited today. Ancient Neapolis, as Gibbon says, "long cherished the language and manners of a Grecian colony; and the choice of Virgil had ennobled this elegant retreat, which attracted the lovers of repose and study from the noise, the smoke, and the laborious opulence of Rome." Horace (here paraphrased by Gibbon), Virgil, and the Neapolitan poet Statius are among numerous classical writers who attest the Hellenism of Naples. The Greek language was preserved throughout the city's first millennium, surviving submission, in the 4th century BC, to the dominion of Rome.

Greek origins

Under the empire, Naples and its environs served as a centre of Greek culture and erudition and as a pleasure resort for a succession of emperors and wealthy Romans, whose coastal villas extended from Misenum on the Gulf of Pozzuoli (the ancient Puteoli) to the Sorrentine peninsula. The amenity of these dwellings, depicted in recovered Vesuvian frescoes, is confirmed in such remains as Tiberius' Villa Jovis on Capri, the villa of Oplontis at Torre Annunziata, and the ruins of Villa Pausilypon, which gave its Greek name—meaning "a pause from care"—to the headland of Posillipo. Near Herculaneum, the buried private establishment known as the Villa of the Papyri yielded, in the mid-18th century, a treasure of antique sculpture and a group of papyrus scrolls presumed to belong to an ancient library. These scrolls, many of them deciphered, are conserved in the National Library at Naples. The villa was never uncovered, and its 18th-century tunnels of approach were reopened only in 1987. A floor plan drawn up in the 18th century was the basis for the J. Paul Getty Museum at Malibu, Calif., U.S.

In Roman times Naples was adorned with temples and baths and with arenas similar to those surviving at Pozzuoli and Pompeii. Principal Roman roads connected the

city to the capital, and aqueducts supplied fresh water. The gulfs of Naples and Pozzuoli were linked by galleries pierced through the yellow tufa of lower Posillipo. Of these, an evocative example may be visited at Mergellina, at the Crypta Neapolitana, beside the Roman tumulus long venerated as the Tomb of Virgil, in tribute to the Mantuan poet who celebrated the Neapolitan ambience in the sixth book of his *Aeneid* and composed the *Georgics* there between 37 and 30 BC.

Eruption of Vesuvius in AD 79

In AD 79 the great eruption of Vesuvius buried the seaside towns of Pompeii, Herculaneum, and Stabiae, engulfing also many villas confidently constructed on the slopes of a mountain that had not erupted for more than seven centuries. A contemporary account of this event survives in two letters addressed to the historian Tacitus by Pliny the Younger, who describes the doomed attempt of his uncle, the polymathic elder Pliny, to rescue survivors by sea. More than 16 centuries later, in 1738, systematic excavation of the buried towns was inaugurated at Herculaneum, under the aegis of the Neapolitan Bourbons—initiating discoveries that would profoundly influence Western aesthetic and scientific concepts and transform our knowledge of the ancient world.

Early tribulations of Christians at Naples are exemplified in the martyrdom of the city's patron, St. Januarius. The Catacombs of St. Januarius, on the Capodimonte slope, antedate in their earliest section the saint's legendary decapitation in AD 305 and are extremely interesting historically and for paleo-Christian decoration. Other early Christian sites include the baptistery incorporated in the Duomo, the ancient apse at the nearby church of San Giorgio Maggiore, and the Catacombs of San Gaudioso below the great church of Santa Maria della Sanità in one of the city's most colourful districts.

During the decline of the Roman Empire, Naples suffered with all the Italian Peninsula, and, having espoused the Gothic cause, drew, in 536, the vengeance of the Roman commander Belisarius. In the division of the late empire the city remained, with some vacillation, under the Exarchate of Ravenna until the 8th century when, rebelling against the Eastern emperors, Naples established a form of republican government that secured embattled independence for more than three centuries. Succumbing at last to the Lombard power established at Capua and Benevento, Naples saw the Lombards dispossessed, in turn, by the Norman conquests that swept southern Italy in the 12th century. While including Naples in that turbulent subjugation, Norman—and, subsequently, Swabian—dominion elevated the metropolis to a regional and cultural capital, a position Naples would retain under diverse rulers until the 19th century. Although maintaining his court at Palermo, the Holy Roman emperor Frederick II fortified Naples, founded the university there in 1224, and nurtured, in a rebellious ambience, the city's intellectual life.

NAPLES FROM THE ANGEVINS TO THE RISORGIMENTO

Renewal of the city's importance

In 1266 establishment of the Angevin dynasty in Naples renewed the city's importance—formidably proclaimed by erection of the Castel Nuovo and the Sant'Elmo fortress. The Angevin kings and their Aragonese successors attracted to Naples great figures of Italian thought and literature and the northern architects and artists whose genius survives in many Gothic and Renaissance monuments. Under Alfonso V of Aragon—a monarch, in the words of the historian Jacob Burckhardt, "brilliant in his whole existence"—culture at Naples transcended warfare. In 1453 fugitives from the fall of Constantinople brought an infusion of Byzantine arts. The growth of Neapolitan political power is implicit in the visit of Lorenzo de'Medici, ruler of Florence, to the court of Ferdinand (Ferrante) I in 1479–80.

In 1503 Naples entered the possession of the Spanish Habsburgs, whose viceroys presided with autocratic severity for more than two centuries. Great churches, convents, and private palaces from this period testify to a concentration of power against which an oppressed populace might periodically but ineffectually rebel—as in the ill-fated revolt led by Masaniello (Tomaso Aniello) in 1647–48. This harsh viceregal power was terminated by Austrian conquest (1707). And, in 1734, Naples became, under the Spanish Bourbons, the capital of a large independent southern kingdom, Don Carlos (the future Charles III of Spain) assuming the old and all but impenetrable title of "king of the Two Sicilies."

Naples now burgeoned as a potent European capital, its implacable divisions of wealth and poverty thrown in relief by 18th-century illumination. It is significant that, despite the importance of preceding Neapolitan artists, it was only with the 18th century that Naples developed its own school of painting. Scholars and statesmen from that era—such as Giambattista Vico, Pietro Giannone, Bernardo Tanucci, Ferdinando Galiani, and Gaetano Filangieri—are of universal rather than exclusively Neapolitan distinction. Another period of prolific construction is commemorated in Bourbon public edifices—including the royal palaces of Portici and Caserta—and in private mansions. The Vesuvian littoral again became a site of busy communities and of the elegant Ville Vesuviane, today mostly in disrepair. The excavations at Herculaneum and Pompeii attracted foreign visitors, while, in a climate of Neoclassicism and incipient Romanticism, artists, writers, and scholars arrived to experience the Neapolitan ambience. Depictions of the city and its surroundings—and of its presiding volcano, somewhat slighted by earlier painters—now found their way around the world.

Ferdinand IV and Maria Carolina

At the court of Ferdinand IV (Ferdinand I of the Two Sicilies) and his masterful queen, Maria Carolina, the cultivated British envoy Sir William Hamilton forged an Anglo-Neapolitan bond that lingers today. Maria Carolina's repressive tendencies were traumatically intensified by the execution in 1793 of her sister Marie Antoinette, queen of France. With the irruption of Napoleon into Italy (1798), the royal family withdrew in panic to Palermo aboard Admiral Horatio Nelson's British ships. The Neapolitan educated classes proclaimed a republic, while the Neapolitan poor, the *lazzaroni*, abandoned by their sovereign, remained vigorously if incomprehensibly monarchist. The nobly conceived Parthenopean Republic collapsed in a welter of blood. A punitive return by the Bourbons and the execution or exile of the republicans make the year 1799 a tragic epoch in the Neapolitan story.

In 1805 the court fled anew to Palermo, and, until 1815, the Kingdom of Naples was ruled, with legislative reforms, by Napoleon's brother Joseph Bonaparte and, subsequently, by Joachim Murat. Following the fall of Napoleon, the Bourbons reentered Naples with Austrian assistance. However, the weakness and corruption of succeeding Bourbon monarchs and their ruthless suppression of progressive ideas set the scene for Giuseppe Garibaldi's triumphant entry into the city in 1860 and for absorption of Naples into the Kingdom of Italy.

THE MODERN CITY

Deprived of territorial power, the city of Naples has, since the late 19th century, increasingly sought survival in an elusive and temperamentally incompatible degree of industrialization and in the ingenuity of its citizens, whose gifts for improvisation have been called forth no less by modern bureaucratic riddles than by the indifference of past monarchies. The cholera epidemic of 1884 aroused a transient spirit of reform, reflected in slum clearance, modernization of water and transport systems, and other public works. (A striking contemporary account of the epidemic and its context may be found in *Il ventre di Napoli*, by the journalist Matilde Serao. In 1973, during a brief reappearance of cholera in the city, this book, reissued, was found all too apposite.) The optimism of the *risanamento* was blighted by the onset of World War I.

The rise of fascism in Italy, compounded by the Great Depression of the 1930s, darkened the interval between the wars—from which, at Naples, the philosopher Benedetto Croce and other enlightened figures stand forth in defense of humanity and reason. While Naples shared with all Italy the degradation of fascism, few Italian cities suffered so heavily in World War II or made so painful and incomplete a recovery. Concerted restoration of decaying monuments was only inaugurated, in any appreciable degree, in the 1980s. That the city survived the postwar period

without complete economic and social collapse can be attributed almost exclusively to the vitality and philosophy of its populace and to the Neapolitan ability to combine strong passions with a resilient endurance.

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(Sh.Ha.)

Napoleon

Napoleon Bonaparte (original Italian, Napoleone Buonaparte), a French general, was first consul and then emperor of the French and carried out many reforms that left a lasting mark on the institutions of France and of much of western Europe. But his driving passion was the military expansion of French dominion, and, though at his fall he left France smaller than it had been at the outbreak of the Revolution in 1789, he was almost unanimously revered during his lifetime and until the end of the Second Empire under his nephew Napoleon III as one of history's great heroes.

Napoleon was born at Ajaccio on the island of Corsica on August 15, 1769, shortly after the cession of Corsica to France by the Genoese. He was the fourth, and second surviving, child of Carlo Buonaparte, a lawyer, and his wife, Letizia Ramolino. His father's family, of ancient Tuscan nobility, had emigrated to Corsica in the 16th century.

Carlo Buonaparte had married the beautiful and strong-willed Letizia when she was only 14 years old; they eventually had eight children to bring up in very difficult times. The French occupation of their native country was resisted by a number of Corsicans led by Pasquale Paoli. Carlo Buonaparte joined Paoli's party, but when Paoli had to flee, Buonaparte came to terms with the French. Winning the protection of the governor of Corsica, he was appointed assessor for the judicial district of Ajaccio in 1771. In 1778 he obtained the admission of his two eldest sons, Joseph and Napoleon, to the Collège d'Autun.

Early years and education in France

A Corsican by birth, heredity, and childhood associations, Napoleon continued for some time after his arrival in Continental France to regard himself a foreigner; yet from the age of nine he was educated in France as other Frenchmen were. While the tendency to see in Napoleon a reincarnation of some 14th-century Italian *condottiere* is an overemphasis on one aspect of his character, he did, in fact, share neither the traditions nor the prejudices of his new country: remaining a Corsican in temperament, he was first and foremost, through both his education and his reading, a man of the 18th century.

Napoleon was educated at three schools: briefly at Autun, for five years at the military college of Brienne, and finally for one year at the military academy in Paris. It was during Napoleon's year in Paris that his father died of a stomach cancer in February 1785, leaving his family in straitened circumstances. Napoleon, although not the eldest son, assumed the position of head of the family before he was 16. In September he graduated from the military academy, ranking 42nd in a class of 58.

He was made second lieutenant of artillery in the regiment of La Fère, a kind of training school for young artillery officers. Garrisoned at Valence, Napoleon continued his education, reading much, in particular works on strategy and tactics. He also wrote *Lettres sur la Corse,* in which he reveals his feeling for his native island. He went back to Corsica in September 1786 and did not rejoin his regiment until June 1788. By that time the agitation that was to culminate in the French Revolution had already begun. A reader of Voltaire and of Rousseau, Napoleon believed that a political change was imperative, but as a career officer he seems not to have seen any need for radical social reforms.



By courtesy of the National Gallery of Art, Washington, D.C., the Samuel H. Kress Collection; photograph: Giraudon—Art Resource

"Napoleon in His Study" by Jacques-Louis David, 1812. In the National Gallery of Art, Washington, D.C.

THE REVOLUTIONARY PERIOD

The Jacobin years. When in 1789 the National Assembly, which had convened to establish a constitutional monarchy, allowed Paoli to return to Corsica, Napoleon asked for leave and in September joined Paoli's group. But Paoli had no sympathy for the young man, whose father had deserted his cause and whom he considered to be a foreigner. Disappointed, Napoleon returned to France; and in April 1791 he was appointed first lieutenant to the 4th regiment of artillery, garrisoned at Valence. He at once joined the Jacobin club, a debating society initially favouring a constitutional monarchy, and soon became its president, making speeches against nobles, monks, and bishops. In September 1791 he got leave to go back to Corsica again for three months. Elected lieutenant colonel in the national guard, he soon fell out with Paoli, its commander in chief. When he failed to return to France, he was listed as a deserter in January 1792. But in April France declared war against Austria and his offense was forgiven.

Apparently through patronage, Napoleon was promoted to the rank of captain but did not rejoin his regiment. Instead he returned to Corsica in October 1792, where Paoli was exercising dictatorial powers and preparing to separate Corsica from France. Napoleon, however, joined the Corsican Jacobins, who opposed Paoli's policy. When civil war broke out in Corsica in April 1793, Paoli had the Buonaparte family condemned to "perpetual execration and infamy," whereupon they all fled to France.

Napoleon Bonaparte, as he may henceforth be called (though the family did not drop the spelling Buonaparte until after 1796), rejoined his regiment at Nice in June 1793. In his *Souper de Beaucaire,* written at this time, he argued vigorously for united action by all republicans rallied round the Jacobins, who were becoming progressively more radical, and the National Convention, the revolutionary assembly that in the preceding fall had abolished the monarchy. At the end of August 1793, the National Convention's troops had taken Marseille but were halted before Toulon, where the royalists had called in British forces. With the commander of the National Convention's artillery wounded, Bonaparte got the post through the commissioner to the army, Antoine Saliceti, who was a Corsican deputy and a friend of Napoleon's family. Bonaparte was promoted to major in September and adjutant

Capture of Toulon

general in October. He received a bayonet wound on December 16, but on the next day the British troops, harassed by his artillery, evacuated Toulon. On December 22 Bonaparte, aged 24, was promoted to brigadier general in recognition of his decisive part in the capture of the town.

Augustin de Robespierre, the commissioner to the army, wrote to his brother Maximilien, by then virtual head of the government and one of the leading figures of the Reign of Terror, praising the "transcendent merit" of the young republican officer. In February 1794 Bonaparte was appointed commandant of the artillery in the French Army of Italy. Robespierre fell from power in Paris on 9 Thermidor (July 27, 1794). When the news reached Nice, Bonaparte, regarded as a protégé of Robespierre, was arrested on a charge of conspiracy and treason. He was freed in September but was not restored to his command. The following March he refused an offer to command the artillery in the Army of the West, which was fighting the counter-revolution in the Vendée. The post seemed to hold no future for him, and he went to Paris to justify himself. Life was difficult on half pay, especially as he was carrying on an affair with Désirée Clary, daughter of a rich Marseille businessman and sister of Julie, the bride of his elder brother, Joseph. Despite his efforts in Paris, Napoleon was unable to obtain a satisfactory command because he was feared for his intense ambition and for his relations with the "Montagnards," the more radical members of the National Convention. He then considered offering his services to the sultan of Turkey.

The Directory. Bonaparte was still in Paris in May 1795 when the National Convention, on the eve of its dispersal, submitted the new constitution of the year III of the First Republic to a referendum, together with decrees according to which two-thirds of the members of the National Convention were to be reelected to the new legislative assemblies. The royalists, hoping that they would soon be able to restore the monarchy, instigated a revolt in Paris to prevent these measures from being put into effect. Vicomte Paul de Barras, who had been entrusted with dictatorial powers by the National Convention, was unwilling to rely on the commander of the troops of the interior; instead, knowing of Bonaparte's services at Toulon, he appointed him second in command. Thus, it was Napoleon who shot down the columns of rebels marching against the National Convention (13 Vendémiaire, year IV; October 5, 1795), thereby saving the National Convention and the republic.

Bonaparte became commander of the army of the interior and, consequently, was henceforth aware of every political development in France. He also became the respected adviser on military matters to the new government, the Directory. Lastly, he came to know an attractive Creole, Joséphine Tascher de La Pagerie, the widow of Gen. Alexandre de Beauharnais (guillotined during the Reign of Terror), the mother of two children, and a woman of many love affairs.

From every point of view, a new life was opening for Bonaparte. Having proved his loyalty to the Directory by dissolving a communist group led by François Babeuf and an Italian, Filippo Buonarroti, whom Bonaparte had known in Corsica, he was appointed commander in chief of the Army of Italy in March 1796. He had been trying to obtain that post for several weeks so that he could personally conduct part of the plan of campaign adopted by the Directory on his advice. He married Joséphine on March 9 and left for the army two days later.

Commander in chief of Army of Italy

Arriving at his headquarters in Nice, Bonaparte found that his army, which on paper consisted of 43,000 men, numbered scarcely 30,000 ill-fed, ill-paid, and ill-equipped men. On March 28, 1796, he made his first proclamation to his troops:

> Soldiers, you are naked, badly fed. . . . Rich provinces and great towns will be in your power, and in them you will find honour, glory, wealth. Soldiers of Italy, will you be wanting in courage and steadfastness?

He took the offensive on April 12 and successively defeated and separated the Austrian and the Sardinian armies and then marched on Turin. King Victor Amadeus III of Sardinia asked for an armistice; and, at the peace treaty in Paris on May 15, Nice and Savoy, occupied by the French since 1792, were annexed to France. Bonaparte continued the war against the Austrians and occupied Milan but was held up at Mantua. While his army was besieging this great fortress, he signed armistices with the duke of Parma, the duke of Modena, and finally with Pope Pius VI.

At the same time, he took an interest in the political organization of Italy. A plan for its "republicanization" by a group of Italian "patriots" led by Buonarroti had to be shelved when Buonarroti was arrested for complicity in Babeuf's conspiracy against the Directory. Thereafter, Bonaparte, without discarding the Italian patriots altogether, restricted their freedom of action. He set up a republican regime in Lombardy but kept a close watch on its leaders, and in October 1796 he created the Cisalpine Republic by merging Modena and Reggio nell'Emilia with the papal states of Bologna and Ferrara occupied by the French Army. Finally he sent an expedition to recover Corsica, which the British had evacuated.

Austrian armies advanced four times from the Alps to relieve Mantua but were defeated each time by Bonaparte. After the last Austrian defeat, at Rivoli in January 1797, Mantua capitulated. Next, he marched on Vienna. He was about 60 miles (100 kilometres) from that capital when the Austrians sued for an armistice. By the preliminaries of peace, Austria ceded the southern Netherlands to France and recognized the Lombard republic but received in exchange some territory belonging to the old Republic of Venice, which was partitioned between Austria, France, and Lombardy. Bonaparte then consolidated and reorganized the north Italian republics and encouraged Jacobin—radical republican—propaganda in Venetia. Some Italian patriots hoped that these developments would soon lead to the formation of a single and indivisible "Italian Republic" modeled on the French.

Defeat of the Austrians and peace terms

Meanwhile, Bonaparte grew uneasy at the successes of the royalists in the French elections in the spring of 1797 and advised the Directory to oppose them, if necessary, by force. In July it attempted a coup d'état against the royalists and failed; thereupon Bonaparte sent Gen. Pierre Augereau to Paris, along with several officers and men. Augereau's successful coup d'état of 18 Fructidor (September 4, 1797) eliminated the royalists' friends from the government and legislative councils and also enhanced Bonaparte's prestige. Thus, Bonaparte could conclude the Treaty of Campo Formio with Austria as he thought best. The Directory was displeased, however, because the Treaty had ceded Venice to the Austrians and did not secure the left bank of the Rhine for France. On the other hand, it raised Bonaparte's popularity to its peak, for he had gained victory for France after five years of war on the Continent.

Only the war at sea, against the British, continued. The directors, who wanted to launch an invasion of the British Isles, appointed Bonaparte to command the army assembled for this purpose along the English Channel. After a rapid inspection in February 1798, he announced that the operation could not be undertaken until France had command of the sea. Instead, he suggested that France strike at the sources of Great Britain's wealth by occupying Egypt and threatening the route to India. This proposal, seconded by Talleyrand, the foreign minister, was accepted by the directors, who were glad to get rid of their ambitious young general.

The expedition, thanks to some fortunate coincidences, was at first a great success: Malta, the great fortress of the Knights Hospitallers of St. John of Jerusalem, was occupied on June 10, 1798, Alexandria taken by storm on July 1, and all the delta of the Nile rapidly overrun. On August 1, however, the French squadron at anchor in Abū Qīr Bay was completely destroyed by Adm. Horatio Nelson's fleet in the Battle of the Nile, so that Napoleon found himself confined to the land that he had conquered. He proceeded to introduce Western political institutions, administration, and technical skills in Egypt; but Turkey, nominally suzerain over Egypt, declared war on France in September. To prevent a Turkish invasion of Egypt and also perhaps to attempt a return to France by way of Anatolia, Bonaparte marched into Syria in February 1799. His progress northward was halted at Acre, where

Failures in Egypt

the British withstood a siege, and in May Bonaparte began a disastrous retreat to Egypt.

The Battle of the Nile showed Europe that Bonaparte was not invincible, and Great Britain, Austria, Russia, and Turkey formed a new coalition against France. The French armies in Italy were defeated in the spring of 1799 and had to abandon the greater part of the peninsula. These defeats led to disturbances in France itself. The coup d'etat of 30 Prairial (June 18, 1799) expelled the men of moderate views from the Directory and brought into it men who were considered Jacobins. Yet the situation remained confused, and one of the new directors, Emmanuel Sieyès, was convinced that only military dictatorship could prevent a restoration of the monarchy: "I am looking for a sabre," he said. Bonaparte did not take long to make up his mind. He would leave his army and return to France—in order to save the republic, of course, but also to take advantage of the new circumstances and to seize power. The Directory had, in fact, ordered his return, but he had not received the order, so that it was actually in disregard of his instructions that he left Egypt with a few companions on August 22, 1799. Their two frigates surprisingly escaped interception by the British, and Bonaparte arrived in Paris on October 14.

By this time French victories in Switzerland and Holland had averted the danger of invasion, and the counter-revolutionary risings within France had more or less failed. A coup d'etat could therefore no longer be justified by any need to save the republic. Sieyès, however, had not given up his project, and now he had his "sabre." From the end of October he and Bonaparte were in league together planning the coup, and on 18–19 Brumaire, Year VIII (November 9–10, 1799), it was carried out: the directors were forced to resign, the members of the legislative councils were dispersed, and a new government, the Consulate, was set up. The three consuls were Bonaparte and two of the directors who had resigned, Sieyès and Pierre-Roger Ducos. But it was Bonaparte who was henceforth the master of France.

The coup of 18–19 Brumaire

THE CONSULATE

Consolidation of power. Bonaparte, now 30 years old, was thin and short and wore his hair cut close—*le petit tondu,* the "little crop-head," as he was called. Not much was known about his personality, but people had confidence in a man who had always been victorious (the Nile and Acre were forgotten) and who had managed to negotiate the brilliant Treaty of Campo Formio. He was expected to bring back peace, to end disorder, and to consolidate the political and social "conquests" of the Revolution. He was indeed exceptionally intelligent, prompt to make decisions, and indefatigably hardworking, but also insatiably ambitious. He seemed to be the man of the Revolution because it was due to the Revolution that he had climbed at so early an age to the highest place in the state. He was not to forget it: but more than a man of the Revolution, he was a man of the 18th century, the most enlightened of the enlightened despots, a true son of Voltaire. He did not believe in the sovereignty of the people, in the popular will, or in parliamentary debate. Yet he put his confidence more in reasoning than in reason and may be said to have preferred "men of talent"—mathematicians, jurists, and statesmen, for instance, however cynical or mercenary they might be—to "technicians" in the true sense of the word. He believed that an enlightened and firm will could do anything if it had the support of bayonets; he despised and feared the masses; and, as for public opinion, he considered that he could mold and direct it as he pleased. He has been called the most "civilian" of generals, but essentially he never ceased to be a soldier.

The military dictatorship

Bonaparte imposed a military dictatorship on France, but its true character was at first disguised by the Constitution of the Year VIII (4 Nivôse; December 25, 1799), drawn up by Sieyès. This constitution did not guarantee the "rights of man" or make any mention of "liberty, equality, and fraternity," but it did reassure the partisans of the Revolution by proclaiming the irrevocability of the sale of national property and by upholding the legislation against the émigrés. It gave immense powers to the first consul, leaving only a nominal role to his two colleagues. The first consul—namely, Bonaparte—was to appoint ministers, generals, civil servants, magistrates, and the members of the Council of State and even was to have an overwhelming influence in the choice of members for the three legislative assemblies, though their members were theoretically to be chosen by universal suffrage. Submitted to a plebiscite, the constitution won by an overwhelming majority in February 1800.

Program of reforms. The Consulate's work of administrative reform, undertaken at Bonaparte's instigation, was to be more lasting than the constitution and so more important for France. At the head of the government was the Council of State, created by the first consul and often effectively presided over by him; it was to play an important part both as the source of the new legislation and as an administrative tribunal. At the head of the administration of the *départements* were the prefects, who carried on the tradition of the intendants of the *ancien régime,* supervising the application of the laws and acting as the instruments of centralization. The judicial system was profoundly changed: whereas from the beginning of the Revolution judges had been elected, henceforth they were to be nominated by the government, their independence assured by their irremovability from office. The police organization was greatly strengthened. The financial administration was considerably improved: instead of the municipalities, special officials were entrusted with the collecting of direct taxes; the franc was stabilized; and the Banque de France, owned partly by shareholders and partly by the state, was created. Education was transformed into a major public service; secondary education was given a semi-military organization, and the university faculties were re-established. Primary education, however, was still neglected.

Bonaparte shared Voltaire's belief that the people needed a religion. Personally, he was indifferent to religion: in Egypt he had said that he wanted to become a Muslim. Yet he considered that religious peace had to be restored to France. As early as 1796, when he was concluding the armistice in Italy with Pope Pius VI, he had tried to persuade the Pope to retract his briefs against the French priests who had accepted the Civil Constitution of the Clergy, which in practice nationalized the church. Pius VII, who succeeded Pius VI in March 1800, was more accommodating than his predecessor, and ten months after negotiations were opened with him a concordat was signed reconciling the church and the Revolution. The Pope recognized the French Republic and called for the resignation of all former bishops; new prelates were to be designated by the First Consul and instituted by the Pope; and the sale of the property of the clergy was officially recognized by Rome. The concordat, in fact, admitted freedom of worship and the lay character of the state.

Religious peace and concordat with Rome

The codification of the civil law, first undertaken in 1790, was at last completed under the Consulate. The code promulgated on March 21, 1804, and later known as the Code Napoléon, gave permanent form to the great gains of the Revolution: individual liberty, freedom of work, freedom of conscience, the lay character of the state, and equality before the law; but, at the same time, it protected landed property, gave greater liberty to employers, and showed little concern for employees. It maintained divorce but granted only limited legal rights to women.

The army received the most careful attention. The First Consul retained in outline the system instituted by the Revolution: recruitment by forced conscription but with the possibility of replacement by substitutes; the mixing of the conscripts with old soldiers; and the eligibility of all for promotion to the highest ranks. Nevertheless, the creation of the Academy of Saint-Cyr to produce infantry officers made it easier for the sons of bourgeois families to pursue a military career. Moreover, the École Polytechnique, founded by the National Convention, was militarized in order to provide officers for the artillery and engineers. Yet Bonaparte was not concerned about introducing new technical inventions into his army. He put his trust in the "legs of his soldiers": his basic strategic idea was a fast-moving army.

Military campaigns and uneasy peace. The First Consul spent the winter and spring of 1799–1800 reorganizing the army and preparing for an attack on Austria alone, Russia having withdrawn from the anti-French coalition. With his usual quick assessment of the situation, he saw the strategic importance of the Swiss Confederation, from which he would be free to outflank the Austrian armies either in Germany or in Italy as he might see fit. His past successes made him choose Italy. Taking his army across the Great St. Bernard Pass before the snow had melted, he appeared unexpectedly behind the Austrian army besieging Genoa. The Battle of Marengo in June gave the French command of the Po Valley as far as the Adige; and in December another French army defeated the Austrians in Germany. Austria was forced to sign the Treaty of Lunéville of February 1801, whereby France's right to the natural frontiers that Julius Caesar had given to Gaul, namely, the Rhine, the Alps, and the Pyrenees, was recognized.

Great Britain alone remained at war with France, but it soon tired of the struggle. Preliminaries of peace, concluded in London in October 1801, put an end to hostilities, and peace was signed at Amiens on March 27, 1802.

General peace was re-established in Europe. The first Consul's prestige increased still more; and his friends—at his suggestion—proposed that a "token of national gratitude" should be offered to him. In May 1802 it was decided that the French people should vote in referendum on the following question: "Shall Napoleon Bonaparte be consul for life?" In August an overwhelming vote granted him the prolongation of his consulate as well as the right to designate his successor.

Consul for life

Bonaparte's conception of international peace differed from that of the British, for whom the Treaty of Amiens represented an absolute limit beyond which they were under no circumstances prepared to go. The British even hoped to take back some of the concessions they had been forced to make. For Bonaparte, on the other hand, the Treaty of Amiens marked the starting point for a new French ascendancy. He was, first of all, intent on reserving half of Europe as a market for France without lowering customs duties—to the indignation of British merchants. To revive France's expansion overseas, he also intended to recover San Domingo (now Hispaniola, which had rebelled), to occupy Louisiana (ceded to France by Spain in 1800), perhaps to reconquer Egypt, and at any rate to extend French influence in the Mediterranean and in the Indian Ocean. Finally, on the Continent of Europe, he advanced beyond France's natural frontiers: incorporating Piedmont into France; imposing a more democratic, decentralized government on the Swiss Confederation; and in Germany compensating the princes dispossessed of territory on the Rhine under the Treaty of Lunéville with shares of the secularized ecclesiastical states.

Great Britain was alarmed by this expansion of France in peacetime and found it scarcely tolerable that one state should command the coastline of the Continent from Genoa to Antwerp. The immediate occasion of Franco-British rupture, however, was the problem of Malta. According to the Treaty of Amiens, the British, who had taken the island on the collapse of the French occupation, should have restored it to the Knights Hospitallers; but the British, on the pretext that the French had not yet evacuated certain Neapolitan ports, refused to leave the island. Franco-British relations became strained, and in May 1803 the British declared war.

THE EMPIRE

The peace settlement had brought about the life consulate; the return of war was to stimulate the formation of the empire. The British government, which would have been glad to see Bonaparte deposed or removed by assassination, renewed its subsidies to the French royalists, who resumed their agitation and plotting. When a British-financed assassination plot was uncovered in 1804, Bonaparte decided to react vigorously enough to deter his opponents from any more such attempts. The police believed that the real head of the conspiracy was the young Duc d'Enghien, a scion of the royal house of Bourbon, who was residing in Germany, a few miles across the frontier. Accordingly, with the agreement of Talleyrand and the police chief Joseph Fouché, the Duc was kidnapped on neutral soil and brought to Vincennes, where he was tried and shot (March 21). This action provoked a resurgence of opposition among the old aristocracy but enhanced the influence of Fouché.

British-financed assassination plot

Founding the empire. In the hope of consolidating his own position, Fouché now suggested to Bonaparte that the best way to discourage conspiracy would be to transform the life consulate into a hereditary empire, which, because of the fact that there would be an heir, would remove all hope of changing the regime by assassination. Bonaparte readily accepted the suggestion, and on May 28, 1804, the empire was proclaimed.

Though there was little change in the organization of the government of France, Napoleon as emperor revived a number of institutions similar to those of the *ancien régime*. In the first place, he wanted to be consecrated by the pope himself, so that his coronation should be even more impressive than that of the kings of France. Pius VII agreed to come to Paris, and the ceremony, which seemed equally outrageous to royalists and to the old soldiers of the Revolution, took place in Notre-Dame on December 2, 1804. At the last moment, the Emperor took the crown from the Pope and set it on his own head himself.

The imperial regime also instituted its symbols and titles. Princely titles were brought back for the members of Napoleon's family in 1804, and an imperial nobility was created in 1808. As opposition was still lively, Napoleon intensified his propaganda and imposed an increasingly strict censorship on the press. A dictatorial regime allowed him to carry on his wars for years without worrying about French public opinion. Having been president of the Italian Republic (as the Cisalpine Republic was renamed) since January 1802, Napoleon in March 1805 was proclaimed king of Italy and crowned in Milan in May.

War with Britain. From 1803 to 1805 Napoleon had only the British to fight; and again France could hope for victory only by landing an army in the British Isles, whereas the British could defeat Napoleon only by forming a continental coalition against him. Napoleon began to prepare an invasion again, this time with greater conviction and on a larger scale. He gathered nearly 2,000 ships between Brest and Antwerp and concentrated his Grande Armée in the camp at Boulogne (1803). Even so, the problem was the same as in 1798: to cross the Channel, the French had to have control of the sea.

Still far inferior to the British Navy, the French fleet needed the help of the Spanish; and even then the two fleets together could not hope to defeat more than one of the British squadrons. Spain was induced to declare war on Great Britain in December 1804, and it was decided that French and Spanish squadrons massed in the Antilles should lure a British squadron into these waters and defeat it, thus making the balance roughly equal between the Franco-Spanish navy and the British. A battle in the entrance to the Channel could then be fought with some chance of success.

Franco-Spanish naval strategy

The plan failed. The French squadron from the Mediterranean, under Adm. Pierre de Villeneuve, found itself alone at the appointed meeting place in the Antilles. Pursued by Nelson and not daring to attack him, it turned back toward Europe and took refuge in Cádiz in July 1805; there the British blockaded it. Accused of cowardice by the angry Napoleon, Villeneuve resolved to run the blockade, with the support of a Spanish squadron; but on October 21, 1805, he was attacked by Nelson off Cape Trafalgar. Nelson was killed in the battle, but the Franco-Spanish fleet was totally destroyed. The British had won a decisive victory, which eliminated the danger of invasion and gave them freedom of movement at sea.

They had also succeeded in organizing a new anti-French coalition consisting of Austria, Russia, Sweden, and Naples. On July 24, 1805, three months before Trafalgar, Napoleon had ordered the Grande Armée from Boulogne to the Danube (thus ruling out an invasion of England even if the French had won at Trafalgar). In the week preceding Trafalgar, the Grande Armée won an outstanding

victory over the Austrians at Ulm, and on November 13 Napoleon entered Vienna. On December 2, 1805, in his greatest victory he defeated the combined Austrian and Russian armies in the Battle of Austerlitz. By the Treaty of Pressburg, Austria renounced all influence in Italy and ceded Venetia and Dalmatia to Napoleon, as well as extensive territory in Germany to his protégés Bavaria, Württemberg, and Baden. The French then proceeded to dethrone the Bourbons in the kingdom of Naples, which was bestowed on Napoleon's brother Joseph. In July 1806 the Confederation of the Rhine was founded—soon to embrace all western Germany in a union under French protection.

Victories in Europe

In September 1806 Prussia entered the war against France, and on October 14 the Prussian armies were defeated at Jena and at Auerstädt. The Russians put up a better resistance at Eylau in February 1807 but were routed at Friedland in June. In Warsaw Napoleon fell in love with Countess Marie Walewska, a Polish patriot who hoped that Napoleon would resurrect her country. Napoleon had a son by her.

The Russian emperor Alexander I could have continued the struggle, but he was tired of the alliance with the British. He met Napoleon at Tilsit, in northern Prussia near the Russian frontier. There, on a raft anchored in the middle of the Niemen River, they signed treaties that created the Grand Duchy of Warsaw from the Polish provinces detached from Prussia and, in effect, divided control of Europe between the emperors, Napoleon taking the west and Alexander the east. Alexander even made a vague promise of a land attack against the British possessions in India.

Blockade and the peninsular campaign. As Napoleon could no longer think of invading England, he tried to induce capitulation by stifling the British economy. By closing all of Europe to British merchandise, he hoped to bring about a revolt of the British unemployed that could force the government to sue for peace. He forbade all trade with the British Isles, ordered the confiscation of all goods coming from English factories or from the British colonies, and condemned as fair prize not only every British ship but also every ship that had touched the coasts of England or its colonies.

For the blockade to succeed, it had to be enforced rigorously throughout Europe. But from the beginning, England's old ally Portugal showed itself reluctant to comply, for the blockade would mean its commercial ruin. Napoleon decided to break down Portuguese opposition by force. Charles IV of Spain let the French troops cross his kingdom, and they occupied Lisbon; but the prolonged presence of Napoleon's soldiers in the north of Spain led to insurrection. When Charles IV abdicated in favour of his son Ferdinand VII, Napoleon, seeing the opportunity to rid Europe of its last Bourbon rulers, summoned the Spanish royal family to Bayonne in April 1808 and obtained the abdication of both Charles and Ferdinand; they were interned in Talleyrand's château. After the bloody suppression of an uprising in Madrid, insurrection spread across the whole country, for the Spaniards would not accept Joseph Bonaparte, king of Naples, as their new king.

Defeats in Spain and Portugal

The subsequent defeat of his forces in Spain and Portugal were sensational blows to Napoleon's prestige. Soon the Iberian Peninsula, up in arms, became a bridgehead on the Continent for the British. Under the energetic Arthur Wellesley (later 1st duke of Wellington), in command from 1809, the Anglo-Spanish-Portuguese forces were to achieve decisive successes.

At the Congress of Erfurt (September–October 1808), a conference with Alexander I, Napoleon assembled a great concourse of princes to impress the Russian emperor in an attempt to extract promises of help. Whether impressed or not, Alexander would make no definite commitment. Alexander's refusal, furthermore, was partly prompted by Talleyrand, who had become dismayed by Napoleon's policies and was already negotiating with the Russian emperor behind his master's back.

By early 1809, however, with most of the Grande Armée thrown into Spain, Napoleon seemed on the point of overcoming the revolt. Then, in April, Austria launched an attack in Bavaria in the hope of rousing all Germany against the French. Napoleon once again defeated the Habsburgs (July 6) and by the Treaty of Schönbrunn (October 14, 1809) obtained the Illyrian Provinces, thus rounding out the continental system.

Consolidation of empire. In 1810 Napoleon's fortunes were at their zenith, despite some failures in Spain and Portugal. He considered himself Charlemagne's heir. He repudiated Joséphine, who had not given him a child, so that he could marry Marie-Louise, daughter of the Austrian emperor Francis I. The birth of a son, the king of Rome, in March 1811 seemed to assure the future of his empire—now at its greatest extent, including not only the Illyrian Provinces but also Etruria (Tuscany), some of the Papal States, Holland, and the German states bordering the North Sea. The empire was surrounded by a ring of vassal states ruled over by the Emperor's relatives: the kingdom of Westphalia (Jérôme Bonaparte); the Kingdom of Spain (Joseph Bonaparte); the Kingdom of Italy (with Eugène de Beauharnais, Joséphine's son, as viceroy); the Kingdom of Naples (Joachim Murat, Napoleon's brother-in-law); and the Principality of Lucca and Piombino (Félix Bacciochi, another brother-in-law). Finally, other territories were closely bound to the empire by treaties: the Swiss Confederation (of which Napoleon was the mediator), the Confederation of the Rhine, and the Grand Duchy of Warsaw. Even Austria seemed bound to France by Napoleon's marriage to Marie-Louise.

The political map of Europe, which had been so complicated before 1796, was now greatly simplified. Yet the frontiers did not coincide either with geographical features or with "nationalities." Whatever he may later have said, Napoleon, while he was in power, was not interested in realizing either German or Italian unity. Yet by reducing the number of states, by pushing the frontiers about, by amalgamating populations, and by propagating institutions like those that the Revolution and nationalism had created in France, he prepared the ground for German and Italian unification. National feeling in Europe, stirred by French ideas and by contact with Frenchmen, in turn gave rise to the first resistance against French domination. From 1809 onward Spanish guerrillas, supported by British troops, were harassing the French, and the national Cortes, convened at Cádiz by the insurrectionaries, in 1812, promulgated a constitution inspired by the ideas of the French Revolution of 1789 and by British institutions.

European unity and the roots of new nationalisms

Disaster in Russia and its aftermath. Since the Congress of Erfurt, the Russian emperor had shown himself less and less inclined to deal with Napoleon as a trusted partner. In the spring of 1812, therefore, Napoleon massed his forces in Poland to intimidate Alexander. After some last attempts at agreement, in late June his Grande Armée—about 453,000 men, including contingents extorted from Prussia and from Austria—began to cross the Niemen River. The Russians retreated, adopting a "scorched earth" policy. Napoleon's army did not reach the approaches to Moscow until the beginning of September. The Russian commander in chief, Mikhail I. Kutuzov, engaged it at Borodino on September 7. The fight was savage, bloody, and indecisive, but a week later Napoleon entered Moscow, which the Russians had abandoned. On that same day, a huge fire broke out, destroying the greater part of the town. Moreover, Alexander unexpectedly refused to treat with Napoleon. Withdrawal was necessary, and the premature onset of winter made it disastrous. After the difficult crossing of the Berezina River in November, fewer than 10,000 men fit for combat remained with Napoleon's main force.

This catastrophe heartened all the peoples of Europe to defy Napoleon. In Germany the news unleashed an outbreak of anti-French demonstrations. The Prussian contingents deserted the Grande Armée in December and turned against the French. The Austrians also withdrew their troops and adopted an increasingly hostile attitude, and in Italy the people began to turn their backs on Napoleon.

Even in France, signs of discontent with the regime were becoming more frequent. In Paris a malcontent general nearly succeeded in carrying out a coup d'etat after announcing, on October 23, 1812, that Napoleon had died in Russia. This incident was a major factor in Napoleon's

Attempted coup d'etat in Paris

decision to hasten back to France ahead of the Grande Armée. Arriving in Paris on December 18, he proceeded to stiffen the dictatorship, to raise money by various expedients, and to levy new troops.

Thus, in 1813 the forces arrayed against France were no longer armies of mercenaries but were those of nations fighting for their freedom as the French had fought for theirs in 1792 and 1793; and the French themselves, for all their courage, had lost their former enthusiasm. The Emperor's ideal of conquest was no longer that of the nation.

In May 1813 Napoleon won some successes against the Russians and Prussians at the battles of Lützen and Bautzen, but his decimated army needed reinforcements. The armed mediation of Austria induced Napoleon to agree to an armistice, during which a congress was held at Prague. There, Austria proposed very favourable conditions: the French Empire was to return to its natural limits; the Grand Duchy of Warsaw and the Confederation of the Rhine were to be dissolved; and Prussia was to return to its frontiers of 1805. Napoleon made the mistake of hesitating too long. The congress closed on August 10 before his reply arrived, and Austria declared war.

The French were even worse off than in the spring. The allies were gaining new troops every day, as one German contingent after another left Napoleon to go over to the other side. The greatest debacle since Napoleon came to power was the Battle of Leipzig, or "Battle of the Nations" (October 16–19, 1813), in which the Grande Armée was torn to shreds. That defeat degenerated fast into collapse. The French armies in Spain, forced to retreat, had been defeated in June; and by October the British were attacking their defenses north of the Pyrenees. In Italy the Austrians took the offensive, crossed the Adige River, and occupied Romagna. Murat, now openly a traitor to the Emperor who had made him king of Naples, entered into negotiations with the Viennese court. The Dutch and the Belgians demonstrated against Napoleon.

Downfall and abdication. In January 1814 France was being attacked on all its frontiers. The allies cleverly announced that they were fighting not against the French people but against Napoleon alone, since in November 1813 he had rejected the terms offered by the Austrian foreign minister Metternich, which would have preserved the natural frontiers of France. The extraordinary strategic feats achieved by the Emperor during the first three months of 1814 with the army of young conscripts were not enough; he could neither defeat the allies, with their overwhelming numerical superiority, nor arouse the majority of French people from their resentful torpor. The Legislative Assembly and the Senate, formerly so docile, were now asking for peace and for civil and political liberties.

Four-nation pact against Napoleon

By the Treaty of Chaumont of March 1814, Austria, Russia, Prussia, and Great Britain bound themselves together for 20 years, undertook not to negotiate separately, and promised to continue the struggle until Napoleon was overthrown. When the allied armies arrived before Paris on March 30, Napoleon had moved east to attack their rear guard. The Parisian authorities, no longer overawed by the Emperor, lost no time in treating with the allies. As president of the provisional government, Talleyrand proclaimed the deposition of the Emperor and, without consulting the French people, began to negotiate with Louis XVIII, the brother of the executed Louis XVI. Napoleon had only reached Fontainebleau when he heard that Paris had capitulated. Persuaded that further resistance was useless, he finally abdicated on April 6.

By the Treaty of Fontainebleau, the allies granted him the island of Elba as a sovereign principality with an annual income of 2,000,000 francs to be provided by France and a guard of 400 volunteers; also, he retained the title of emperor. After unsuccessfully trying to poison himself, Napoleon spoke his farewell to his "Old Guard," and after a hazardous journey, during which he narrowly escaped assassination, he arrived at Elba on May 4.

ELBA AND THE HUNDRED DAYS

"I want from now on to live like a justice of the peace," Napoleon declared on his little island. But a man of such energy and imagination could hardly be expected to resign himself to defeat at the age of 45.

In France, moreover, the Bourbon Restoration was soon exposed to criticism. Though in 1814 the majority of the French people were tired of the Emperor, they had expressed no wish for the return of the Bourbons. They were strongly attached to the essential achievements of the Revolution, and Louis XVIII had come back "in the baggage train of the foreigners" with the last surviving émigrés who had "learnt nothing and forgotten nothing" and whose influence seemed to threaten most of the Revolution's achievements. The apathy of April 1814 quickly gave way to mistrust. Old hatreds were revived, resistance organized, and conspiracies formed.

From Elba, Napoleon kept a close watch on the Continent. He knew that some of the diplomats at Vienna, where a congress was deciding the fate of Europe, considered Elba, between Corsica and Italy, too close to France and to Italy and wanted to banish him to a distant island in the Atlantic. Also, he accused Austria of preventing Marie Louise and his son from coming to join him (in fact, she had taken a lover and had no intention of going to live with her husband). Finally, the French government refused to pay Napoleon's allowance so that he was in danger of being reduced to penury.

Napoleon's return to France

All these considerations drove Napoleon to action. Decisive as ever, he returned to France like a thunderbolt. On March 1, 1815, he landed at Cannes with a detachment of his guard. As he crossed the Alps, the republican peasants rallied round him, and near Grenoble he won over the soldiers dispatched to arrest him. On March 20 he was in Paris.

Napoleon was brought back to power as the embodiment of the spirit of the Revolution rather than as the emperor who had fallen a year before. To rally the mass of Frenchmen to his cause he should have allied himself with the Jacobins; but this he dared not do. Unable to escape from the bourgeoisie whose predominance he himself had assured and who feared above all else a revival of the socialist experiments of 1793 and 1794, he could only set up a political regime scarcely distinguishable from that of Louis XVIII. Enthusiasm ebbed fast, and the Napoleonic adventure seemed a dead end.

To oppose the allied troops massing on the frontiers, Napoleon mustered an army with which he marched into Belgium and defeated the Prussians at Ligny on June 16, 1815. Two days later, at Waterloo, he met the British under Wellington, the victor of the Peninsular War. A savage battle followed. Napoleon was in sight of victory when the Prussians under Gebhard Blücher arrived to reinforce the British, and soon, despite the heroism of the Old Guard, Napoleon was overthrown.

Back in Paris, Parliament forced Napoleon to abdicate; he did so, in favour of his son, on June 22, 1815. On July 3 he was at Rochefort, intending to take ship for the United States, but a British squadron prevented any French vessel from leaving the port. Napoleon then decided to appeal to the British government for protection. His request granted, he boarded the "Bellerophon" on July 15. The allies were agreed on one point: Napoleon was not to go back to Elba. Nor did they like the idea of his going off to America. It would have suited them if he had fallen a victim to the "White Terror" of the returned counter-revolutionaries or if Louis XVIII had had him summarily tried and executed. Great Britain had no choice but to send him to detention in a far-off island. The British government announced that the island of Saint Helena in the southern Atlantic had been chosen for his residence; because of its remote position Napoleon would enjoy much greater freedom than would be possible elsewhere. Napoleon protested eloquently: "I appeal to history!"

EXILE ON SAINT HELENA

On October 15, 1815, Napoleon disembarked in Saint Helena with those followers who were voluntarily accompanying him into exile: Gen. Henri-Gratien Bertrand, grand marshal of the palace, and his wife; the comte Charles de Montholon, aide-de-camp, and his wife; Gen. Gaspard Gourgaud; Emmanuel Las Cases, the former chamberlain;

and several servants. After a short stay at the house of a wealthy English merchant, they moved to Longwood, originally built for the lieutenant governor.

Daily life at St. Helena

Napoleon settled down to a life of routine. He got up late, breakfasting about 10 PM, but seldom went out. He was free to go anywhere on the island so long as he was accompanied by an English officer, but he soon refused to comply with this condition and so shut himself up in the grounds of Longwood. He wrote and talked much. At first Las Cases acted as his secretary, compiling what was later to be the *Mémorial de Sainte-Hélène* (first published in 1823). From 7 to 8 PM Napoleon had dinner, after which a part of the evening was spent in reading aloud—Napoleon liked to hear the classics. Then they played cards. About midnight Napoleon went to bed. Some of his time was devoted to learning English, and he eventually began reading English newspapers; but he also had a large number of French books sent from Europe, which he read attentively and annotated.

Saint Helena has a healthful climate, and Napoleon's food was good, carefully prepared, and plentiful. His inactivity undoubtedly contributed to the deterioration of his health. The man who for 20 years had played so great a role in the world and who had marched north, south, east, and west across Europe could hardly be expected to endure the monotony of existence on a little island, aggravated by a self-imposed life of a recluse. He had also more intimate reasons for unhappiness: Marie-Louise sent no word to him, and he may have learned of her liaison with the Austrian officer appointed to watch over her, Graf Adam von Neipperg (whom she eventually married in secret without waiting for Napoleon's death); nor did he have any news of his son, the former king of Rome, who was now living in Vienna with the title of duke of Reichstadt. Finally, though the severity of Sir Hudson Lowe has been much exaggerated, it is certain that this "jailer," who arrived as governor of Saint Helena in April 1816, did nothing to make Napoleon's life easier. Napoleon from the start disliked him as the former commander of the Corsican rangers, a band of volunteers largely composed of enemies of the Bonaparte family. Always anxious to carry out his instructions exactly, Lowe came into conflict with Las Cases. He saw Las Cases as Napoleon's confidant and had him arrested and expelled. Thenceforward, relations between the governor and Napoleon were limited strictly to those stipulated by the regulations.

First signs of illness

Napoleon showed the first signs of illness at the end of 1817; he seems to have had an ulcer or a cancer of the stomach. The Irish doctor Barry O'Meara, having asked in vain for a change in the conditions under which Napoleon lived, was dismissed; so also was his successor John Stokoe, who was likewise thought to be well-disposed toward Napoleon. The undistinguished Corsican doctor who took their place, Francesco Antommarchi, prescribed a treatment that could do nothing to cure his patient. It is uncertain, however, whether Napoleon's disease was curable at all, even by 20th-century methods.

From the beginning of 1821, the illness became rapidly worse. From March, Napoleon was confined to bed. In April he dictated his last will:

> I wish my ashes to rest on the banks of the Seine, in the midst of that French people which I have loved so much. . . . I die before my time, killed by the English oligarchy and its hired assassins.

On May 5 he spoke a few coherent phrases: "My God . . . The French nation . . . my son . . . head of the army . . . ." He died at 5:49 PM on that day, not yet 52 years old. His body was dressed in his favourite uniform, that of the Chasseurs de la Garde, covered by the gray overcoat that he had worn at Marengo. The funeral was conducted simply, in the Rupert Valley where Napoleon had sometimes walked, beside a stream in which two willows were reflected. The stone covering his tomb bore no name, only the words "Ci-Gît" ("Here Lies").

THE NAPOLEONIC LEGEND

Napoleon's fall had set loose a torrent of hostile books designed to sully his reputation. One of the least violent of these was the pamphlet *De Buonaparte, des Bourbons, et de la nécessité de se rallier à nos princes légitimes* (1814; *On Buonaparte and the Bourbons, and the Necessity of Rallying Around Our Legitimate Princes, for the Safety of France and of Europe*) by François de Chateaubriand, a well-known writer of royalist sympathies. But this anti-Napoleonic literature soon died down, while the task of defending Napoleon was taken up. Lord Byron had published his "Ode to Napoleon Buonaparte" as early as 1814; the German poet Heinrich Heine wrote his ballad "Die Grenadiere"; and in 1817 the French novelist Stendhal began his biography *Vie de Napoléon.* At the same time, the Emperor's most faithful supporters were working toward his rehabilitation, talking about him, and distributing reminders of him, including engravings. They idealized his life ("What a novel my life is!" he himself had said) and began to create the Napoleonic legend.

Early memoirs and chronicles

As soon as the Emperor was dead, the legend grew rapidly. Memoirs, notes, and narratives by those who had followed him into exile contributed substantially to it. In 1822 Dr. O'Meara, in London, had his *Napoleon in Exile, or a Voice from Saint Helena* published; in 1823 the publication of the *Mémoires pour servir à l'histoire de France sous Napoléon, écrits à Sainte-Hélène sous sa dictée* (*Memoirs of the History of France during the Reign of Napoleon, Dictated by the Emperor at St. Helena*) by Montholon and Gourgaud, began; Las Cases, in his famous *Mémorial,* presented the Emperor as a republican opposed to war who had fought only when Europe forced him to fight in defense of freedom; and in 1825 Antommarchi published his *Derniers moments de Napoléon.* Thereafter the number of works in Napoleon's honour increased continually; among them were Victor Hugo's "Ode à la Colonne," the 28 volumes of the *Victoires et conquêtes des Français,* and Sir Walter Scott's *Life of Napoleon Buonaparte, Emperor of the French.* Neither police action nor prosecutions could prevent books, pictures, and objects evoking the imperial saga from multiplying in France.

After the July Revolution of 1830, which created the bourgeois monarchy under Louis-Philippe, thousands of tricolour flags appeared in windows, and the government had not only to tolerate the growth of the legend but even to promote it. In 1833 the statue of Napoleon was put back on the top of the column in the Place Vendôme in Paris; and in 1840 the King's son François, prince de Joinville, was sent in a warship to fetch the Emperor's remains from Saint Helena to the banks of the Seine in accordance with his last wishes. A magnificent funeral was held in Paris in December 1840, and Napoleon's body was conveyed through the Arc de Triomphe in the Place de l'Étoile to entombment under the dome of the Invalides.

Napoleon's nephew Louis-Napoleon exploited the legend in order to seize power in France. Though his attempts at Strasbourg in 1836 and at Boulogne in 1840 were failures, it was chiefly because of the growth of the legend that he won election to the presidency of the Second Republic with an overwhelming majority in 1848 and was able to carry out the coup d'etat of December 1851 and make himself emperor in 1852.

The disastrous end of the Second Empire in 1870 damaged the Napoleonic legend and gave rise to a new anti-Napoleonic literature, best represented by Hippolyte Taine's *Origines de la France contemporaine* (1876–94). World Wars I and II, however, together with the experience of the 20th-century dictatorships, made it possible to judge Napoleon more fairly. Any comparison with Stalin or Hitler, for instance, can only be to Napoleon's advantage. He was tolerant, he released the Jews from the ghettos, and he showed respect for human life. Brought up on the rationalist *Encyclopédie* and on the writings of the Philosophes of the Enlightenment, he remained above all a man of the 18th century, the last of the "enlightened despots." One of the gravest accusations made against Napoleon is that he was the "Corsican ogre" who sacrificed millions of men to his ambition. Estimates indicate that the Napoleonic Wars of 1800–15, notwithstanding the many foreigners conscripted to fight for France, resulted in the loss of about 1,000,000 French troops—about half of whom were killed or wounded. The loss of these men did not greatly affect the growth of the population, however.

Assessment and legacy

The social structure of France changed little under the First Empire. It remained roughly what the Revolution had made it: a great mass of peasants comprising three-quarters of the population—about half of them working owners of their farms or sharecroppers and the other half with too little land for their own subsistence and hiring themselves out as labourers. Industry, stimulated by the war and the blockade of English goods, made remarkable progress in northern and eastern France, whence exports could be sent to central Europe; but it declined in the south and west because of the closing of the Mediterranean and the Atlantic. The great migrations from rural areas toward industry in the towns began only after 1815. The nobility would probably have declined more swiftly if Napoleon had not restored it; but it could never recover its former privileges.

Above all, Napoleon left durable institutions, the "granite masses" on which modern France has been built up: the administrative system of the prefects, the Code Napoléon, the judicial system, the Banque de France and the country's financial organization, the universities, and the military academies. Napoleon changed the history of France and of the world. (J.Go.)

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Navigation

Navigation, a word derived from the Latin *navis,* "ship," and *agere,* "to drive," originally denoted the art of ship driving, including steering and setting the sails. The skill itself is even more ancient than the word, and it has evolved over the course of many centuries into a science and a technology that encompasses the planning and execution of safe, timely, and economical operation of watercraft, aircraft, and spacecraft.

Many animals can find their way home from considerable distances by remembering what they saw or smelled along the way. For example, a honeybee returning to its hive with food performs a dance to communicate to its fellows the direction (relative to the Sun) and distance (as far as six miles [10 kilometres]) they should fly to reach the source of the food. Many species of birds migrate thousands of miles with great precision, orienting themselves by the Sun and stars. Such pathfinding feats have undoubtedly been performed since long before human sailors first ventured out of sight of land, but detailed investigation of these activities has made no direct contribution to the analogous skills that have been developed and refined by human navigators.

Early mariners who embarked on voyages of exploration gradually developed systematic methods of observing and recording their position, the distances and directions they traveled, the currents of wind and water, and the hazards and havens they encountered. The facts accumulated in their journals made it possible for them to find their way home and for them or their successors to repeat and extend their exploits. Each new landfall became a signpost along a route that could be retraced and integrated into a growing body of reliable information.

For these pathfinders, the danger of running into another vessel was of negligible concern, but as heavy traffic developed along established routes, collision avoidance became a serious matter. In all fields of navigation, emphasis shifted from finding the way to maintaining an appropriate distance between craft moving in various directions at different speeds. The larger a ship is, the easier it is to see, but, by the same token, the larger a ship is, the more time it requires to change its speed or direction. When many ships are in a small area, an action taken by one to avoid colliding with another may endanger a third. This problem has been alleviated near busy seaports by confining incoming and outgoing ships to separate lanes, which are clearly marked and divided by the greatest practical distance. Airplanes travel so fast that even though two pilots may see one another in time to initiate evasive action, their maneuvers may be nullified if either one incorrectly predicts the other's move. Ground-based air traffic controllers are charged with the responsibility for assigning aircraft to selected paths that minimize the likelihood of collision. Civil air navigation is profoundly influenced by the requirements of following the instructions of these controllers.

The advent of steam-powered ships during the first half of the 19th century added the problem of fuel consumption to the navigator's duties. In the air as well as at sea, the need to carry large amounts of fuel for long trips reduces the cargo capacity; even if plenty of fuel is on board, economy requires that its consumption be kept to a minimum. In spaceflight, fuel is a major navigational consideration. The route to be followed and even the moment for lift-off must be chosen to keep the fuel requirements as small as possible.

Adherence to a predetermined schedule, a matter of vital importance in space navigation in connection with fuel consumption, has become important in sea and air navigation for a different reason. Today each voyage or flight is a single link in a coordinated network of transport that carries people and goods from any starting place to any chosen destination. The efficient operation of the whole system depends upon assurance that each journey will begin and end at the specified times.

Modern navigation, in short, has to do with the whole of a preconceived passage, from start to finish, and is concerned with four basic objectives: selecting the course (and staying on it); avoiding collision with other moving ships and crashing into fixed obstacles; minimizing fuel consumption; and conforming to an established timetable.

(E.W.A./Ed.)

This article deals with the methods and devices integral to the science of navigation. It also provides a brief historical survey of their development.

For coverage of related topics in the *Macropædia* and *Micropædia,* see the *Propædia,* sections 723, 735, 736, and 738, and the *Index.*

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DEVELOPMENT OF MARINE NAVIGATION

Ancient sea voyages

The earliest navigators probably learned to steer their ships between distant ports by familiarizing themselves with the sequences of intervening landmarks. Keeping these reference points in view required them to stay quite close to shore, but they made the transition to ocean voyages well out of sight of land thousands of years ago in various parts of the world. Regular trade was carried on between the island of Crete and Egypt, a distance of approximately 300 miles (500 kilometres), more than 25 centuries before the Christian era. A passage in the *Odyssey* describes such a voyage from Crete: running before a north wind, sailing ships reached the mouth of the Nile in five days. Longer and longer routes became established by later sailors. By 600 BC the Phoenicians were routinely importing tin from Cornwall. Well before the 10th century AD, Irish seafarers successively reached the Shetland Islands, the Faeroe Islands, and Iceland, crossing 200 to 300 miles of the North Atlantic at each stage. The Vikings repeated those passages and ventured even farther, settling Greenland and visiting North America. In about AD 400, Polynesian navigators had reached Hawaii from the Marquesas Islands, 2,300 miles (3,700 kilometres) across the open Pacific.

Direction finding. The details of how these voyagers found their way are not known, but the use of the Sun and stars as guides is mentioned in many sources, including

the works of Homer and Herodotus, the Bible, and the Norse sagas.

East and west are traditionally synonymous with the directions of sunrise and sunset; north and south are determined by the directions of shadows cast by the noonday Sun. By night the stars rise in the east and set in the west, and in the Northern Hemisphere their apparent rotation around the Pole Star has long been a fact of the navigator's life.

For many centuries practical navigators oriented themselves by relying just as strongly on meteorological clues (the directions from which steady winds blew) as on astronomical ones (the positions and apparent motions of the Sun and stars). The Mediterranean sailor could confidently distinguish the cold north wind from the warm south wind. Names were assigned to eight principal winds, and the directions of these winds became the eight equally spaced points of the wind rose (*rosa ventorum*) of the classical mariner. The wind rose may have been devised by the Etruscans, whose power reached its peak around the 6th century BC; it certainly antedates the octagonal Tower of the Winds built in Athens by Andronicus of Cyrrhus in about 100 BC. From Roman times through the Middle Ages, an alternative 12-point wind rose was used by some navigators, but it was discarded in the 15th century when the Portuguese, at the opening of the great age of discovery, subdivided the eight points of the ancients and introduced a 16-point system.

Wind rose

Sailing instructions. The first written aid to coastal navigation was the pilot book, or periplus, in which the courses to be steered between ports were set forth in terms of wind directions. These books, of which examples survive from the 4th century BC, described routes, headlands, landmarks, anchorages, currents, and port entrances. No doubt the same information had formerly been passed along by word of mouth, as it still is in some parts of the world. It seems improbable that any sort of sea chart was used with these sailing guides, even though Herodotus' map of the known world, drawn in the 5th century BC, delineated the Mediterranean shoreline quite accurately. Reliable sea charts were not introduced until the advent of the magnetic compass (see below) and of methods for determining latitude and longitude.

Distance and speed measurements. Distances were cited in the early pilot books in units of a day's sail. Later, distances were deduced from estimates of the ship's speed and the lengths of time over which these speeds were maintained. Probably the oldest method of determining the speed is the so-called Dutchman's log, in which a floating object, the log, was dropped overboard from the bow of the ship; the time elapsing before it passed the stern was counted off by the navigator, who kept it in sight while walking the length of the vessel. This technique was eventually replaced by that in which the log, attached to a reel of light line, was dropped from the stern; as the ship moved away from the log, the length of line paid out during the emptying of a sandglass was the measure of the speed. In 1637 the English navigator Richard Norwood recommended the use of a line knotted at intervals of 47¼ feet (14.3 metres) and a 28-second sandglass; if the first knot appeared as the sand ran out, the ship's speed was 6,076 feet (1,852 metres [one nautical mile]) per hour, or one knot. As early as 1688 an English instrument maker, Humphry Cole, invented the so-called patent log, in which a vaned rotor was towed from the stern, and its revolutions were counted on a register. Logs of this kind did not become common until the mid-19th century, when the register was mounted on the taffrail, where it could be read at any time; another Englishman, Thomas Walker, introduced successive refinements of the patent log beginning in 1861. This form of log is still in use. (M.W.Ri.)

Maritime logs

The magnetic compass. *Development.* It is not known where or when it was discovered that the lodestone (a mineral composed of an iron oxide) aligns itself in a north–south direction, as will a piece of iron that has been magnetized by contact with a lodestone. Neither is it known where or when marine navigators first availed themselves of these discoveries. Plausible records indicate that the Chinese were using the magnetic compass around AD 1100, western Europeans by 1187, Arabs by 1220, and Scandinavians by 1300. The device could have originated in each of these groups, or it could have been passed from one to the others. All of them had been making long voyages, relying on steady winds to guide them and sightings of the Sun or a familiar star to inform them of any change. When the magnetic compass was introduced, it probably was used merely to check the direction of the wind when clouds obscured the sky.

The first mariner's compass may have consisted of a magnetized needle attached to a wooden splinter or a reed floating on water in a bowl. In a later version the needle was pivoted on a pin fixed to the bottom of the bowl. By the 13th century a card bearing a painted wind rose was mounted on the needle; the navigator could then simply read his heading from the card. So familiar has this combination become that it is called the compass, although that word originally signified the division of the horizon. The suspension of the compass bowl in gimbals (originally used to keep lamps upright on tossing ships) was first mentioned in 1537.

On early compass cards the north point was emphasized by a broad spearhead and the letter *T* for tramontana, the name given to the north wind. About 1490 a combination of these evolved into the fleur-de-lis, still almost universally used. The east point, pointing toward the Holy Land, was marked with a cross; the ornament into which this cross developed continued on British compass cards well into the 19th century (see Figure 1). The use of 32 points by sailors of northern Europe, usually attributed to Flemish compass makers, is mentioned by Geoffrey Chaucer in his *Treatise on the Astrolabe* (written in 1391). It also has been said that the navigators of Amalfi, Italy, first expanded the number of compass points to 32, and they may have been the first to attach the card to the needle.

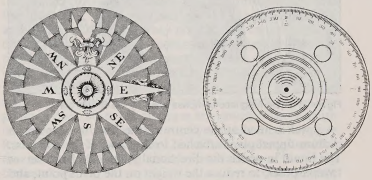


Figure 1: *Compass cards.*
(A) Eighteenth-century compass card divided into points and having ornamentation at the east point. (B) U.S. Navy compass card made of metal with graduations perforated through it.

During the 15th century it became apparent that the compass needle did not point true north from all locations but made an angle with the local meridian. This phenomenon was originally called by seamen the northeasting of the needle but is now called the variation or declination. For a time, compass makers in northern countries mounted the needle askew on the card so that when the needle pointed to magnetic north the fleur-de-lis indicated true north. This practice died out about 1700 because it succeeded only for short voyages near the place where the compass was made; it caused confusion and difficulty on longer trips, especially in crossing the Atlantic to the American coast, where the declination was west instead of east as in Europe. The declination in a given location varies over time. For example, in northern Europe in the 16th century the magnetic north pole was east of true geographic north; in subsequent centuries it has drifted to the west.

Compass variation

Despite its acknowledged value, the magnetic compass long remained a fragile, troublesome, and unreliable instrument, subject to mysterious disturbances. The introduction of iron and then steel for hulls and engines in the 19th century caused further concern because it was well known that nearby ironwork would deflect the compass needle. In 1837 the British Admiralty set up a commit-

tee to seek rational methods of ensuring the accuracy of compasses installed on iron ships. In 1840 the committee introduced a new design that proved so successful that it was promptly adopted by all of the principal navies of the world. Further refinements, aimed at reducing the effects of engine vibration and the shock of gunfire, continued throughout the century.

The modern magnetic compass. The liquid magnetic compass (see Figure 2), now almost universally used, is commonly accompanied by an azimuth instrument for taking bearings of distant objects. The compass consists of a set of steel needles with a compass card, attached to a float, in a bowl of water and alcohol. In modern instruments, the magnetic element is often in the form of a ring magnet, fitted within the float. The card is usually of mica or plastic with photographically printed graduations; metal cards with perforated graduations also are used. Cards are usually graduated clockwise from 0° at north to 359°, with the eight principal points indicated.

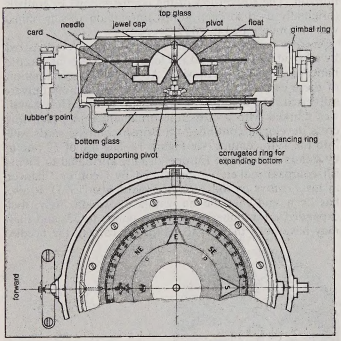


Figure 2: Liquid magnetic compass used by the British Navy.

A jewel is fitted at the centre of the float to bear on an iridium-tipped pivot attached to the bowl of the compass. The liquid in which the directional system is placed serves two purposes: to reduce the weight on the pivot point, and thereby to minimize friction; and to damp out oscillations from the ship's motion. The bowl is closed on the top and bottom by glass, the bottom glass permitting illumination from below, and is mounted in gimbals. A flexible diaphragm or bellows attached to the bowl accommodates the change in volume of the liquid caused by temperature changes. The ship's heading is read with the aid of the lubber's point, at the forward part of the compass, which indicates the direction of the ship's centre line.

When the ship alters course, liquid at the side of the bowl tends to displace slightly, deflecting the card and causing what is known as swirl error. To minimize swirl error the card is often made considerably smaller in diameter than the bowl. The directional system is made sufficiently bottom-heavy (pendulous) to counteract the downward pull of the vertical component of the Earth's magnetic field, which would otherwise cause the system to tilt.

The simplest, and probably earliest, azimuth instrument consisted of two sights on opposite sides of the compass bowl connected by a thread. The assembly could be rotated to permit sighting on the distant object. Because it was impossible to sight through the instrument and look at the compass card simultaneously, a prism (mirror) was positioned to reflect an image of the card, which was given a second set of graduations with reversed figures. Modern azimuth instruments embody a number of refinements, but the principle remains unchanged.

The binnacle

The binnacle, formerly called the bittacle, is the receptacle in which the compass is mounted. Originally constructed in the form of a cupboard, it is now usually a cylindrical pedestal with provision for illuminating the compass card, usually from below. It contains various correctors to reduce the deviations of the compass caused by the magnetism of the ship. These usually consist of properly placed magnets, a pair of soft iron spheres (or small strips close to the compass), and a vertical soft iron bar called the Flinders bar, which originated in recommendations made by the English navigator Matthew Flinders.

Binnacles are sometimes constructed so that an image of part of the compass card can be projected or reflected through a tube onto a viewing screen on the deck below. This arrangement can make it unnecessary to provide a second compass for the helmsman and may allow the binnacle to be placed in a position less susceptible to magnetic disturbances. (W.E.M./J.L.H./Ed.)

Marine charts. *The portolano.* During the course of 15 centuries or more the coastal pilot book of classical times evolved into the portolano, the harbour-finding manual of the Middle Ages. An early portolano for the whole Mediterranean Sea, *Lo Compasso da Navigare* (1296), gives directions in terms of half points, that is, halves of the angles defined by the 32-point compass. From such works, accumulated over generations and collected during the 13th century into a single volume for the entire Mediterranean, the first marine charts were drawn. On these charts, most of which were compiled in Genoa, Venice, and Majorca, north was at the top, rather than east, as was the practice on most land maps of the time. They carried a scale of distances and a pattern of rhumb lines (each of constant bearing) in different colours. To set a course between two ports, the pilot would join the corresponding points on the chart with a straight line, find the rhumb line most nearly parallel to it, and trace the rhumb line back to its parent wind rose, from which he obtained the required heading. As long as the ship's location was to be found by dead reckoning (keeping a running record of the distances and directions traveled), the Mediterranean chart was entirely adequate. Questions of latitude, longitude, compass variation, and curvature of the Earth's surface could be safely ignored.

Rhumb lines

The Mercator chart. When the Portuguese, under the leadership of Prince Henry the Navigator, ventured farther south along the west coast of Africa, they encountered navigational difficulties by assuming that the charts used in the Mediterranean could simply be extended. Over long distances the rhumb lines could not be taken as straight, and the charts bore no relation to the new methods of checking the dead reckoning that Portuguese astronomers and mathematicians had devised. These methods required a chart on which positions were expressed as latitudes and longitudes rather than bearings and distances. Such a chart had to embody a practical method of representing the curved meridians and parallels on a flat surface. Even for an area as large as the Mediterranean, this can be done without grossly falsifying either distances or directions, but for larger regions some distortions are inevitable, and a choice has to be made between alternative mapping techniques. On certain types of charts, distances can be shown accurately, but directions cannot; on other types, directions are reliably presented, but the scale of distance varies greatly between different parts of the chart. The navigator accepts the second type because the risk of lengthening the voyage is preferable to that of missing the target.

Map distortions

In 1569 the Flemish cartographer Gerardus Mercator published a world map that he had composed using a "projection suitable for navigation," the details of which he did not disclose. (The Mercator and other projections are treated in the article MAPPING AND SURVEYING.) On a Mercator chart the meridians of longitude are represented by equally spaced vertical lines, and the parallels of latitude are represented by horizontal lines that are closer together near the Equator than near the poles. The uneven spacing of the parallels compensates for the increasing exaggeration of the east–west distance between adjacent meridians at higher latitudes; this distance decreases on the Earth but remains the same on the chart. In 1599 the English mathematician Edward Wright supplied a rational explanation of Mercator's projection and provided tables by which the distorted distances could be corrected.

Latitude measurements. Portuguese seamen determined latitude by observing the altitude of the Pole Star, that is, the angle between its direction and the horizontal. They knew from astronomical studies that the star does not lie exactly on the extension of the Earth's axis, so that it appears to move daily in a small circle around the celestial pole, but the necessary correction (as much as 3½° in the 15th century) could be applied by noting the position of the nearby star Kochab. When the navigators got close to the Equator, these stars fell below the horizon; there it became necessary to rely on observing the altitude of the noonday Sun and calculating latitude with the aid of an almanac.

The first instruments used at sea for altitude measurements seem to have been the quadrant and the astrolabe, long known to astronomers. For both devices the reference direction was the vertical, rather than the horizontal, but conversion of the readings was an elementary matter.

The cross-staff

The mariner's astrolabe, however, was less widely used than its 16th-century successor, the cross-staff, a simple device consisting of a staff about three feet long fitted with a sliding crosspiece. The navigator, holding the staff to one eye, would move the crosspiece until its lower end coincided with the horizon and its upper end with the Pole Star (see Figure 3). The desired altitude could then

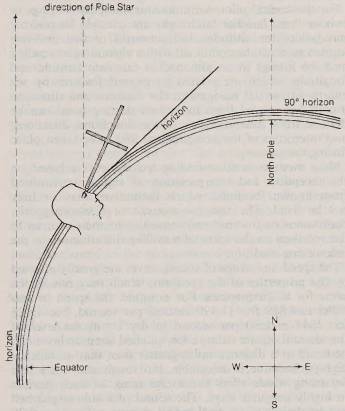


Figure 3: Altitude of Pole Star and latitude.

be read from the intersection of the crosspiece with the staff, on which a scale was marked in degrees. The cross-staff remained in use until the 18th century despite several drawbacks, the most serious being that it required the observer to look directly into the Sun. Coloured shades were fitted to the crosspiece, but the decisive improvement was made in 1594 by the English navigator John Davis. His instrument, called the backstaff because it was used with the observer's back to the Sun, remained common even after 1731 when the octant (an early form of the modern sextant) was demonstrated independently by John Hadley of England and Thomas Godfrey of Philadelphia. In the octant and the sextant, two mirrors—one fixed, the other movable—bring the image of the Sun into coincidence with the horizon. In the hands of the practiced observer, the modern sextant can be used to measure altitudes with an accuracy of 10 seconds of arc, that is, closely enough to determine a ship's north–south position within a few hundred metres.

Longitude measurements. *Almanacs and tables.* One of the earliest tabulations of the day-to-day positions of the heavenly bodies was *Ephemerides,* compiled by the German astronomer Regiomontanus and published by him in Nürnberg in 1474. This work also set forth the principle of determining longitude by the method of lunar distances, that is, the angular displacement of the Moon from other celestial objects. This method, which was destined to become the standard for a time during the 19th century, remained impracticable for more than three centuries because of the inaccuracy of the existing lunar tables, and because special knowledge and tedious computations were necessary in its use. Meanwhile, during the 16th and 17th centuries, working from translations of Portuguese and Spanish manuals, a flourishing school of instrument makers, chart makers, and teachers grew in England. This group rapidly improved the theory of navigation and compiled tables of increasing accuracy. In 1675 the Royal Observatory was established at Greenwich with the specific object of providing the sailor with astronomical data of the required precision. At Paris the *Connaissance des temps,* the first national almanac, was founded in 1679; it contained tables for the crude determination of longitude from observations of the eclipses of Jupiter's satellites, first seen by Galileo in 1610. (Galileo himself had advocated the preparation of such tables for this purpose, but the method, though sound in principle, could not be made practical.) In 1755 Johann Tobias Mayer, a German astronomer, published remarkably accurate tables of the motion of the Moon. To make them useful to navigators, however, it was necessary to prepare from them an ephemeris of the Moon for every noon and midnight. The English astronomer royal, Nevil Maskelyne, supervised this task; the results were published in the annual *Nautical Almanac,* which was inaugurated in 1766.

Mayer's lunar tables

The marine chronometer. Latitude could be determined by measuring the altitude of the Sun at noon or the altitude of any tabulated star when it crossed the local meridian, but the determination of longitude at sea remained a serious problem. By the Middle Ages, astronomers knew that the local time of an eclipse depended on the longitude, and in the 16th century they pointed out the principle of determining longitude by comparing the local time with the reading of a clock that reliably kept the time of a known meridian. No such clock was then available, but in 1714 the British Parliament offered a prize of £20,000 to anyone who could discover a method of finding the longitude within 30 miles during a sea voyage. The English inventor John Harrison eventually was awarded the prize for a chronometer tested in 1761–62. His success heralded the practice of making timed observations of heavenly bodies at sea. (M.W.Ri./Ed.)

Other aids to navigation. An Egyptian temple decoration dating from about 1600 BC shows a ship on which a member of the crew is measuring the depth of the water with a long pole. The Viking sailor took soundings with a lead weight on a line, hauling in the line and measuring it by the span of his arms. Depths are still cited in six-foot (1.8-metre) intervals called fathoms from the Old Norse word *fathmr* ("outstretched arms"). The weight was commonly given a hollow bottom filled with tallow to pick up a sample of the seabed for comparison with the composition indicated on the chart. Distance from a cliff could be estimated by timing the echoes of shouts or drumbeats.

Running lights

To reduce the risk of collision, a ship under way at night displayed running lights by which sailors on nearby vessels could judge its course and speed. The traditional coloured lights, red to port and green to starboard, were augmented on steamships with a white light at the head of the foremast. In foggy weather, gongs, bells, or explosives were used to produce loud warning sounds; eventually these devices were replaced by foghorns. Rules that specified what lights must be shown, what signals must be given, and how ships must navigate in respect of each other were formulated for British mariners in 1862. These rules formed the basis of the International Regulations for Preventing Collisions at Sea, which were adopted by nearly all maritime nations after a conference held in 1889. Collision avoidance also was fostered by general acceptance of the recommendation—separate lanes for eastbound and westbound steamers in the heavily traveled North Atlantic—appearing in *Sailing Directions* (1855), prepared by the

U.S. naval officer Matthew F. Maury. The danger of running aground was lessened by a worldwide system of lighthouses, lightships, buoys, bells, and channel markers; the development of these aids to navigation is treated in the article PUBLIC WORKS: *Lighthouses*.

20TH-CENTURY NAVIGATION

Navigation, in sharp distinction from aimless sailing or flying, presupposes a specific objective and may be subdivided into three stages. The first stage is the selection of the route along which the craft is to move and, ordinarily, a schedule that specifies the times at which the craft leaves its starting point, passes intermediate points, and reaches its destination. The route consists of a continuous succession of points, either on the surface of the sea or below it, in the air, on land, or in space. The second stage is the execution of the planned movement of the craft by driving it in the directions defined by the course at the speeds necessary to conform to the schedule. The third stage is the application of various accelerations at appropriate times and places. These accelerations are changes in velocity; they include increases and decreases in speed as required by the timetable or as dictated by external conditions along with alteration of direction as required to stay on the chosen course.

As the craft proceeds, the navigator regularly finds its position, comparing the progress with the predetermined route. If a deviation is detected, the navigator amends the route, adjusting speed and direction as needed to restore the craft to the proper path. Progress along the amended route is checked again by finding further positions, and further corrections are undertaken as required. The repetitive process of assessing progress and taking appropriate action is known as a closed loop.

Closed-loop navigation

Closed loops are seldom simple but consist of a series of loops one inside the other like the skins of an onion. Inside the outer position-finding loop there is an inner course and speed loop. In this loop, the course to be steered and the speed to be maintained are checked by compass and speedometer or log. Within the inner course and speed loop, there is also an innermost driving loop that relies on instruments to measure accelerations or, alternatively, on the judgment of the navigator. Finding the way thus involves three loops. Of these, the outer position-finding loop is used only at intervals, the course and speed loop is corrected more frequently, and the innermost driving loop is continually in action. A motor vehicle driver, by analogy, looks only occasionally at signposts, more frequently at the speedometer, but always keeps one or both hands on the steering wheel.

The aids that are employed in the outer position-finding loop cannot effectively be adapted to measure course and speed. For example, in the case of an aid that tells the distance to the destination, a minor irregularity, which momentarily diminishes this distance, would be translated as a complete reversal of speed, giving a completely false picture.

The reverse process is, however, quite possible. It has already been shown how, by dead reckoning, course, speed, and time can be used to find position. Similarly, devices used for driving may be adapted to give useful course and speed information and even position. To avoid collision, an outer position loop is used that relies on separation; for example, by one-way traffic lanes. There is also an inner course and speed loop that enables vehicles to avoid more imminent collision with each other by changing course or speed. (E.W.A./Ed.)

By the end of the 19th century, marine navigation had evolved into a fully systematic technique, combining the simplicity and reliability required by its practitioners with the rigour and accuracy founded in the skills and knowledge of astronomers, mathematicians, cartographers, and instrument makers. Accurate and detailed sea charts and books of sailing directions were available for the planning of any proposed voyage. At any stage during the voyage, dependable almanacs, sextants, and chronometers made it possible to ascertain the ship's position with great precision through observation of the altitudes and azimuths of a few familiar stars. Routine trigonometric procedures for making the needed computations had been introduced by Thomas H. Sumner of the United States in 1837 and Marcq St. Hilaire of France in 1875. These astronomical determinations were supplemented by dead reckoning, which had been made more trustworthy by the continued development of compasses and logs.

The navigational principles, techniques, and devices in use around 1900 formed a secure foundation upon which to superimpose the changes brought about during the 20th century. The advent of air travel and then space travel made it necessary to modify some of the concepts that had been developed for the period in which voyages had been restricted to the surface of the Earth. Many of the new problems, however, were solved by the application of technological innovations, notably radio communication and electronic instrumentation and computation. (Ed.)

Position finding. To find the position of a craft on the surface of the Earth, it is necessary to measure or estimate distances or directions, or both, in relation to one or more ground features at known locations. For vessels that travel above or below the surface, information about their altitude or depth also is needed; for those that move beyond the Earth's gravitational field, the reference points may be transferred to features of the Moon or to the predictable positions of the planets in relation to each other and to the Sun.

For the coastal pilot, simultaneous compass bearings of two or three familiar landmarks are enough. In celestial navigation, the altitudes and azimuths of two or three known stars can be combined with a chronometer reading and the listings in an almanac to calculate latitude and longitude, which are related to ground features by sea charts. In inertial navigation, the distance and direction a craft has moved from its known starting point can be derived from measurements of the directions, durations, and intensities of the accelerations that have taken place during the journey.

Transmission of signals

Most modern position-finding techniques are based on the reception and interpretation of signals transmitted from known locations, which themselves may or may not be fixed. The signals—acoustic or electromagnetic, continuous or intermittent—travel from their sources to the receivers in the form of wavelike disturbances in the intervening medium.

The speed and range of sound waves are greatly affected by the properties of the medium, which may not be the same for all frequencies. For example, the speed in seawater is 4,889 feet (1,490 metres) per second, but 1,128 feet (344 metres) per second in dry air at sea level. If the sea and air are calm, a low-pitched siren or horn can be heard at a distance miles greater than that at which a high-pitched one is detectable, but rough and noisy seas or strong winds affect the useful range of such devices in highly irregular ways. The sound of a submerged bell can be detected in a steel-hulled ship at a distance of 20 miles or more.

Electromagnetic radiation, including light and radio waves, travels very fast: about 186,000 statute miles (162,000 nautical miles; 300,000 kilometres) per second through empty space. This speed varies somewhat, depending on whether the waves are passing through space, air, water, the ground, or a telegraph wire; the wavelengths are inversely proportional to the speeds, but the frequencies remain unchanged. Frequency intervals, therefore, ordinarily are used to designate the bands into which the broad electromagnetic spectrum is divided for various purposes. In many microwave radar systems, for example, the frequencies of the waves lie in the so-called superhigh frequency band, between three and 30 gigahertz; the corresponding wavelengths are between one and 10 centimetres. The classification of these bands and their applications are treated in the article BROADCASTING: *Radio systems and equipment*.

At altitudes of tens to hundreds of kilometres above the Earth's surface, ionizing radiation from the Sun produces high concentrations of electrically charged particles in certain layers of the upper atmosphere. In the lower layers of this region, which is called the ionosphere, the charged particles revert to their neutral forms during the night.

Low-frequency waves reaching the ionized layers bounce back toward the Earth; such waves also are transmitted long distances through the ground and the oceans. High-frequency waves that strike the ionosphere at glancing angles also are reflected, but those incident at large angles (perpendicular or nearly so) pass through into outer space. High-frequency ground waves do not travel very far, so there is a gap, or dead space, between the range at which the ground wave dies out and that at which the waves reflected from the ionosphere (called sky waves) are first detectable.

Electromagnetic waves with frequencies greater than 30 gigahertz have wavelengths less than one centimetre. They are strongly scattered or reflected by raindrops, mist, fog, and snowflakes; for this reason, they are of no value for long-distance communication.

Speed measurement. The classical methods of measuring speed through the water have already been described. In the mid-18th century the French hydraulic engineer Henri Pitot, studying the flow of water in rivers and canals, invented a device—now called the Pitot tube—for measuring the speed of the flow past a given point. The Pitot tube has been applied to the measurement of wind speed, and it is equally useful as a log for ships or aircraft. A typical Pitot marine log consists of a pair of thin-walled tubes projecting through the bottom of the ship and bent so as to face the direction of motion. One tube is open at the forward end; the opening is referred to as the dynamic-pressure orifice. The second tube is closed at the end but has openings at right angles to its length; these openings are the static-pressure orifices. When the ship is dead in the water, the pressure is the same in the dynamic and static connections, but, when the vessel moves ahead, the dynamic pressure exceeds the static pressure by an amount that varies as the square of the ship's speed. Another part of the log consists of a centrifugal water pump driven by a variable-speed electric motor. The dynamic pressure that is produced by such a pump varies as the square of the speed of the motor. The pressure produced by the motion of the ship is exerted against one face of a diaphragm; that produced by the pump is exerted against the other. Movement of the diaphragm operates the speed control of the motor so as to equalize the two pressures and thereby make the speed of the motor directly proportional to the speed of the ship. A magneto attached to the shaft of the motor generates a voltage proportional to the speed, and on the ship's bridge a voltmeter calibrated in knots provides a continuous indication of the progress of the vessel. Analogous Pitot logs, with less bulky attachments for translating air pressure differentials to speed readings, are almost universally installed in aircraft. (M.R.Da./Ed.)

Pitot tube

Electro-acoustic log

In ships, a modern form of log incorporates a pair of electroacoustic transducers. One of these launches a sound wave from a point close to the keel; the second, a few metres ahead or astern, detects this wave and measures the time required for it to traverse the known distance. Motion of the ship relative to the water changes this interval in a way directly related to the speed of the ship. The speed of sound through water is slightly affected by temperature and salinity; even so, the electroacoustic log is much more accurate than its mechanical forerunners, and it is much less susceptible to malfunction caused by fouling by barnacles or weeds.

The Doppler effect—the familiar shift in the pitch of the sound of an automobile engine as it passes a stationary listener—also can be exploited to measure the speed of a vessel or an aircraft. Such an effect can be accurately measured in either sound waves or electromagnetic waves emitted from a moving craft and reflected from a fixed object. (S.S.D.J.)

Dead reckoning. *Correction for drift.* Starting from a known point, the mariner with a compass could draw a line on the chart to represent a vessel's course, then mark off the distance given by the log. The calculation of a new position was known as dead reckoning. In addition to errors in the compass and in the log, dead reckoning suffered from errors due to the drift of the water. When ocean currents were first marked on charts of the open sea, and tidal streams appeared on coastal charts, navigators could make allowance for drift. Fortunately, the currents were seldom fast and, on long voyages, often tended to cancel each other out. The situation in the air, however, was quite different. Early airplanes flew at around 100 knots, and the air that supported them was blown over the ground by the wind at speeds of up to 40 knots. It was therefore necessary to determine the velocity of the aircraft through the air and the velocity of the air over the ground in order to find the true velocity of the aircraft with respect to the ground. This was achieved by the triangle of velocities as shown in Figure 4. A line was drawn to show the direction in which the aircraft was heading, the length of the line representing the distance that the aircraft would travel through still air in one hour—in other words, the true air speed. Such a line represents a vector; that is, a quantity that embodies both magnitude and direction. From the end of this line, a second line or vector was drawn in the direction toward which the wind was blowing, the length of this second line being determined by the wind speed. Finally, a third line drawn from the starting point of the first line to the end of the second line showed the path that the aircraft was following over the ground, the length of this line representing the true ground speed. Stated mathematically, the true ground speed was the vector sum of the craft's air velocity and the wind velocity.

Calculating aircraft velocity

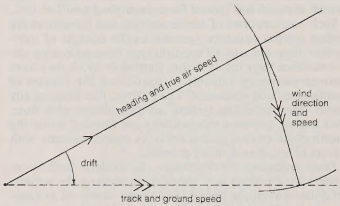


Figure 4: Triangle of velocities.

The angle between the heading of the aircraft and its track along the ground was known as the drift because it resulted from the drifting effect of the wind. Early aircraft were fitted with drift sights through which the aviator visually aligned a grid with the moving ground below and so determined the drift. The plotting of triangles of velocity was simplified by using graphic instruments called computers before that term was appropriated for much more complex devices.

Paradoxically, higher aircraft speeds failed to eliminate the problem of wind drift because jet aircraft fly higher as well as faster, and, above 20,000 feet (6,100 metres), very narrow belts of wind—known as jet streams, which travel at speeds of 100 or 200 knots—occur under certain meteorological conditions.

Sea navigators did not follow the practice of air navigators and allow for ocean currents and tidal drifts in their initial calculations. Dead reckoning, long established as a navigational technique, continued to be used; an estimate for ocean current or tidal drift was added afterward. This practice continues today.

By dead reckoning, the navigator can quickly find a position that can often be checked by a landmark. On the other hand, the errors that are inherent in dead reckoning accumulate; when a position has been checked, the reckoning is therefore generally restarted from that position.

Importance of dead reckoning

Dead reckoning enables the navigator to plot not only where the craft is but also where it will be at any given time, provided the planned course and speed are maintained. It also makes it possible for the navigator to plan the journey in its entirety, including the time of arrival at the destination. Planning is a part of all navigation; the preparation of a complete flight plan is mandatory before taking off in a civil aircraft. Space navigation is based even more completely on flight planning, and the time of splashdown is calculated to within minutes many weeks before lift-off.

Inertial guidance systems. By established principles of mathematical physics, the velocity of an object is defined as the rate of change of its position, and the acceleration is defined as the rate of change of the velocity. These relations can be applied to the navigational problem of position finding if an instrument can be devised to measure acceleration and then to convert it successively to velocity and to position. In the terminology of the calculus, velocity is the first derivative of distance (hence, position) with respect to time, and acceleration is the first derivative of velocity (the second derivative of distance). The process of evaluating a variable quantity (in this case, the distance) when its derivatives (velocity and acceleration) are known is called integration.

Accelerometers

In one form of accelerometer, a reference mass is suspended on springs within a housing firmly attached to the craft. The inertia of the mass causes it to tend to remain stationary, but any acceleration of the craft tends to displace the housing relative to the mass. The forces required to nullify relative motion of the mass and the housing—in three directions fixed by gyroscopes—can be measured electrically. The electrical signals are directly related to the forces and, by Newton's second law of motion, to the accelerations. Standard electronic circuitry performs the necessary integrations of the accelerations to provide the distances and directions, in three dimensions, through which the craft has moved from its original position.

Such combinations of accelerometers and integrators are called inertial guidance systems; in the context of navigation they amount to sophisticated dead-reckoning devices. Since their introduction, starting in 1950, they have proved extremely valuable in controlling the courses of submarines and spacecraft. Their errors, like those of any other dead-reckoning system, are cumulative with time, but nuclear-powered submarines have traveled under the north polar ice cap, guided solely by inertial systems, with errors of less than a mile per week.

Dead reckoning by computer. In modern craft, computers have proved well suited to processing the streams of data—directions, speeds, and times—involved in keeping track of position. In military land vehicles, computers are fed by compasses and signals taken from the wheels. Navigators aboard ships depend on the gyrocompass and the log; those in aircraft rely on the gyromagnetic compass and Doppler-effect speed measurements. The computers can be programmed to print periodically updated positional information. Generally, inertial guidance systems provide dead-reckoning information only, though compass and Doppler data can be included with inertial outputs. Information from radio fixing systems can be added to the dead reckoning; each item of information can be automatically compared with the others.

Radio fixing systems that can provide continuous indication of position are eliminating the distinction between position fixing and dead reckoning. Navigation is effected by supplying both the classical dead-reckoning data (speed and direction) and the continuously updated position to a computer, which determines the speed, heading, and rate of climb or descent that must be maintained to execute the flight plan. Many computers apply the technique called Kalman filtering, which weights each of the several supplied data according to its expected quality.

Instead of being mapped on a chart, position may be continuously displayed on a moving map. If the route is known beforehand, the map may be prepared in the form of a strip driven by rollers with a pointer moving to and fro to indicate exact position. When greater flexibility of route is essential, a series of maps covering a very wide area may be printed on film and projected on a ground glass screen on the bridge or in the cockpit.

Dead reckoning plays an important role in air traffic control. Not only does every air navigator have to file a complete flight plan showing courses and timings, but, during the flight, air traffic controllers keep what is virtually a dead-reckoning check on each aircraft. The flight plans are split into sections, and flight strips are prepared showing height, speed, and timings of each aircraft in a section. The air traffic controller responsible for that section can thus see which aircraft will be arriving and in what sequence. These flight strips are continually updated by reports sent by radio from the aircraft and also by changes in height and course ordered by the air traffic controller to maintain adequate separation. In modern systems, automatic flight strips are displayed on cathode-ray tubes.

Flight strips

Radio navigation. *Direction finders.* To avoid the hazards marked on the charts, a mariner needs to know the vessel's exact position. By means of a sight fitted to the compass, the direction of any visible landmark or buoy can be measured. This direction, called a bearing, can be marked on the chart as a line passing through the identified reference point. A similar line corresponding to a second bearing will intersect the first and fix the position of the vessel, as shown in Figure 5.

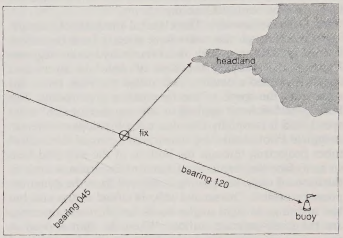


Figure 5: Determining position by intersection of compass bearings to known points.

The invention of radio transmission and reception led to an improvement in this navigational technique, making it possible to obtain bearings from reference points obscured by fog or darkness. The signals picked up by a loop antenna are weakest when the plane of the loop is perpendicular to the direction in which the radio waves are traveling. If the receiver is tuned to the frequency of a particular transmitter and the loop is rotated for minimum signal pickup, the direction to the transmitter can be found and plotted. A second position line then fixes the navigator's position, as before.

Loop antennas

Soon after ships were first equipped with radio, direction-finding stations were placed on shore at strategic points along navigational routes and near harbour approaches. Upon receiving a request by radio from a ship, two or more shore stations determined the directions from which the ship's signal arrived and transmitted this information to the vessel. The navigator then could fix his position. The limitation of this service to one vessel at a time, however, was a serious drawback in bad weather, when demands were heavy. Beginning in 1921, continuously operating transmitters were placed ashore and the direction finder on the ship to eliminate the possibility of overloading the system and to give the navigator two further advantages: that of taking continuous or frequent bearings on any shore beacon and that of taking bearings of any receivable signal, such as transmissions from commercial broadcasting stations and from other vessels. This change in the system was roughly coincident with the initial growth of aviation, and the airborne direction finder immediately became a valuable aid to air navigation.

Under ideal conditions a well-designed direction finder will provide bearings within 1° or 2° of the true value. The uncertainty can be considerably increased, however, if the direction of the radio waves is altered by reflection from the ionosphere or refraction in the atmosphere.

The loop-antenna radio direction finder, almost as old as radio itself, developed into a device in which a motor turned the loop, and electronic circuitry identified the direction of the source of the signals. This instrument, originally called a radio compass, could guide the navigator toward any detectable transmitter. It was often linked to a compass so as to display not merely the direction of the radio station compared to the heading of the craft but the actual direction as plotted on a chart.

Radio-beam systems. The directional selectivity of loop antennas when they are used as receivers is duplicated when they are used as transmitters. Such an antenna can be oriented so that it radiates strong signals to the north and south but practically none to the east or west. Pathway-defining ground stations for aircraft were developed during the 1920s and '30s. They were equipped with loop antennas in pairs at right angles, arranged so that one antenna broadcast the International Morse Code character *A* (dot–dash), and the other broadcast the character *N* (dash–dot). Midway between the directions in which only *A* or only *N* could be heard, the characters interleaved to produce a steady tone; these four intermediate directions were the preferred courses, called beams. Only a slight deviation of the receiver from a beam disrupted the steady tone, and the direction in which the craft was off the beam was indicated by the predominance of one Morse character or the other. The pilot flew in one of the four directions toward or away from the transmitting beacon, which was called a four-course beacon or a radio range.

The distance at which the signals could be detected was limited, and the four-course beacons were replaced by VOR (very-high-frequency omnidirectional radio range), the beacons of which operated on an entirely different principle. At each beacon, one antenna sent out waves that had the same intensity in all directions. A second antenna rotated and sent out a narrow beam of waves that, when directed north, coincided in phase with those of the first antenna; that is, the peaks of the waves from the two antennas reached the receiver at the same instant. When the rotating beam pointed east, the two sets of waves were out of phase by 90° (one quarter of a wavelength); when the beam pointed south, the phase difference was 180°; and so on. A receiver in the aircraft measured the phase difference and displayed the bearing of the VOR beacon along with the heading of the aircraft.

VOR beacons

From the radio range, with its so-called beams, true beam systems have developed. In these the loops are replaced by improved antennas that concentrate the radio waves into narrow beams a few degrees wide; the dots and dashes are replaced by more sophisticated patterns or modulations. In the instrument landing system (ILS), used to help aircraft approach and land on an airfield, the two antennas transmit waves about three metres long. This wavelength, though shorter than those employed in earlier systems, necessitates antenna structures about 100 feet (30 metres) long on the ground. Such installations make it possible for suitably equipped aircraft to land in conditions of practically zero visibility. The beams point in almost the same direction, and, once the aircraft has entered the beams, a receiver can measure the angular displacement from the centre line and display this displacement on an instrument or use it to guide the aircraft along a line toward the point of landing. In addition to the steering beams, which make up the localizer element of the ILS, there are two similar but even narrower beams transmitted in the vertical plane that guide the aircraft down the correct slope toward the point of touchdown.

Instrument landing systems have been made highly reliable, but further development with wavelengths of a metre or more is limited by the interference resulting from reflections of these waves from hills, buildings, and other aircraft. Systems based on microwaves (about one centimetre in length) are less susceptible to such interference.

Distance measurement. The echo sounder, already mentioned, measures the time that elapses between the transmission of a sharp acoustic "ping" from the keel of a ship and the return of the echo from the sea bottom. A radar altimeter similarly measures the distance between an aircraft and the ground by timing the reflection of short pulses of radio waves. A more common form of radio altimeter, better suited for measuring rate of change of altitude, transmits waves continuously and derives the height from the phase difference between the transmitted signal and that reflected from the ground. An observed phase difference is, in fact, consistent with a large set of discrete altitudes, but in practice such radio altimeters are used in connection with instrument landing systems for measuring altitude and rate of descent during the last few seconds before touchdown. At this stage, the lowest altitude consistent with the observed phase difference is the correct one. When the aircraft reaches a height of about 65 feet (20 metres) the landing system initiates a programmed reduction in rate of descent to ensure a firm but safe touchdown.

In the usage of navigation, distance-measuring equipment (DME) denotes a specific system, defined by internationally accepted standards. Aircraft fitted with DME transmit radio pulses at one of 126 designated frequencies; arrival of these pulses at a DME beacon on the ground causes the beacon—after a 50-microsecond delay—to transmit responding pulses at another frequency. The time elapsing between the aircraft's transmission and its reception of the response is measured by a clock accurate to a few nanoseconds and converted into the distance, which is displayed in digital form. The position of the aircraft can be determined by combining the distance indicated by the DME with the direction from a VOR beacon at the same site as the DME beacon. Alternatively, position can be established by triangulation, using the distances between the aircraft and two well-separated DME beacons.

Position hyperbolas. If a gun at position M in Figure 6 were fired, a listener 1,100 feet (340 metres) away in any direction—that is, anywhere on the smallest circle centred at M—would hear the sound one second later; a listener 2,200 feet away, on the second circle, two seconds later;

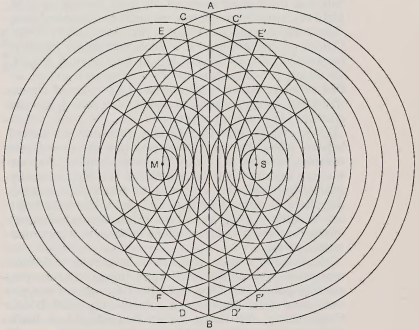


Figure 6: Hyperbolic position lines (see text).

and so on. If guns at M and S were fired simultaneously, a listener anywhere on AB, equidistant from M and S, would hear them at the same time. On a craft closer to one gun than the other, the sound of the nearer gun would be detected first. If gun M were heard one second before gun S, the craft would lie on CD, one of the two branches of a hyperbola; at a craft on *C′D′*, the other branch of the same hyperbola, gun S would be heard one second earlier than gun M. At a craft 2,200 feet closer to gun M, that gun would be heard two seconds before gun S, and the craft would lie on EF. Hence, by timing the interval to the nearest second, it is possible to find nearest which hyperbola the observer is located; knowledge of which gun was fired first makes it possible to choose between the two branches.

Signals from two sources

For navigation, the firing of guns is replaced by radio transmissions. A family of hyperbolas as shown in Figure 6 may be printed on a chart. A second family of hyperbolas, referring to a second pair of stations, can be printed on the same chart; the position of a craft is determined by the unique intersection of two curves. In radio systems, one of the two stations in a pair (the master) controls the other (the slave) to ensure accurate synchronization of the signals. In some systems, two or three slaves are distributed around a single master, and two or three families of hyperbolas are printed on the appropriate chart.

Loran

Systems of this kind are called loran, an acronym for long-range navigation.

Loran in its original form (now called loran A) was introduced during World War II; it operated at frequencies near two megahertz, but interference with and by other services and unreliable performance at night and over land led to its replacement by loran C. Loran C transmitters operate at the frequency of 100 kilohertz, and the signals are useful at distances of 1,800 nautical miles or more.

Decca, named for the British company that introduced it in 1946, is a hyperbolic system related to loran. Its master and slave transmitters broadcast different harmonics of a common frequency as continuous waves, rather than pulses. The hyperbolic position lines for any pair of transmitters are determined by the phase difference between the signals received, rather than the difference in arrival times of pulses. This arrangement provides a remarkably accurate and reliable system covering a range of 100–300 miles (160–480 kilometres) from the master station. Decca equipment is widely installed on ships and enjoys particular favour among fishermen, who can use it to return to specific shoals with great precision. Aircraft installations are less common than those of VOR/DME, the internationally accepted system for position finding. Decca is very well suited to navigation of helicopters, however, which usually operate at altitudes well below those at which VOR/DME is most effective.

Omega is a very-long-wave hyperbolic system that probably has the longest range of all radio navigation aids. Eight permanent transmitters, mutually synchronized, provide worldwide service. There is little redundancy in the Omega system, however; if a single transmitter becomes inoperative, a considerable gap in the coverage results. Its signals penetrate seawater to a substantial extent, so that submarines can receive them. Like those of Decca, transmissions are continuous, rather than pulsed, and are encoded to prevent ambiguities.

During World War II, Germany produced the Sonne beacon, which has been developed into the consol and consolan systems, in which the masters and slaves are so close together that the hyperbolas become practically straight lines radiating out from the centre. By changing the phase of transmissions of the slaves, the hyperbolas can be made to swing to and fro. Morse signals are superimposed so that a craft can tell its location in a particular lane or sector.

Decca covers a wide area and is inherently a flexible navigation system. Before Decca's invention, however, aviation policy had been committed to signpost navigation using VOR beacons and subsequently VOR/DME. Consequently, the Decca system was adapted to work with a computer that would make the area system work as if there were beacons placed anywhere the navigator wished. Thus Decca could work as a signpost or point navigation system.

The point navigation philosophy has since run into difficulties. As air traffic builds up, more and more routes are needed; thus more and more signposts must be set up. VOR/DME computers, however, have been developed so an aircraft can follow any track irrespective of the position of the VOR/DME. Thus the computer has restored to the point navigation system the flexibility originally possessed only by the area navigation system, a flexibility increasingly needed to ensure adequate separation between aircraft.

The computer has already become part of the inertial navigator; it is used also in automatic dead reckoning. Originally, analog computers were used in navigation systems, and calculations of a relatively simple nature involving inputs from various electrical sources were continuously performed. Today, digital computers are employed for performing the necessary calculations.

Use of the digital computer

The digital computer works so fast that for navigational purposes it can be considered virtually instantaneous and can therefore provide continuous information for control purposes. It has a memory to store information for use when needed. It is built from electronic modules that are mass-produced at low cost. It has only one disadvantage. Conversion of analog information into digital form is costly. Hence, although far superior to the analog computer, it is less economical whenever a large number of electrical signals must be combined in relatively simple ways without any need for memory. Such situations still apply to control systems in many craft.

(E.W.A./S.S.D.J./Ed.)

Satellites as navigation aids. Artificial satellites can be equipped to transmit electromagnetic radiation at precisely controlled times and frequencies. The frequencies are chosen to avoid interference with other services, to minimize attenuation or delay as the signals penetrate the ionosphere, and to minimize the power needed by the satellite for broadcasting the signals. The practical range of frequencies corresponds to wavelengths between 10 and 100 centimetres.

Transit satellites

During the early 1960s a series of satellites named Transit was launched by the U.S. Navy to provide a worldwide navigation system. These satellites circled the Earth about every 90 minutes, moving in polar orbits about 600 miles (1,000 kilometres) above the Earth's surface. They radiated continuous signals modulated to indicate departures from the nominal frequencies and orbits. A receiver on the surface or in a submarine could compare the frequency received with that known to be transmitted and identify its own location by measuring both the magnitude and the rate of change of the Doppler shift. The calculations, which were performed by a small digital computer, were accurate to about 180 yards (160 metres).

Movement of the user modifies the Doppler shift and introduces an error unless it is taken into account. An uncertainty of one metre per second (two knots) in the velocity of the user causes an uncertainty of one kilometre in the deduced position. Such an error is of no great consequence in the case of ships, but it disqualifies the Transit system for the navigation of aircraft.

A global position system suitable for aircraft navigation was initiated by the U.S. Air Force in 1978, when the first two of the series of NavStar satellites were launched. These move in circular orbits inclined at 63° to the equatorial plane at an altitude of about 12,500 miles (20,200 kilometres); their period is 12 hours. Eighteen of these satellites can provide continuous worldwide coverage adequate for determining latitude and longitude within about 10 metres and, in many places, altitude with the same accuracy. A system of 24 NavStar satellites would give worldwide three-dimensional coverage.

NavStar

The NavStar system does not depend on the Doppler effect. The satellites transmit their signals on a time schedule precisely controlled by atomic clocks. The receivers automatically select the three (or four, if possible) satellites most favourably located and relay their signals into a computer, which calculates the position of the receiver by solving three or four simultaneous algebraic equations. The variables in these equations are the desired two or three position coordinates and a time-dependent quantity. The system is related to the hyperbolic systems loran and Decca, but the hyperbolas (two-dimensional figures) are replaced by hyperboloids of revolution (three-dimensional) that are moving rapidly in relation to the Earth. The complexity of the calculations makes the use of a fast digital computer essential.

(S.S.D.J./Ed.)

Improved compasses. In the early days of aviation, it was soon learned that a liquid-filled mariner's compass could not operate satisfactorily in a rapidly accelerating and sharply turning aircraft. Spring-mounted bowls and cards of extremely small diameter alleviated the problem, but tilting still occurred, bringing the system frequently under the influence of the vertical component of the Earth's magnetic field and causing erroneous readings. The most important of such effects, called northerly turning error, caused the compass to indicate a greater or smaller angle than was actually being turned through. Other problems were the difficulty of obtaining stable magnetic conditions in the cockpit, with its array of metal and electrical equipment, and the need for the compass reading to be fed to other navigational aids. In the end, the direct-reading magnetic compass was reduced to a secondary role, its place being taken for most purposes by the gyromagnetic compass (see below).

Saturable-inductor compasses

The inductor compass. Whereas the pivoted-needle magnetic compass indicates direction by aligning itself with the horizontal component of the Earth's magnetic field, the inductor compass measures, in effect, the strength of this horizontal component and indicates the direction in which the strength is greatest. One such instrument, the saturable-inductor compass, makes use of magnetic materials that are easily saturated—that is, materials in which it is easy to build up the maximum number of lines of magnetic flow, or flux. The amount of flux through such a material depends on its orientation in the Earth's field, being greatest when it is aligned in the magnetic north–south direction. By means of suitable electronic circuitry, it is possible to determine the exact orientation of a bar of such material and thus indicate precisely the direction of magnetic north. Compasses of this type require no rotating parts. Several can be installed at various points aboard a craft and their outputs combined electronically.

The gyromagnetic compass. The errors that occur in aircraft and small, fast vessels during alterations of course or speed can be avoided by mounting the compass on a platform kept horizontal by a gyroscope. The directive element must be nonpendulous. The vertical pin supporting the compass needle can be pivoted at both ends, or an inductor element can be employed. In one such arrangement, a saturable inductor is mounted on a gyroscope, but this is not always convenient from the point of view of size and weight. (W.E.M./J.L.H.)

Complementary compasses

Another system has a means of comparison between the gyroscope heading and that of the magnetic element. The gyroscope maintains a specific directional line in space with a possible error caused by drift of two or three degrees in each half hour that the gyroscope is left free. The utility of this instrument may appear to be very limited, but it happens to complement the magnetic compass very well. By itself, neither is satisfactory as a directional reference, but a combination of the directional gyroscope with a magnetic compass gives the pilot complete and stable directional information. The magnetic compass is useful in an airplane only so long as the airplane continues on a straight course in smooth air. While the airplane is making banked turns, the magnetic compass may err by 90° or more. Therefore, if the pilot desires to change course by a definite number of degrees, the magnetic compass will be of little use. On the other hand, the directional gyroscope is not affected by banked turns or rough air. It accordingly gives a reliable and stable indication of the exact number of degrees of turn that the airplane makes. The relatively slow drift of the directional gyroscope from its heading may be corrected manually from time to time when the airplane is in level and straight flight.

(R.E.Gi./A.L.Ra./R.J.S./Ed.)

The gyrocompass. The gyrocompass is independent of the magnetic field of the Earth and depends upon the properties of the gyroscope and upon the rotation of the Earth.

The axis of a free gyroscope will describe a circle around the pole of the heavens. To convert it into a gyrocompass, a control must be introduced that, when the axis tilts, will operate to precess (turn) it toward the meridian. The case of the gyroscope is made pendulous, or a liquid is arranged to flow from side to side. Either will convert the path traced by the axis into an ellipse. By delaying the flow of the liquid or by making eccentric the point of action of the control, a damping factor is introduced that converts the ellipse into a spiral so that the gyrocompass finally settles pointing true north (see Figure 7).

(W.E.M./J.L.H.)

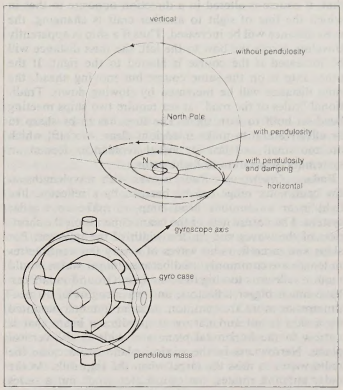


Figure 7: *Gyrocompass operation.*
Circular line shows the apparent motion of the axis of a gyroscope around the Pole Star in the absence of a pendulous mass. The addition of the pendulous mass (lower drawing) converts the circular motion into an ellipse; the ellipse can then be damped out and the gyroscope becomes a gyrocompass pointing to true north.

Instruments. The tactical management of a craft demands, for steering, continuous indication of heading and speed through the water or air and, for the propulsion system, information—either continuous or on demand—on engine speed, temperatures at critical regions, fuel flow, and fuel supply. In a modern aircraft, continuous monitoring by the crew of the numerous variables is impractical; instead, each instrument that indicates the value of a critical variable is designed so that any departure beyond specified limits is brought to the attention of the crew by warning lights, audible signals, or in the particular case of airspeed, "stick shake"; that is, artificially induced vibration of the control column in the event that indicated airspeed falls close to stalling speed.

Alarm systems

Rate of climb and, particularly, rate of descent must be indicated continuously because of their vital safety connotations. Rate of turn also is important in aircraft, and it is sometimes indicated in ships.

Airspeed is correctly indicated by the Pitot apparatus only if the air has the density typical at sea level at 15° C. Altitude has a major effect on air density, and temperature a minor one; in modern aircraft, indicated airspeed, altitude, and temperature are combined by a computer that indicates true airspeed and Mach number. Similarly, the independently operating compass, artificial horizon (an instrument that shows the degree of pitch and roll), and other instruments have been integrated into a so-called attitude and heading reference system.

The combination of daylight-visible optical displays with systems for storage and retrieval of digital data simplifies the design of aircraft cockpits and ship bridges by allowing the presentation of essential information on demand, relieving the navigator of the task of interpreting the readings of numerous separate indicators. (S.S.D.J./Ed.)

Collision avoidance. Figure 4 illustrates the calculation of an airplane's true ground velocity. A similar procedure can be used to calculate the course an airplane must avoid to prevent collision with another aircraft. In Figure 4 the wind is replaced by the course and speed of the other craft drawn in the opposite direction. What was track and ground speed in Figure 4 becomes the line of sight to the craft to be intercepted and the speed at which the two planes are approaching each other. If both planes maintain the speeds and directions indicated in Figure 4, a collision will occur.

Interception theory is based on a development of the way in which one animal hunts another. The predator runs toward its prey, and, as the prey tries to escape, the pursuer changes direction so that it is always running straight toward its target. Thus the hunter changes course at the same rate as its line of sight to its prey changes direction. Missiles that have to intercept ships or aircraft do a little better than this; they alter course faster than the direction of the line of sight changes, moving toward a predicted position rather than the present one.

Modern collision-avoidance theory depends on the fact

that, if course is altered in a direction opposite to that in which the line of sight to another craft is changing, the miss distance will be increased. Thus if a ship is apparently traveling across the bow to the left, the miss distance will be increased if the course is altered to the right. If the other ship is on the same course but moving ahead, the miss distance will be increased by slowing down. Traditional "rules of the road" at sea require two ships meeting head-on both to turn right. The turn has to be sharp to be effective and to make intentions clear. Aircraft, which are too small and fast for visual avoidance, depend on systematic separation of flight paths.

Radar. *Operation.* Radio waves with wavelengths in the centimetre range can be beamed by a reflector, like light in an automobile head lamp, to make up a radar system. The narrowness of the beam depends on the shortness of the waves and on the width of the reflector. For ships and aircraft, radio waves of a very few centimetres in length are commonly used because longer waves would require reflectors too big to be mobile. Ground radars can have much bigger reflectors, and wavelengths of 10 centimetres or more are common. A radar antenna mounted on a ship is tall and narrow to produce a beam that is narrow in the horizontal plane and wide in the vertical plane. Narrowness in the vertical plane could cause the radio waves to miss the target when the ship rolls. As the radar antenna rotates, the transmitter sends out a series of very short pulses every degree or so. When the pulse strikes an object, it is reflected back to the radar aerial and thence passed to the radar receiver. The pulse is displayed on a cathode-ray tube. Electronic lines are drawn from the centre outward, each starting as the pulse starts from the transmitter. When an echo returns, the image on the tube brightens. Thus a spot of light appears on the cathode-ray tube at a distance from the centre proportional to the time the pulse takes to go out and back and in a direction the same as that in which the pulse was transmitted. Hence, on the cathode-ray tube a faint ray of light rotates around the screen like a searchlight, following the rotation of the antenna, and paints in the positions of any reflecting objects as if they were on a map. The face of the cathode-ray tube is coated with a persistent phosphor—that is, one that continues to glow for several seconds after it is excited—thus allowing the viewer time to study and analyze the image.

Antenna shapes and sizes

The strength of the return signals will vary depending on the reflectivity of the surface of the reflecting object and on its distance. There will be little reflection from water unless it is very rough. From cliffs, ships at sea, and buildings, there will be strong reflections from the vertical surfaces. From the ground, there will be only scattered reflections, generally stronger in wooded country. Nevertheless, because the shortest radar waves are so much longer than light waves, the picture painted by radar shows little detail and requires careful interpretation.

Applications. The main use of radar is in avoiding collision. Using radar, the navigator of a ship can see other vessels irrespective of light conditions. It is therefore safe for a craft to proceed—though slowly—even in thick fog, whereas without radar it would be necessary to heave to or anchor. Since the radar picture is imperfect, collision avoidance requires great skill in interpretation. In particular, it is not easy to see the direction in which other vessels are traveling, and the navigator has to make particularly bold alterations of course to make certain that other navigators do not misinterpret them.

Use of radar to avoid collision

With radar, air traffic controllers can watch the progress of aircraft in a large area. As each one approaches and lands, one radar follows it in the vertical plane and another in the horizontal plane. If necessary, the aircraft can be "talked down" (told exactly how to land) by the radar operator on the ground.

Special systems. For military purposes, infrared waves may be used; these are midway in frequency between radio and light waves. An infrared detector can distinguish between objects of different temperatures and can identify a ship on the water or a man hidden in undergrowth. Infrared radiation needs only a very small transmitter or receiver and therefore has been used to guide small missiles launched from aircraft to strike at enemy planes. The detectors, however, are distracted by other sources of infrared radiation, including the Sun and the engines of friendly aircraft.

Use of infrared waves

Lasers can also be adapted to produce radar-like devices of extreme precision. In addition, there is increased interest in simple television cameras; when equipped with light intensifiers, they can "see" in almost total darkness. Finally, for underwater detection of either submarines or shoals of fish, sonar systems have been developed.

Automation. The computer has already been mentioned in connection with point and area navigation systems, the use of satellites, and the mixing of various aids with inertial navigators. Automation is needed because craft speeds are increasing to meet demands for quick delivery of passengers and cargo and to lower operating costs. A jet aircraft with a crew of fewer than 10 can carry more passengers across the Atlantic than an ocean liner with a crew of hundreds, because its greater speed enables it to make many more trips a year.

Automation can also reduce crew sizes by taking over tasks that machines can do more reliably and more consistently. On the other hand, because engineers must design machines years before they are used, they cannot foresee some situations that arise. The first landing of astronauts on the Moon involved events not anticipated by the designers of the landing module. Had a human crew not been in the spacecraft, it would have crashed. Therefore the human navigator will doubtless be required in many types of craft well into the foreseeable future. Although the machine can manipulate, it cannot manage except insofar as it is programmed.

The navigator, although increasingly a manager of systems, is required to undertake certain manipulative tasks because there is no substitute for human judgment in dealing with unexpected situations. (E.W.A.)

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Nebula

Nebula (Latin: "mist") is a term formerly used in astronomy to denote any object situated beyond the solar system that is seen as a bright or dark area, in contrast to the pointlike images of stars. This definition, adopted at a time when very distant objects could not be resolved into great detail, unfortunately includes two unrelated classes of objects: the extragalactic nebulae, now called galaxies, which are enormous collections of stars and gas; and the galactic nebulae, which are composed of the interstellar medium (the gas between the stars, with its accompanying small solid particles) within a single galaxy. Today the term nebula generally refers exclusively to the interstellar medium.

In a spiral galaxy the interstellar medium makes up 3 to 5 percent of the galaxy's mass, but within a spiral arm its mass fraction increases to about 20 percent. About 1 percent of the mass of the interstellar medium is in the form of "dust"—small, solid particles that are efficient in absorbing and scattering radiation. Much of the rest of the mass within a galaxy is concentrated in visible stars, but there are strong indications from the rotation of galaxies about their centres that there is also some form of dark matter accounting for a substantial fraction of the mass in the outer regions. This material might consist of dim stars or compact objects such as neutron stars or black holes.

The most conspicuous property of interstellar gas is its clumpy distribution on all size scales observed, from the size of the entire Milky Way Galaxy (about 10^{20} metres, or hundreds of thousands of light-years) down to the distance from the Earth to the Sun (less than 10^{11} metres, or a few light-minutes). The large-scale variations are seen by direct observation; the smallest are observed by fluctuations in the intensity of radio waves, similar to the "twinkling" of starlight caused by unsteadiness in the Earth's atmosphere. Various regions exhibit an enormous range of densities and temperatures. Within the Galaxy's spiral arms about half of the mass of the interstellar medium is concentrated in molecular clouds, in which hydrogen occurs in molecular form (H_2) and temperatures are as low as 10 kelvins. These clouds are inconspicuous optically and are detected principally by their carbon monoxide (CO) emissions in the millimetre wavelength range. Their densities in the regions studied by carbon monoxide emissions are typically 1,000 H_2 molecules per cubic centimetre. At the other extreme is the gas between the clouds with a temperature of 10 million kelvins and a density of only 0.001 H^+ ion per cubic centimetre. Such gas is produced by supernovas, the violent explosions of unstable stars.

This article surveys the basic varieties of galactic nebulae distinguished by astronomers and their chemical composition and physical properties. For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, sections 131 and 132, and the *Index*.

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CLASSES OF NEBULAE

All nebulae observed in the Galaxy are forms of interstellar matter—namely, the gas between the stars that is almost always accompanied by solid grains of cosmic dust. Their appearance differs widely, depending not only on the temperature and density of the material observed but also on how the material is spatially situated with respect to the observer. Their chemical composition, however, is fairly uniform; it corresponds to the composition of the universe in general in that approximately 90 percent of the constituent atoms are hydrogen and nearly all of the rest are helium, with oxygen, carbon, neon, nitrogen, and the other elements together making up about two atoms per thousand. Based on appearance, nebulae can be divided into two broad classes: dark nebulae and bright nebulae. Dark nebulae appear as irregularly shaped black patches in the sky and blot out the light of the stars lying beyond them. Bright nebulae appear as faintly luminous, glowing surfaces; they either emit their own light or reflect the light of nearby stars.

Two major classes

Dark nebulae are very dense and cold molecular clouds; they contain about half of all interstellar material. Typical densities range from hundreds to millions (or more) of hydrogen molecules per cubic centimetre. These clouds are the sites where new stars are formed through the gravitational collapse of some of their parts. Most of the remaining gas is in the diffuse interstellar medium, relatively inconspicuous because of its very low density (about 0.1 hydrogen atom per cubic centimetre) but detectable by its radio emission of the 21-centimetre line of neutral hydrogen.

Bright nebulae are comparatively dense clouds of gas within the diffuse interstellar medium. They have several subclasses: (1) reflection nebulae, (2) diffuse nebulae, (3) planetary nebulae, (4) supernova remnants, and (5) diffuse ionized gas.

Reflection nebulae reflect the light of a nearby star from their constituent dust grains. The gas of reflection nebulae is cold, and such objects would be seen as dark nebulae if it were not for the nearby light source.

Diffuse nebulae are clouds of hydrogen ionized (separated into positive H^+ ions and free electrons) by a neighbouring hot star. The star must be of stellar type O or B, the most massive and hottest of normal stars in the Galaxy, in order to produce enough of the radiation required to ionize the hydrogen.

Planetary nebulae are composed of the outer parts of stars that are dying but are not massive enough to become supernovas—namely, red giant stars. That is to say, a red giant has shed its outer envelope in a less violent event than a supernova explosion and has become an intensely hot star surrounded by a shell of material that is expanding at a speed of tens of kilometres per second. Planetary nebulae typically appear as rather round objects of relatively high surface brightness. Their name is derived from their superficial resemblance to planets—*i.e.*, their regular appearance when viewed telescopically as compared to the chaotic forms of other types of nebula.

Supernova remnants are the clouds of gas expanding at speeds of hundreds or even thousands of kilometres per second from comparatively recent explosions of massive stars. If a supernova remnant is younger than a few thou-

sand years, it may be assumed that the gas in the nebula was mostly ejected by the exploded star. Otherwise, the nebula would consist chiefly of interstellar gas that has been swept up by the expanding remnant of older objects.

Diffuse ionized gas

Diffuse ionized gas, so pervasive among the nebular clouds, has been recently recognized as a major component of the Galaxy. It is observed by faint emissions of H^+, N^+, and S^+ (positive hydrogen, nitrogen, and sulfur ions) detectable in all directions, collectively requiring far more power than the much more spectacular diffuse nebulae, planetary nebulae, or supernova remnants that occupy a tiny fraction of the volume. The origin of the diffuse ionized gas is still somewhat controversial (see below *Diffuse ionized gas*).

HISTORICAL SURVEY OF THE STUDY OF NEBULAE

Pre-20th-century observations of nebulae. In 1610, two years after the invention of the telescope, the Orion Nebula (see Plate 2), which looks like a star to the naked eye, was discovered by the French scholar and naturalist Nicolas-Claude Fabri de Peiresc. In 1656 Christiaan Huygens, the Dutch scholar and scientist, using his own greatly superior instruments, was the first to describe the bright inner region of the nebula and to determine that its inner star is not single but a compact quadruple system.

Early 18th-century observational astronomers gave high priority to comet seeking. A by-product of their search was the discovery of many bright nebulae. Several catalogs of special objects were compiled by comet researchers; by far the best known is that of the Frenchman Charles Messier who in 1781 compiled a catalog of 103 nebulous, or extended, objects in order to prevent their confusion with comets. Most are clusters of stars, 35 are galaxies, and 11 are nebulae. Even today many of these objects are commonly referred to by their Messier catalog number: M20, for instance, is the great Trifid Nebula, in the constellation Sagittarius.

The work of the Herschels. By far the greatest observers of the early and middle 19th century were the English astronomers William Herschel and his son John. Between 1786 and 1802 William Herschel, aided by his sister Caroline, compiled three catalogs totaling about 2,500 clusters, nebulae, and galaxies. John Herschel later added to the catalogs 1,700 other nebulous objects in the southern sky visible from the Cape Observatory in South Africa but not from London and 500 more objects in the northern sky visible from England.

The origin of NGC and IC numbers

The catalogs of the Herschels formed the basis for the great *New General Catalogue* (NGC) of J.L. Dreyer, published in 1888. It contains the location and a brief description of 7,840 nebulae, galaxies, and clusters. In 1895 and 1908 it was supplemented by two *Index Catalogues* (IC) of 5,386 additional objects. The list still included galaxies as well as true nebulae, for they were often at this time still indistinguishable. Most of the brighter galaxies are still identified by their NGC or IC numbers according to their listing in the *New General Catalogue* or *Index Catalogues*.

Advances brought by photography and spectroscopy. The advent of photography, which allows the recording of faint details invisible to the naked eye and provides a permanent record of the observation for study of fine details at leisure, caused a revolution in the understanding of nebulae. In 1880 the first photograph of the Orion Nebula was made, but really good ones were not obtained until 1883. These early photographs showed a wealth of detail extending out to distances unsuspected by visual observers.

Much can be learned about the physical nature of an astronomical object by studying its spectrum—*i.e.,* the resolution of its light into different wavelengths (or colours). Study of the spectrum of an object provides a decisive test as to whether it is composed of unresolved stars (as are galaxies) or glowing gas. Stars radiate at almost all wavelengths, with perhaps dark absorption lines superimposed, while hot, transparent gas clouds radiate only emission lines at certain wavelengths characteristic of their constituent gases. In 1864 observation of the spectrum of the Orion Nebula showed bright emission lines of glowing gases, with conspicuous hydrogen lines and some green lines even brighter. By contrast, the spectrum of galaxies was found to be stellar, so that a distinction between galaxies and nebulae—that nebulae are gaseous and galaxies are stellar—was appreciated at this time, although the true sizes and distances of galaxies were not demonstrated until the 20th century.

20th-century discoveries. The 20th century has witnessed enormous advances in observational techniques as well as scientific understanding of the physical processes that operate in interstellar matter.

Advances in instrumentation

In 1930 a German optical worker, Bernhard Schmidt, invented an extremely fast wide-angled camera ideal for photographing faint, extended nebulae. In addition, photographic plates became progressively more sensitive to an ever-widening range of colours. Since about 1960, however, photography has been almost completely replaced for research purposes by photoelectric devices. Most images are now recorded with so-called charge-coupled devices (or CCDs) that act as arrays of tiny photoelectric cells, each recording the light from a small patch of sky. Modern CCDs consist of square arrays of up to 4,000 cells on each side, or 16 million independent photocells, capable of observing the sky simultaneously. CCDs possess three advantages over photography: (1) their sensitivity to light is up to 100 times greater; (2) the range of light levels that they can record in one exposure is much greater, so that information about both the bright and faint parts of the same nebula can be obtained in a single exposure; and (3) they (or similar arrays) can record light ranging from 0.1 micrometre in the vacuum ultraviolet (accessible only from satellites orbiting above the Earth's atmosphere) to more than 1.2 micrometres in the infrared.

The most important recent development for the study of nebulae has been the use of spacecraft, which allows the observation of radiation normally absorbed by the Earth's atmosphere: X rays (which have very short wavelengths), far-ultraviolet radiation (with wavelengths shorter than about 0.3 micrometre, below which atmospheric ozone is strongly absorbing), and infrared (from about 3 micrometres to 1 millimetre) strongly absorbed by atmospheric water vapour and carbon dioxide. X rays and ultraviolet radiation reveal the physical conditions in the hottest regions in space (extending to some 100 million kelvins in shocked supernova gas). Infrared radiation reveals the conditions within dark, cold clouds, into which starlight cannot penetrate because of absorbing dust layers.

Principal means of studying nebulae

The primary means of studying nebulae is not by images but by spectra, by means of prisms (in the earlier part of the century), diffraction gratings, or crystals in the case of X rays. A particularly useful instrument is the echelle spectrograph, in which one coarsely ruled grating spreads the electromagnetic radiation in one direction, while another finely ruled grating disperses it in the perpendicular direction. This device, often used both in spacecraft and on the ground, allows astronomers to record simultaneously a wide range of wavelengths with very high spectral resolution (*i.e.,* to distinguish slightly differing wavelengths). For even higher spectral resolution astronomers employ Fabry-Pérot interferometers. Spectra provide powerful diagnostics of the physical conditions within nebulae. Images and spectra provided by Earth-orbiting satellites, especially the Hubble Space Telescope, have yielded data of unprecedented quality.

Ground-based observations also have played a major role in recent advances in scientific understanding of nebulae. The emission of gas in the radio and submillimetre ranges of wavelengths provides crucial information regarding the physical conditions and molecular composition of gas. Large radio telescope arrays, in which several individual telescopes function collectively as a single enormous instrument, give spatial resolutions in the radio regime vastly better than any yet achieved by optical means.

CHEMICAL COMPOSITION AND PHYSICAL PROPERTIES OF NEBULAE

Many characteristics of nebulae are determined by the physical state of their constituent hydrogen, by far the most abundant element. For historical reasons, nebulae in which hydrogen is mainly ionized (H^+) are called H II regions; those in which hydrogen is mainly neutral are

designated H I regions; and those in which the gas is in molecular form (H_2) are referred to as molecular clouds. The distinction is important because neutral hydrogen atoms are extremely efficient at absorbing ionizing radiation, with an energy per photon of at least 13.6 electron volts or, equivalently, a wavelength of 0.0912 micrometre or less. If the hydrogen is mainly neutral, no ionizing radiation can penetrate except for photons with energies in the X-ray range and above, or thousands of electron volts or more, in which case the hydrogen becomes somewhat transparent. For photon energies less than 13.6 volts, the radiation within an H I region has a spectrum similar to that of a fairly hot star (*i.e.*, about 15,000 K), since hot stars produce much more radiation than do cooler ones. However, the absorption by neutral hydrogen abruptly reduces the radiation field to almost zero for energies above 13.6 volts. This dearth of hydrogen-ionizing radiation within the H I region implies that no ions requiring more energy than hydrogen can be produced, and the ionic species of all elements are limited to the lower stages of ionization. Within H II regions, with almost all of the hydrogen ionized and thereby rendered nonabsorbing, photons of all energies propagate, and ions requiring energetic radiation for their production (*e.g.*, O^{++}) occur.

Ultraviolet photons of more than 11.2 volts can dissociate molecular hydrogen (H_2) into two H atoms. In H I regions there are enough of these photons to prevent the amount of H_2 from becoming large, but the destruction of H_2 as fast as it forms takes its toll on the number of photons of suitable energies. Furthermore, interstellar dust is a fairly efficient absorber of photons throughout the optical and ultraviolet range. In some regions of space the number of photons with energies higher than 11.2 volts is reduced to the level where H_2 cannot be destroyed as fast as it is produced on grain surfaces. In this case, H_2 becomes the dominant form of hydrogen present. The gas is then part of a molecular cloud. The role of interstellar dust in this process is crucial because H_2 cannot be formed efficiently in the gas phase.

Absorption of stellar radiation by interstellar dust

Interstellar dust. Only about 0.7 percent of the mass of the interstellar medium is in the form of solid grains, but these grains have a profound effect on the physical conditions within the gas. Their main effect is to absorb stellar radiation; for photons unable to ionize hydrogen and for wavelengths outside of absorption lines or bands, the dust grains are much more opaque than the gas. The dust absorption increases with photon energy, so that long-wavelength radiation (radio and far-infrared) can penetrate dust freely, near-infrared rather well, and ultraviolet relatively poorly. Dark, cold clouds, within which all star formation takes place, owe their existence to dust. Besides absorbing starlight, the dust acts to heat the gas under some conditions (by ejecting electrons produced by the photoelectric effect, following the absorption of a stellar photon) and to cool the gas under other conditions (because the dust can radiate energy more efficiently than the gas, and so in general is colder). The optical appearance of most nebulae is significantly modified by the obscurating effects of the dust.

The chemical composition of the gas phase of the interstellar medium alone, without regard to the solid dust, can be determined from the strength of narrow absorption lines in the spectra of background stars that are produced by the gas. Comparison of the composition of the gas with cosmic (solar) abundances shows that almost all of the iron, magnesium, and silicon, much of the carbon, and only some of the oxygen and nitrogen are contained in the dust. The absorption and scattering properties of the dust reveal that the solid grains are composed partially of silicaceous material similar to terrestrial rocks, though of an amorphous rather than crystalline variety; the grains also have a carbonaceous component. The carbon dust probably occurs in at least two forms: (1) graphitic grains, produced by the temporary heating of very small amorphous carbon particles after the absorption of a single photon of ultraviolet light, and (2) individual freely floating hydrocarbon molecules, with a range varying from 70 to several hundred carbon atoms and some hydrogen atoms that dangle from the outer edges of the molecule or are trapped in the middle of it. It is merely convention that these molecules are referred to as dust, since the smallest may be only somewhat larger than the largest molecules observed with a radio telescope. Both of the dust components are needed to explain spectroscopic features arising from the dust. In addition, there are probably mantles of hydrocarbon on the surfaces of the grains. The size of the grains ranges from perhaps as small as 0.0003 micrometre for the tiniest hydrocarbon molecules to a substantial fraction of a micrometre; there are many more small grains than large ones.

The dust cannot be formed directly from purely gaseous material at the low densities found even in comparatively dense interstellar clouds, which would be considered an excellent laboratory vacuum. For a solid to condense, the gas density must be high enough to allow a few atoms to collide and stick together long enough to radiate away their energy to cool and form a solid. Grains are known to form in the outer atmospheres of cool supergiant stars where the gas density is comparatively high (perhaps 10^9 times what it is in such nebulae). The grains are then blown out of the atmosphere by radiation pressure (the mechanical force of the light they absorb and scatter). Calculations indicate that refracting materials, such as the constituents of the grains proposed above, should condense in this way.

There is clear indication that the dust is heavily modified within the interstellar medium by interactions with itself and with the interstellar gas. The absorption and scattering properties of dust show that there are many more smaller grains in the diffuse interstellar medium than in dense clouds; apparently in the dense medium the small grains have coagulated into larger ones, thereby lowering the ability of the dust to absorb radiation with short wavelengths (namely, ultraviolet, near 0.1 micrometre). The gas-phase abundances of some elements, such as iron, magnesium, and nickel, also are much lower in the dense regions than in the diffuse gas, although even in the diffuse gas most of these elements are missing from the gas and are therefore condensed into dust. These systematic interactions of gas and dust show that dust grains collide with gas atoms much more rapidly than one would expect if the dust and gas simply drifted together. There must be disturbances, probably magnetic in nature, that keep the dust and gas moving with respect to each other.

Dark nebulae. The dark nebulae are clumps or clouds that become opaque because of their internal dust grains. The form of such dark clouds is very irregular: they have no clearly defined outer boundaries and sometimes take on convoluted serpentine shapes. The largest dark nebulae are visible to the naked eye, appearing as dark patches against the brighter background of the Milky Way. An example is the Coalsack in the southern sky.

Giant molecular clouds

The hydrogen of these opaque dark clouds exists in the form of H_2 molecules. The largest nebulae of this type, the so-called giant molecular clouds, are more than a million times as massive as the Sun. They contain much of the mass of the interstellar medium, are some 150 light-years across, and have an average density of 100 to 300 molecules per cubic centimetre and an internal temperature of only 7 to 15 K. Molecular clouds consist mainly of gas and dust but contain many stars as well. The cloud cores are completely hidden from view and would be undetectable except for the microwave emissions from their constituent molecules. This radiation is not absorbed by dust and readily escapes the cloud. The material within the clouds is clumped together in all sizes, with some clouds ranging down to the masses of individual stars. The density within the clumps may reach up to 10^5 H_2 per cubic centimetre or more. Small clumps may extend about one light-year across. The clouds have an internal magnetic field that provides support against their own gravity (see below).

As one penetrates into the interior of a molecular cloud, the chemistry and physical conditions become quite different from those of the surrounding low-density interstellar medium. In the outer parts of the dark cloud, the hydrogen is neutral. Deeper within it, as dust blocks out an increasing amount of stellar ultraviolet radiation, the cloud becomes darker and colder. As the centre is approached,

the predominant form of carbon changes successively from C^+ (on the outside) to neutral C to finally the molecule carbon monoxide (CO), which is so stable that it remains the major form of carbon in the gas phase in the darkest regions. At great depths within the cloud other molecules can be seen from their microwave transitions, and more than 70 chemical species have been identified within the constituent gas. Owing to the comparatively low densities and low temperatures, the chemistry is very exotic, as judged by terrestrial experiments; some rather unstable species can exist in space because there is not enough energy to convert them to more stable forms. An example is the near equality of the abundances of the interstellar molecule HNC (hydroisocyanic acid) and its isomer HCN (hydrocyanic acid); in ordinary terrestrial conditions there is plenty of energy to allow the nitrogen and carbon atoms in HNC to exchange positions and produce HCN, by far the preferred species for equilibrium chemistry. In the cold clouds, however, not enough energy exists for the exchange to occur. There is less than one-thousandth as much starlight within a cloud as in the interstellar space outside the cloud, and the heating of the material in the cloud is provided primarily by cosmic rays. Cooling within the cloud occurs chiefly by transitions between low-lying levels of the carbon monoxide molecule.

Recent observations of the emission lines from C^+, C^0, and CO show that the edges of the dark nebulae are very convoluted spatially, with stellar ultraviolet radiation able to penetrate surprisingly far throughout the cloud despite the absorption of the dust. Stellar radiation can apparently enter the cloud through channels where the dust (and gas) density is lower than average. The clumpiness of the interstellar material has profound effects on its properties.

Star formation

In the inner regions of dark nebulae important events take place: the formation of stars. The discussion that follows will be slightly oversimplified by the assumption that a nebula has very little net rotation. Since the density in a star is immensely greater than that in a nebula, star formation must occur through condensation. The force of gravity in the nebula constantly pulls it together, working against the disruptive collisions of any one nebula or cloud with its neighbours and against the pressure provided by an internal magnetic field. But, even if gravity can hold the cloud together against other forces, the cloud cannot collapse unless it can cool; gravitational energy is released in a contraction and would heat the gas cloud, thus increasing the outward pressure and preventing further collapse. The dust grains are efficient emitters of infrared radiation, which escapes, removing the energy from the nebula. A cloud, therefore, contracts under its own gravity, radiating away half of the gravitational energy of the contraction, the other half going into heating the gas. As it contracts, the density and gravitational binding increase until finally the cloud's gravity so dominates the internal pressure that the material rushes inward in almost a free fall.

While the entire cloud has been collapsing, it does not have a smooth density distribution but rather consists of a chaotic jumble of smaller clouds. These cloudlets pull themselves together by their own gravity into "protostars," each of which is destined to be an individual stellar system. Most of these protostars are smaller than one solar mass, but a very few may be several (up to about 100) times as massive as the Sun. These few massive stars have a profound influence in the evolution of the nebula.

Each protostar collapses very quickly; its gas falls inward in free fall. A protostar can collapse from a size equal to the outer diameter of the solar system to about 30 times the Sun's size (the size of Mercury's orbit) in about six months. After it reaches that size, the material becomes so hot it has become a star—that is, an opaque body radiating energy only from its surface. Around it is a whirling ring of cold, dusty material, which will also break up into even smaller fragments, the "protoplanets." It is now believed that planetary systems are made out of this dusty chaos.

Origin of planetary systems

Such newly formed stars continue to contract, becoming hotter but less luminous in the process, until they start to produce heat by converting hydrogen into helium rather than by contracting. If massive enough, a star ionizes the nebular material, producing a bright nebula around it.

These ideas are given encouraging confirmation by observations of dark nebulae in very long wavelength infrared radiation. Some of the brightest infrared sources are associated with such dark dust clouds; a good example is the class of T Tauri variables, named for their prototype star in the constellation Taurus. The T Tauri stars are known for a variety of reasons to be extremely young. The variables are always found in or near dark nebulae; they often are also powerful sources of infrared radiation, corresponding to warm clouds of dust heated by the T Tauri star to a few hundred kelvins. There are some strong infrared sources (especially in the constellation of Orion) that have no visible stars with them; these are presumably "cocoon stars" completely hidden by their veils of dust.

Neutral clouds (H I regions). Neutral hydrogen is dominant in clouds that have enough starlight to dissociate molecular hydrogen but lack hydrogen-ionizing photons from hot stars. These clouds can be seen as separate structures within the lower-density interstellar medium or else on the outer edges of the molecular clouds. Because a neutral cloud moves through space as a single entity, it often can be distinguished by the absorption line that its atoms or ions produce at their common radial velocity in the spectrum of a background star.

Neutral clouds have two possible temperatures (with little material at intermediate values), both determined by the balance of heating and cooling rates. Cold H I regions are at about 80 K; heating is provided by electrons ejected from the dust grains by interstellar ultraviolet radiation incident upon such a cloud from outside. Cooling is mainly by C^+ because passing electrons or hydrogen atoms can excite it from its normal energy state, the lowest, to one slightly higher, followed by emission of radiation at 158 micrometres. This line is observed to be very strong in the spectrum of the Galaxy as a whole, indicating that a great deal of energy is removed from interstellar gas by this process. Warm H I regions (about 8,000 K) are cooled by excitation of the $n = 2$ level of hydrogen, which is at a much higher energy than the lowest level of C^+ and therefore requires a higher temperature for its excitation. The density is much lower in the hotter regions, rendering the cooling by C^+ less efficient because it requires collisions for the excitation. At any particular density there is far more neutral hydrogen available for cooling than C^+. Clouds of either temperature can exist at the same pressure, so the interstellar medium separates itself into the two phases depending on the past history of each parcel of gas.

Reflection nebulae. If a cloud that would normally be a dark nebula happens to be illuminated by a nearby bright star not hot enough to ionize the cloud's hydrogen, the dust grains in the cloud reflect the starlight and give rise to a reflection nebula. The famous nebulosity in the Pleiades star cluster is of this type; it was discovered in 1912 that the spectrum of this nebula mimics the absorption lines of the nearby stars, whereas bright nebulae that emit their own light show characteristic emission lines quite unlike stars. The brightest reflection nebulae are illuminated by B-type stars that are very luminous but have temperatures lower than about 25,000 K, somewhat cooler than the O-type stars that would ionize the hydrogen in the gas and produce a diffuse emission nebula. The extent and brightness of reflection nebulae show conclusively that dust grains are excellent reflectors in the broad range of wavelengths extending from the ultraviolet (as determined from observations from space) through the visible. Optical observations suggest that about 60–70 percent of the light is reflected rather than absorbed, while the corresponding fraction for the whole Earth is only 35 percent and for the Moon a mere 5 percent. Grains reflect light almost as well as fresh snow, more because of their favourable size (which promotes scattering rather than absorption) than their chemical composition. Calculations show that even graphite, which is black in bulk, reflects visible light well when dispersed into small particles.

Illumination by B-type stars

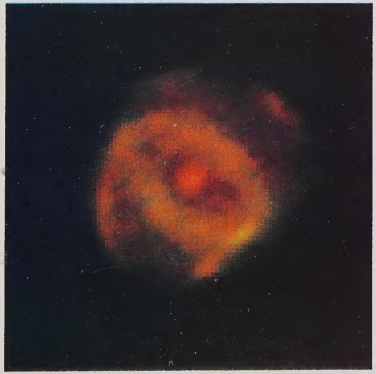
Diffuse nebulae (H II regions). As noted above, clouds of gas and dust that contain stars hot enough to ionize their hydrogen are called diffuse nebulae, or H II regions. In contrast to dark or reflection nebulae, their spectrum consists of emission lines at various wavelengths charac-



Veil Nebula (NGC 6992) in the constellation Cygnus. It glows as it collides with dust and gas in interstellar space. Blue light is emitted from the hot leading edge of the nebula, where the most energetic collisions occur; the red glow is from hydrogen in the cooler gas.



A small part of the Cygnus Loop supernova remnant, which marks the edge of an expanding blast wave from an enormous stellar explosion that occurred some 15,000 years ago. The remnant is located in the constellation Cygnus the Swan.



Planetary Nebula Hen 1357, as photographed by the Hubble Space Telescope. It is located about 18,000 light-years from Earth and lies in the constellation Ara the Altar. This expanding cloud of gas was expelled from an aging star in the nebula's centre.



Lagoon Nebula (M8, NGC 6523) in the constellation Sagittarius. This bright diffuse nebula is so large that light from the stars involved does not penetrate its boundaries, and the bright nebula appears to be seen against a larger darker one.

Plate 1: (top left, bottom right) Palomar Observatory; photograph, © California Institute of Technology (top left) 1969, (bottom right) 1961, (bottom left, top right) National Aeronautics and Space Administration



Crab Nebula (M1, NGC 1952) in the constellation Taurus, a gaseous remnant of the galactic supernova of AD 1054, 6,000 light-years away, expanding at 1,125 kilometres per second.



Ring Nebula (M57, NGC 6720) in the constellation Lyra, a planetary nebula consisting mainly of gases thrown off by the star in the centre.





(Above) The inner part of the 30 Doradus Nebula, the most luminous nebula in the entire Local Group of galaxies. It is located in the Large Magellanic Cloud.

(Left) Bright nebulosity in the Pleiades (M45, NGC 1432), distance 490 light-years. Cluster stars provide the light, and surrounding clouds of dust reflect and scatter the rays from the stars.



A star-forming region in the Orion Nebula (M42, NGC 1976). This composite image shows an area one light-year square near the edge of a cavity of ionized hydrogen heated by ultraviolet radiation from a star cluster at the nebula's centre.



A plume of gas (lower right) in the Orion Nebula. This highly supersonic shock wave—moving at a speed of more than 238,000 kilometres per hour—was produced by a beam of material emanating from a newly formed star.

Plate 2: (Top left, top right, centre left) California Institute of Technology/Palomar Observatory (top left, top right) 1959, (centre left) 1961, (centre right) National Optical Astronomy Observatories, (bottom left, bottom right) National Aeronautics and Space Administration.

teristic of their ions. Like dark clouds, diffuse nebulae typically have little regular structure or sharp boundaries—hence their name. Their sizes and masses vary widely. There is even a faint region of ionized gas around the Sun and other comparatively cool stars, but it cannot be observed from nearby stars with existing instruments. The largest diffuse nebulae (none of which occur in the Milky Way Galaxy) are 500 light-years across and contain at least 100,000 solar masses of ionized gas. These enormous H II regions are powered by clusters of massive hot stars rather than by any single stellar body. A typical diffuse nebula within the Galaxy measures about 30 light-years in diameter and has an average density of about 10 atoms per cubic centimetre. The mass of such a cloud amounts to several hundred solar masses. The only diffuse nebula visible to the naked eye is the beautiful Orion Nebula (see Plate 2). Located in the constellation named for the Greek mythological hunter, it is seen as the central "star" in Orion's sword. The entire constellation is enveloped in faint emission nebulosity, powered by several stars in Orion's belt rather than by the star exciting the much smaller Orion Nebula itself. The largest diffuse nebula in terms of angular size is the Gum Nebula, named after its discoverer, the Australian astronomer Colin S. Gum. It measures 40° in angular diameter and is mainly ionized by two very hot stars (Zeta Puppis and Gamma Velorum).

Largest known diffuse nebulae

The spectra of H II regions show bright emission lines arising from two fundamentally different processes. The first are recombination lines, which are produced when any ion combines with an electron to form a neutral atom (or lower stage of ionization), radiating away some or all of the energy it had from its previous ionization. All elements produce these lines, but the lines are bright only for recombination of the very abundant ions H^+ and He^+. The observed lines are produced when the newly formed atom is in an excited energy level and cascades from that level to a lower one with the emission of a line photon. One of the brightest lines in diffuse nebulae, for example, is the red Hα line of hydrogen, arising either from recombination of an H^+ ion to the $n = 3$ level of a hydrogen atom or from a recombination to a higher level followed by a cascade to the $n = 3$ level. A hydrogen atom in the $n = 3$ level can undergo a transition to the $n = 2$ level with the emission of the Hα photon.

Forbidden lines

The second are what are termed forbidden lines, which are produced by the excitation of an atom or ion from its lowest level to a higher level by a collision with an electron, followed by the emission of a photon from the higher level downward to a lower one (not necessarily the lowest). The name forbidden is appropriate because these emission lines are not observed directly in the laboratory; the downward transition that produces the photon requires a relatively long time to take place, and in the laboratory the excited atom encounters another particle or the container walls before it emits the photon. This encounter allows the excited atom to give up its energy to its collision partner without radiating a photon. In a diffuse nebula it has time to produce the radiation before it can collide with another atom or ion. The strongest lines in most diffuse nebulae are the forbidden lines from either O^{++} (at 4959 and 5007 angstroms) or from O^+ (at 3726 and 3729 angstroms). These lines provide very strong cooling above about 10,000 K and act to limit the temperatures of H II regions to approximately that value, unless the abundance of oxygen is significantly lower than solar abundance, in which case higher temperatures can be reached.

Diffuse nebulae are almost always accompanied by dark nebulae on their borders. The Orion Nebula, for example, is merely a conspicuous ionized region on the nearby face of a much larger dark cloud; the diffuse nebula is almost entirely produced by the ionization provided by a single hot star, one of the four bright central stars (the Trapezium) identified by Huygens in 1656. The shape of the Orion Nebula appears at visible wavelengths as irregular (see Plate 2). However, much of this seeming chaos is spurious, caused by obscuration of dust in foreground neutral material rather than by the actual distribution of ionized material. Radio waves can penetrate the dust unhindered, and the radio emission from the ionized gas reveals it to be quite circular in shape and surprisingly symmetrical as seen in projection on the sky. The foreground dark material obscures about half of the ionized nebula.

In most cases, a diffuse nebula is found on the outer edge of a large molecular cloud in which star formation is occurring, induced by the very presence of the diffuse nebula. For instance, behind the bright Orion Nebula, deeper within the dark, cold Orion molecular cloud, new stars are being formed today. At present, none of the new stars is massive and hot enough to produce its own diffuse nebula, but presumably one of them eventually will be. When a diffuse nebula is produced from cold molecular gas by the formation of a hot star, the temperature is raised from roughly 25 to 8,000 K, and the number of particles per cubic centimetre is almost quadrupled because each H_2 molecule is split into two ions and two electrons. Gas pressure is proportional to the product of the temperature and number of particles per cubic centimetre (regardless of their mass, so electrons are as important as the much heavier ions). Thus, the pressure in a diffuse nebula is some 800 times the pressure of the cold gas from which it formed. The excess pressure causes a violent expansion of the gas into the dense cloud. Rapid star formation may occur in the compressed region, producing an expanding group of young stars. Such groups, the so-called O Associations (with O stars) or T Associations (with T Tauri stars), have been observed. The component stars simultaneously generate extremely fast outflows from their atmospheres (see below). These winds create regions of hot, tenuous gas surrounding the association. Eventually the massive stars in the association explode as supernovas, which further disturb the surrounding gas.

Region of new star formation

This picture of the evolution of diffuse and dark nebulae is one of constant turmoil, a few transient O stars serving to keep the material stirred, in constant motion, continually producing new stars and churning clouds of gas and dust. In this way some of the stellar thermonuclear energy is converted into the kinetic energy of interstellar gas.

Recently "ultracompact" H II regions have been discovered inside the molecular clouds in which they were formed. These nebulae are observed only at the wavelengths of radio and far-infrared radiation, which are able to penetrate the thick dust in the clouds. They are extremely bright at wavelengths of 50 micrometres, and the most luminous ones were detected throughout the Galaxy by the orbiting Infrared Astronomical Satellite (IRAS), which in 1983 mapped almost the entire sky at 12, 25, 60, and 100 micrometres. There are about 2,500 of these objects in the Galaxy, representing 10 to 20 percent of the total O-type star population. Usually only a light-month in size, 100 times smaller than a typical diffuse nebula, they show densities in the ionized region of 10^5 hydrogen atoms per cubic centimetre. They cannot be at rest with respect to the surrounding gas; if they were, the immense pressure exerted by their dense, hot gas would cause a violent expansion. (Their lifetimes would be only about 3,000 years—exceedingly short on an astronomical time scale—and not nearly as many could be seen as the number observed by astronomers.) Rather, their gas is kept confined because they are moving through the surrounding cloud at speeds of about 10 kilometres per second, and what is observed is the cloud of freshly ionized gas ahead of them that has not yet had time to expand. The ultracompact diffuse nebulae leave behind a trail of ionized material that is not as bright as the confined gas ahead of them. This trail gradually fades as it recombines after the ionizing star has passed. The radio radiation is produced by the ionized gas, but the far-infrared radiation is emitted by the 5,000 solar masses of surrounding dust warmed by the luminosity of the embedded star.

Ultra-compact H II regions

High-resolution studies of diffuse nebulae reveal one of the surprises that make the study of astrophysics delightful. Instead of the smooth structure that might be expected of a gas, a delicate tracery of luminous filaments can be detected, down to the smallest scale that can be resolved. In the Orion Nebula this is about 10 times the diameter of the orbit of Pluto around the Sun. Even finer detail may exist, and there is evidence from spectra that much of the matter may be gathered into dense condensations,

Luminous filaments

or knots, the rest of the space being comparatively empty. The time it would take unrestrained gas to fill a vacuum between the visible filaments is only about 200 years, much less time than the age of the nebula. The nebular gas is presumably restrained from expansion by the pressure of tenuous material, which has a temperature of a few million kelvins. Its pressure, however, is comparable to that in the visible "warm" (8,000 K) gas of the diffuse nebula. Hence, the density of the hot material is several hundred times lower, which effectively prevents it from radiating. Moreover, the material is invisible except in low-energy X rays. The space throughout the plane of the Galaxy is largely filled with this hot component, mainly produced and heated from supernovas. In diffuse nebulae, it also arises from the "wind" blown off the atmospheres of the exciting stars at speeds of up to 3,000 kilometres per second. This stellar wind creates a large cavity or bubble in the denser, cooler gas originally surrounding such a star. In the interior of the bubble, the radially flowing stellar wind passes through a transition in which its radial motion is converted into heat. The hot gas then fills most of the cavity (perhaps 90 percent or more) and serves to separate the filaments of the warm, comparatively dense diffuse nebula. Within the condensations of visible plasma, there are neutral globules in which the gas is quite cold (about 100 K) and dense enough (typically, 10,000 atoms per cubic centimetre) to have about the same pressure as the hot and warm materials. In short, a diffuse nebula is much more complicated than its visual radiation would suggest.

The most energetic diffuse nebulae in the Galaxy are revealed only by radio telescope—they are so heavily obscured by dust that they are inconspicuous optically. These nebulae have over 100 times more ionizations per second than does the Orion Nebula, too many to be provided by a single star (unless there are stars more luminous than any known within the Galaxy). Indeed, very high resolution images of the most luminous nebulae show there are clumps of ionized gas—probably ionized by tight groupings of single stars—embedded in rather diffuse gas that emit most of the radio radiation. Similar objects, about 200 light-years in diameter, are formed in other galaxies; if they were located at the Orion Nebula, they would cover the entire constellation of Orion with brightly glowing gas.

Supergiant nebulae

These supergiant nebulae are more than 10 times as luminous as any in the Galaxy. The entire Local Group—the cluster of galaxies consisting of the Galaxy, the great spiral galaxy in Andromeda, the smaller spiral in Triangulum, and more than 20 other stellar assemblages—contains but one supergiant nebula: the object called 30 Doradus, in the Large Magellanic Cloud (see Plate 2). This nebula requires over 1,000 times more ionizations per second than the Orion Nebula. It contains a stellar cluster called R136, the source of most of the energy radiated by the nebula. This grouping consists of dozens of the most massive known stars of the Galaxy, all packed into a volume only a thousandth of a typical stellar spacing in size. How such a cluster could form, in either case, is a fascinating puzzle. There are other supergiant nebulae outside of the Local Group, some of which radiate 10 times the energy of 30 Doradus.

Location of diffuse and dark nebulae in the Galaxy. One of the remarkable features of diffuse and dark nebulae is their concentration in the spiral arms in the plane of the Galaxy. While there is no definite boundary to the arms, which have irregularities and bifurcations, the nebulae in other spiral galaxies are strung out along these narrow lanes and form a beautifully symmetric system when viewed from another galaxy. The nebulae are remarkably close to the galactic plane; most are within 300 light-years, only 1 percent of the Sun's distance from the centre. The details of the explanation of why the gas is largely confined to the spiral arms is beyond the scope of this article (see GALAXIES: *The Milky Way Galaxy: Major components*). Briefly, the higher density of the stars in the arms produces sufficient gravity to hold the gas to them.

The question may be asked: why doesn't the gas simply condense into stars and disappear? The present rate of star formation is about one solar mass per year in the entire Galaxy, which contains something like 2×10^9 solar masses of gas. Clearly, if the gas received no return of material from stars, it would be depleted in roughly 2×10^9 years, about one-fifth the present age of the Galaxy. Several processes by which gas is returned to the interstellar medium from stars have been observed. Possibly the most important is the ejection of planetary nebula shells, discussed below; other processes are ejection of material from massive O- and B-type normal stars or from cool M giants and supergiants. This rate of gas ejection is roughly equal to the rate of star formation, so that the mass of free gas is declining very slowly.

Processes by which gas is returned to the interstellar medium

This cycling of the gas through stars presumably has had one major effect: the chemical composition of the gas has been changed by the nuclear reactions inside the stars. There is excellent evidence that the Galaxy originally consisted of 77 percent hydrogen by mass and that almost all of the rest of the constituent matter was helium. All heavy elements have been produced inside stars by being subjected to the exceedingly high temperatures and densities in the central regions. Thus, most of the atoms and molecules on the Earth, as well as in human bodies, owe their very existence to processes that occur within stars.

Chemical composition of diffuse nebulae. The composition of diffuse nebulae can be estimated by relating the strengths of the emission lines found in their spectra to the numbers of atoms producing them. Great strides have been made in calculating the necessary atomic properties. The principal difficulties in determining the abundances of elements from nebular emission lines are (1) the estimation of the nebular temperature, which is necessary because line emission for a given abundance increases rapidly with increasing temperature, and (2) the estimation of the abundances of stages of ionization of the element, if these stages do not have any observable lines. There are at least two reliable indicators of nebular temperatures. The first uses the relative strengths of lines arising from two or more upper levels of ions of elements heavier than helium. The levels must be reasonably different in energy. The ratio of line strengths depends sensitively on the electron temperature. Unfortunately, there are not many such diagnostic line pairs. The most frequently available pair is that of doubly ionized oxygen. The line from the upper level, at a wavelength of 4363 angstroms, is very faint, often less than 1 percent of the strong green line at 5007 angstroms. If there are fluctuations of temperature within a nebula, this method estimates the temperature to be too high. The second method of determining nebular temperature is based on the strengths of emission lines of hydrogen in very high quantum states, such as the transition between the 110 and 109 levels. Because the higher levels are closely spaced, the transitions between two higher levels have low energies and correspondingly long wavelengths—six centimetres, in this case. This radio wavelength implies that the line can be observed through large amounts of dust. There is some action originating in nebulae to amplify the emission by means of a mechanism fundamental to the laser and maser—namely, stimulated emission. The strength of a radio line depends on the nebular temperature. If there are regions of various temperatures within a nebula, such radio lines, in contrast to the forbidden lines, give an estimate that is lower than the true average. The two methods of estimating nebular temperature yield gratifyingly similar results when they are applied to the same object. This fact indicates that temperature fluctuations within a nebula may not be a serious problem.

All abundant chemical elements have some stages of ionization that are associated with observable emission lines from which the abundance of a given ion can be determined after the temperature has been estimated in the manner discussed above. The primary interest, though, is in the total abundance of the element and not simply that of an individual stage of ionization. Ions that have no observable lines are accounted for by theoretical calculations. Elaborate computer calculations predict the ionization structure of gas ionized by a hot star; the temperature of the star is determined by matching the observed stages of ionization with the computer model. The

Use of computer models

calculations then provide predictions of the abundances of the invisible ions. The correction for unobserved stages is of little significance for some elements (oxygen) but absolutely crucial for others (argon and carbon). The final estimates for—in order of decreasing reliability—oxygen, sulfur, nitrogen, and neon abundances in diffuse nebulae are comparable in accuracy to determinations of stellar composition. Those for carbon and argon, however, are more problematic. The well-established abundances have uncertainties of about 30 percent. Such determinations apply only to the portions of the elements in the gas phase. Solids (dust grains) do not produce emission lines.

In the Orion Nebula, the abundances of elements other than hydrogen are (in atoms per million hydrogen atoms) as follows: helium, 80,000; oxygen, 400; carbon, 320; neon, 70; nitrogen, 50; sulfur, 12; and argon, 4. One of the most enigmatic results of the Orion investigations is that the oxygen abundance in the nebula is only about 0.6 that in the Sun. This finding is most unexpected because supernovas presumably have been adding oxygen to the interstellar gas ever since the Sun formed some five billion years ago. Grains are probably not responsible for the "missing" oxygen in the Orion Nebula because the inner part of the nebula seems to be free of dust. Furthermore, nitrogen and neon, both unlikely to be found in dust grains, also are deficient in Orion in exactly the same proportion as oxygen. One possibility is that there are chemical inhomogeneities within the Galaxy and that the Sun formed from material richer than average in heavy elements.

It is, in fact, clear that the Galaxy is not chemically homogeneous at the present time. Observations of radio recombination lines show that there is a gradient, or variation, in the temperature of nebulae throughout the Galaxy. This gradient almost surely implies a variation in the principal coolant, oxygen, and presumably in other heavy elements as well. The oxygen abundance is perhaps twice the solar value at one-third the Sun's distance from the galactic centre, and down to two-thirds of the solar abundance at the most distant points for which reliable determinations can be made (about 1.5 times the Sun's distance, or 45,000 light-years). These differences in heavy-element content reflect varying amounts of nucleosynthesis by massive stars. Similar gradients are found in other galaxies.

Determining the compositions of nebulae outside the Galaxy

The composition of nebulae in other galaxies can be determined by direct optical observations of emission lines. This method is not practical throughout the Milky Way because of the obscuration of dust. The Large Magellanic Cloud has compositions that are uniformly about one-half those of the Orion Nebula for oxygen, neon, argon, and sulfur and are one-quarter those of Orion for carbon and nitrogen. It appears that the first group of elements must be manufactured together, presumably in massive stars, and ejected together into the interstellar gas that is currently observable. Stars of a different mass (probably lower) must produce carbon and nitrogen. Planetary nebulae (discussed below) also suggest the same scenario.

The abundance of helium in nebulae has received considerable attention because the helium content of the oldest objects provides clues to the origin of the universe. The value cited above for the Orion Nebula is in agreement with the predictions of the big-bang model, the prevailing cosmological theory according to which the universe began with an enormous explosion involving rapid expansion from a highly compressed primordial state. In order to determine the precise nature of this so-called big bang, a more precise estimate of helium abundance is needed than can be presently derived from nebulae.

Planetary nebulae. There are about 20,000 objects called planetary nebulae in the Galaxy, each representing gas expelled relatively recently from a central star very late in its evolution. By contrast, diffuse and dark nebulae are clouds of gas from which young stars form. Because of the obscuration of dust in the Galaxy, only about 1,500 planetary nebulae have been catalogued.

Forms and structure. Compared to the diffuse nebulae, planetary nebulae are small objects, having a radius, typically, of one light-year and containing a mass of gas equivalent to about 0.3 solar mass. One of the largest known planetary nebulae, the Helix Nebula (NGC 7293) in the constellation Aquarius, subtends an angle of about 20′ of arc—two-thirds the angular size of the full Moon.

Density of planetary nebulae

Planetary nebulae are considerably denser than most diffuse nebulae, typically containing 1,000–10,000 atoms per cubic centimetre within their dense regions, and have a surface brightness 1,000 times as large. Many are so far away that they appear stellar when photographed directly, but the conspicuous examples have an angular size up to 20′ of arc across, 10″–30″ being usual. Those that show a bright disk have much more regular forms than the chaotic diffuse nebulae, but there are still usually some brightness fluctuations over the disk. The planetaries generally have regular, sharp outer boundaries; often they have a relatively regular inner boundary as well, giving them an appearance like a ring. Many have two lobes of bright material, resembling arcs of a circle, connected by a bridge—somewhat resembling the letter Z.

Most planetaries show a central star, called the nucleus, which provides the ultraviolet radiation required for ionizing the gas in the ring or shell surrounding it. Those stars are among the hottest known and are in a state of comparatively rapid evolution.

As with diffuse nebulae, the overall structural regularity conceals large-scale fluctuations in density. High-resolution photographs of a planetary nebula usually reveal tiny knots and filaments down to the resolution limit of the photograph. The spectrum of the planetary nebula is basically the same as that of the diffuse nebula; it contains bright lines from hydrogen and helium recombinations and the forbidden lines (defined above) of other ions. In general, the spectra of planetaries differ from those of diffuse nebulae in that they show much higher degrees of ionization. In some planetaries most of the helium is doubly ionized, and appreciable amounts of five-times-ionized oxygen and argon and four-times-ionized neon exist. In diffuse nebulae helium is mainly once ionized and neon and argon only once or twice. This difference in the states of the atoms results from the temperature of the planetary nucleus (up to about 150,000 K), which is much higher than that of the exciting star of the diffuse nebula (less than 60,000 K for an O star, the hottest). One of the conspicuous features of planetaries is that the high stages of ionization are found close to the central star. The rare heavy ions, rather than hydrogen, absorb the photons of several hundred volts' energy. Beyond a certain distance from the central star, all the photons of energy sufficient to ionize a given species of ion have been absorbed, and that species therefore cannot exist farther out. Detailed theoretical calculations have rather successfully predicted the spectra of the best-observed nebulae.

The spectra of planetary nebulae reveal another interesting fact: they are expanding from the central star at 24 to 56 kilometres per second. The gravitational pull of the star is quite small at the distance of the shell from the star, so the shell will continue its expansion until it finally merges with the interstellar gas around it. The expansion is proportional to the distance from the central star, consistent with the entire mass of gas having been ejected at one brief period from the star in some sort of instability.

The distances of planetary nebulae. Not a single planetary nebula is close enough to the Sun to allow a direct determination of its distance; the nearest, reasonably bright one (Helix Nebula) is about 300 light-years away. It is necessary, therefore, to use indirect methods to find the distances. One method is to assume a nebular mass, estimate the true rate of emission of one of the hydrogen lines from the nebula (from the gas density and temperature), and compare this with the observed brightness. From the intrinsic and apparent brightness the distance can be found. One planetary, NGC 246, has a normal G star as a companion, whose distance can be estimated if it is similar in intrinsic brightness to nearby G stars of similar type. Once the distance is known, other quantities (such as size and mass) can easily be determined. Unfortunately, different methods of estimating distances give results differing by factors of more than two. A more reliable way of estimating distance is to consider the planetaries found in the

Reliance on indirect methods of determining distance to planetary nebulae

nearest external galaxies, such as the Andromeda Galaxy or the Magellanic Clouds. The distances to the galaxies are known from their other stars, such as the Cepheid variables. Even the most luminous planetary nebulae are very faint in other galaxies, and so only the few brightest and atypically massive nebulae can be studied.

From the best available average distance determination, the true size of any nebula can be found, within the limits of error, from its angular size; typically, planetary nebulae are found to be a few tenths of a light-year in radius. If this distance is divided by the expansion speed, the age of the nebula since ejection is obtained, with values up to roughly 30,000 years. After this time, the expanding gas becomes indistinguishable from the interstellar medium.

Chemical composition. The chemical composition of planetaries can be found from their spectra in the way discussed above for diffuse nebulae. Planetary nebulae definitely show signs of chemical enrichment from elements produced by nuclear processing within the central star. Some are carbon-rich, with twice as much carbon as oxygen, while the opposite is true for the Sun. Others are overabundant in nitrogen; the most luminous ones, observed in external galaxies, are conspicuous examples. Helium is modestly enhanced, up to a factor of two over the solar value. There is one object that contains almost no hydrogen; it is as if the gas had been ejected from the object at the very end of the nuclear-burning process. Planetary nebulae also show a clear indication of the general heavy-element abundance gradient in the Galaxy, presumably a reflection of the original composition of the stars that gave rise to the present nebulae.

Presence of cosmic dust

Some, but not all, planetary nebulae contain internal dust. In general, this dust cannot be seen directly but can be detected from the infrared radiation it emits after being heated by nebular and stellar radiation. The presence of dust implies that planetary nebulae are even richer in heavy elements than gas-phase abundance studies suggest.

Among nebulae so far discovered, two are particularly deviant in chemical composition: one is in the globular cluster M15 and the other in the halo (tenuous outer regions) of the Galaxy. Both have very low heavy-element content (down from normal by factors of about 50) but normal helium. Both objects are very old, suggesting that the primeval gas in the Galaxy had a low heavy-element content but an almost normal amount of helium. The origin of helium in the Galaxy was probably the initial explosion of the universe itself.

Positions in the Galaxy. One of the best indicators of the average age of astronomical objects is their position and motion in the Galaxy. The youngest are in the spiral arms, near the gas from which they have formed; the oldest are not concentrated in the plane of the Galaxy, nor are they found within the spiral arms. By these criteria, the planetaries reveal themselves to be rather middle-aged; they are moderately but not strongly concentrated in the plane; rather, they are concentrated toward the galactic centre, as the older objects are. Their motions in the Galaxy follow elliptical paths, whereas circular orbits are characteristic of younger stars. They belong to the type of distribution often called a "disk population," to distinguish them from the Population II (very old) and Population I (young) objects proposed by the German-American astronomer Walter Baade. It is likely that there is a wide variation in the ages of planetaries and that some are very young objects.

Evolution of planetary nebulae. A description of the evolution of a planetary nebula begins before the ejection of the nebula itself. As will be discussed below, the central star is a red giant before the ejection. In such a phase it experiences a rapid loss of mass, up to 0.01 Earth mass per day, in the form of a comparatively slowly expanding stellar wind. At this stage the red giant might be heavily obscured by dust, which forms from the heavy elements in the wind. Eventually the nature of both the star and its wind changes. The star becomes hotter because its hot core is exposed by the loss of the overlying atmosphere. The inner gas is ionized by radiation from the hot star. The ionization zone moves steadily outward through the slowly moving material of what was formerly the stellar wind. The expansion speed of the gas is typically 30 kilometres per second. Nebulae in this stage are bright but have starlike images as seen from the Earth, because they are too small to show a disk. The gas is at a relatively high density—about one million atoms per cubic centimetre—but becomes more dilute as the gas expands. During this stage the nebula is surrounded by neutral hydrogen. It appears to expand faster than the individual atoms of gas in it are moving; the ionized shell is "eating into" the neutral material as the density falls.

Red giant as the central star

The middle stage of evolution occurs when the density has dropped to the point at which the entire mass of gas is ionized. After this stage is reached, some of the ultraviolet radiation escapes into space, and the expansion of the nebula is caused entirely by the motion of the gas. Most planetaries are now in this middle stage. Finally the central star becomes less luminous and can no longer provide enough ultraviolet radiation to keep even the dilute nebula ionized. Once again the outer regions of the nebula become neutral and therefore invisible. Eventually the gas is mingled with the general interstellar gas.

Faint outer rings

A curious feature of several planetaries is that faint rings surrounding the bright, inner nebula can be observed. Possibly the outer rings are the remnants of a previous shell ejected earlier by the star. Alternately, they might be at the outer edge of the expanding neutral (and invisible) gas, which is ramming into quiescent interstellar gas originally present when the planetary ejection occurred. There would be a strong shock wave at this interface, and the shocked matter would be heated to several thousand kelvins, causing the emission. The matter would quickly radiate its heat and become cold and invisible again. The key to the choice of those alternatives would be the spectrum of the faint ring, if it could be determined.

The central stars. The central stars are known from their spectra to be very hot. A common type of spectrum has very broad emission lines of carbon or nitrogen, as well as of ionized helium, superimposed upon a bluish continuum. These spectra are indistinguishable from those from the very bright rare stars known as Wolf-Rayet stars, but the planetary nuclei are about 100 times fainter than true Wolf-Rayet objects. The stars appear to be losing some mass at the present time, though evidently not enough to contribute appreciably to the shell.

The presence of the nebula allows a fairly precise determination of the central star's evolution. The temperature of the star can be estimated from the nebula from the amounts of emission of ionized helium and hydrogen by a method devised by the Dutch astronomer H. Zanstra. The amount of ionized-helium radiation is determined by the number of photons of more than 54 volts' energy, while hydrogen is ionized by photons in excess of 13.6 volts. The relative numbers of photons in the two groups depend strongly on temperature, since the spectrum shifts dramatically to higher energies as the temperature of the star increases. Hence, the temperature can be found from the observed strengths of the hydrogen and helium lines. The rate of evolution of the stars can be determined from the sizes of their nebulae, as the time since ejection of the shell is the radius of the nebula divided by the expansion rate. The energy output, or luminosity, of the central star can be estimated from the brightness of the nebula, because the nebula is converting the star's invisible ultraviolet radiation (which contains the greater part of the star's luminous energy) into visible radiation.

The resulting theoretical description of the star's evolution is quite interesting. While there seem to be real differences in stars at a given stage, the trends are quite clear. The central stars in the youngest planetary nebulae are about as hot as the massive O and B stars—35,000–40,000 K—but roughly 10 times fainter. They have half the diameter of the Sun but are 1,000 times as luminous. As the nebula expands, the star increases its brightness and temperature, but its radius decreases steadily. It reaches a maximum energy output, when it is roughly 10,000 times as luminous as the Sun, about 5,000 years after the initial expansion. This is an amazingly small fraction of the star's age of several times 10^9 years; it represents a period equivalent to about half an hour in a human life. From

this point on the star becomes fainter, but for some time the temperature continues to increase while the shrinkage of the star continues. At its hottest the star is perhaps 200,000 K, almost five times hotter than the hottest of most of the stars. It then cools and after about 10,000 years becomes a very dense white dwarf star, scarcely larger than the Earth but with a density of thousands of kilograms per cubic centimetre. From this point it cools very slowly, becoming redder and fainter indefinitely.

Final stages of central star's evolution

While there is not yet a very detailed theoretical picture of this contraction, a few results have emerged rather clearly: (1) white dwarf stars must obtain nearly all of their energy from the contraction noted above, not from nuclear sources; therefore, (2) they must contain practically no hydrogen or helium, except perhaps in a very thin shell on their surfaces. These conditions would have to be met for the evolution to take place so quickly.

The absence of hydrogen in the star's interior is quite surprising; the planetary nebulae are all found to have a normal hydrogen abundance of about 1,000 times as many hydrogen atoms as heavy elements, such as oxygen. Thus, the mechanism of expulsion of the envelope must be very efficient at ejecting the hydrogen-rich outer layers of a star while leaving heavy-element-rich material behind.

The nature of the progenitor stars. The progenitor must have mass not much in excess of a solar mass because of the distribution of the planetaries in the Galaxy. Very massive stars are young and more closely confined than are nebulae to the galactic plane. Also, the mass of the nebula is roughly 0.3 solar mass, and the mass of a typical white dwarf (the final state of the central star) is roughly 0.7 solar mass. Next, the expansion velocity of the nebula is probably comparable with the velocity of escape from its progenitor, which implies that the progenitor was a red giant star, large and cool, completely unlike the small, hot, blue, nuclear star remaining after the ejection. Likely candidates are members of the class of long-period variable stars, which have about the right size and mass and are known to be unstable. Symbiotic stars (*i.e.,* stars with characteristics of both cool giants and very hot stars) also are candidates. Novas, stars that brighten temporarily while ejecting a shell explosively, are definitely not candidates; the nova shell is expanding at hundreds of kilometres per second.

The cause of the ejection is the outward force of radiation on the outer layers of red giant stars. The ejection is triggered by a rapid variation in the nuclear luminosity in the interior of the giant, caused by instability in the helium-burning shell. The ejection takes place during more than one phase of the giant's evolution. Nitrogen-rich nebulae develop during an early episode when convection inside the star carries nitrogen, produced from carbon in a series of nuclear reactions (*i.e.,* the carbon-nitrogen cycle of hydrogen burning), to the surface. A later ejection takes place with an enrichment of both nitrogen and helium, which also is produced by hydrogen burning. A still later phase occurs when convection carries carbon, the product of helium burning, to the surface.

Supernova remnants. The supernova phenomenon is a spectacular explosion in which a star ejects most of its mass in a violently expanding cloud of debris that soon becomes a nebula. At the brightest phase of the explosion, the expanding cloud radiates as much energy in a single day as the Sun has done in the past three million years. Such explosions occur roughly every 50 years within a large galaxy. They have been observed less frequently in the Milky Way Galaxy because most of them have been hidden by the obscuring clouds of dust. Galactic supernovas were observed in 1006 in Lupus, in 1054 in Taurus, in 1572 in Cassiopeia (Tycho's nova, named after Tycho Brahe, its observer), and finally in 1604 in Serpens, called Kepler's nova. The stars became bright enough to be visible in the daytime. The only naked-eye supernova to occur since 1604 was Supernova 1987A in the Large Magellanic Cloud (the galaxy nearest to the Milky Way system), but it was visible only from the Southern Hemisphere. On Feb. 23, 1987, a blue supergiant star brightened to gradually become third magnitude, easily visible at night, and has subsequently been followed in every wavelength band available to scientists. The spectrum showed hydrogen lines expanding at 12,000 kilometres per second, followed by a long period of slow decline that is expected to continue for years.

Known galactic supernovas

Supernova remnants evolve through four stages as they expand. At first, they expand so violently that they simply sweep all older interstellar material before them, acting as if they were expanding into a vacuum. The shocked gas, heated to millions of kelvins by the explosion, does not radiate its energy very well and is readily visible only in X-ray emissions. This stage typically lasts several hundred years, after which time the shell has a radius of about 10 light-years. As the expansion occurs, little energy is lost but the temperature falls because the same energy is spread into an ever-larger volume. The lower temperature favours more emission, and during the second phase the supernova remnant radiates its energy at the outermost, coolest layers. This phase can last thousands of years. The third stage occurs after the shell has swept up a mass of interstellar material that is comparable to or greater than its own; the expansion is then slowed substantially. The dense material, mostly interstellar at its outer edge, radiates away its remaining energy for hundreds of thousands of years. The final phase is reached when the pressure within the supernova remnant becomes comparable to the pressure of the interstellar medium outside the remnant, so that the remnant loses its distinct identity. In the later stages of expansion, the magnetic field of the galaxy is important in determining the motions of the weakly expanding gas. Even after the bulk of the material has merged with the local interstellar medium there might be regions of very hot gas remaining from the supernova explosion that produce soft X rays (*i.e.,* those of a few hundred volts) observable locally and also confine the clumps of the diffuse ionized gas and diffuse nebulae.

The recent galactic supernovas observed are in the first phases of the evolution suggested above. At the sites of Kepler's and Tycho's novas, there exist heavy obscuring clouds, and the optical objects remaining are now inconspicuous knots of glowing gas. Near Tycho's nova, in Cassiopeia, there are similar optically insignificant wisps that appear to be remnants of yet another supernova explosion. To a radio telescope, however, the situation is spectacularly different: the Cassiopeia remnant is the strongest radio source in the entire sky. Study of this remnant, called Cassiopeia A, reveals that a supernova explosion occurred there in approximately 1680, missed by observers because of the obscuring dust.

Strongest source of radio waves

The Crab Nebula. At the site of the 1054 supernova is one of the most remarkable objects in the sky, the Crab Nebula. Photographed in colour (Plate 2), it is revealed as a beautiful red, lacy network of long and sinuous, glowing hydrogen filaments surrounding a bluish, structureless region whose light is strongly polarized. The filaments emit the spectrum characteristic of a diffuse nebula. The gas is expanding at 1,100 kilometres per second—but still slower than the 6,400 kilometres per second in the shells of new supernovas in other galaxies. The bluish, amorphous inner region of the Crab Nebula is even more remarkable. The glow is produced by the so-called synchrotron radiation—*i.e.,* from electrons spiraling about a magnetic field at almost the speed of light. This radiation is dramatically different from what it would be if it were emitted from electrons moving at low speeds: it becomes (1) strongly concentrated in the forward direction, (2) spread out over a broad range of frequencies but with the average frequency increasing with the electron's energy, and (3) highly polarized. Electrons of many different energies produce radiation in a large range of wavelengths: radio, infrared, optical, and ultraviolet. Even X rays are emitted copiously by the Crab, which is the second-brightest X-ray source in the sky after Scorpius X-1 (an X-ray binary star), indicating that the electrons must have energies in the cosmic-ray range. After almost 1,000 years, the nebula is still losing 100,000 times as much energy per second as the Sun.

On the basis of this huge outpouring of energy, it is easy to calculate how long the nebula can shine without a new supply of energy. The electrons emitting the X rays should decay, or drop to lower energies, in about 30 years—

Source of energy for the Crab Nebula

far less than the age of the nebula. The source of energy within the Crab Nebula supplying energy to the electrons that emit the X rays was discovered in 1969 to be a pulsar designated NP 0532, the remains of the stellar body that exploded to form the nebula.

In the case of the Crab Nebula, the pulsar has been found to flash optically as well as at radio wavelengths, blinking on and off with the same period, owing to its rotation: 0.033099324 second (on June 28, 1969). This period is slowly increasing (at the rate of 0.0012 second per century), which implies the pulsar is slowing down and thereby losing its energy to the nebula. The corresponding rate of energy loss is about equal to the nebula's rate of energy loss, convincing evidence that a tiny, extremely dense pulsar can supply the energy to the nebula, which is about four light-years across.

The Crab Nebula is unique in being a young supernova remnant and relatively free from obscuration, while Tycho's and Kepler's supernovas are conspicuous radio sources, apparently radiating by synchrotron emission; in neither case has a detectable pulsar been found. The failure to detect pulsars at the sites of Kepler's and Tycho's novas, or Cassiopeia A, does not mean that they are not there; the radiation from the pulsar is probably strongly beamed, and the Earth may not be located in the direction to which the pulsars are sending their energy.

The Crab Nebula is still in a stage of violent expansion. The gas will continue to expand and the pulsar lose energy until the nebula enters a second stage: one in which the pulsar can no longer put much energy into the nebula, and the nebula expands like a hot bubble of gas into the cold surrounding interstellar gas. As the hot gas rams into the cold much faster than the speed of sound, a strong shock wave results. The cold gas is heated to several million kelvins as it is hit by the shock wave and then cools by radiating forbidden and recombination lines. Almost all the mass inside the shocked "bubble" will consist of this material swept up by the expanding shock wave.

The Cygnus Loop. As a general mechanism this picture seems well corroborated. The best-observed old supernova remnant is the Cygnus Loop (or the Veil Nebula; see Plate 1), a beautiful, filamentary object roughly in the form of a circular arc in Cygnus. Its patchiness is striking: the loop consists of a series of wisps rather than a continuous cloud of gas. The most likely interpretation of this patchiness is that the interstellar medium into which the shock wave is propagating contains small clouds of denser material; many lines of reasoning from other evidence lead to the same result. The present speed of the filaments is about 100 kilometres per second; the approximate age of the Cygnus Loop is 50,000 years.

Other supernova remnants. Many other such old supernova remnants in the Galaxy are recognized, because they are also sources of radio emission from synchrotron radiation. Optically, in general, they show a wispy appearance similar to that of the Cygnus Loop.

Supernova remnants modify the interstellar medium in two important ways: (1) They leave behind the elements that have been made in the presupernova star by a long process of heating and thermonuclear processing. Some very heavy elements are made in the extremely high temperatures right after the explosion. These elements are ejected into the supernova nebula and are finally merged with the interstellar medium. In this way the heavy-element content of the interstellar medium is increased. There is observational confirmation of this; both the Crab Nebula and the remnant of Tycho's supernova seem heavy-element rich. (2) Supernova remnants provide kinetic energy to the surrounding gas by their violent expansion, heating and accelerating the interstellar gas clouds.

Source of cosmic rays

In addition, they provide large quantities of very high energy cosmic rays by accelerating them in the expanding shock wave. These cosmic rays, as well as the X rays emitted by the remnant, heat the interstellar gas. Some supernovas explode within the hot phase of the interstellar medium that has remained from previous supernovas and from stellar winds. In this case, the violently expanding shock reheats the tenuous gas that fills most of the volume of space in a galaxy but makes up very little of its mass. Thus, supernovas serve to maintain a hot component of gas, which is revealed only in X rays.

Diffuse ionized gas. A recently recognized major component of interstellar gas has been discovered by means of its Hα emission line at 6563 angstroms, produced by a hydrogen atom dropping from the third to the second energy level. The American astronomer Ronald Reynolds and his collaborators have used a Fabry-Pérot interferometer to map and study this line and a few others (N^+, S^+, O^{++}). The Hα line is produced by an H^+ ion recombining with a free electron, exactly as in diffuse nebulae. Each Hα photon requires about two recombinations of an H^+ ion, and each of these recombinations must be balanced by an ionization. The Hα line is faint, but it is seen in every direction, and the total amount of energy required to produce it is amazingly large. The net energy requirement of the Hα is about 15 percent of the luminosity of all O and B stars that provide ionization for diffuse nebulae. This energy output is about equal to the total power provided by all known supernovas, but the latter radiate the large bulk of their energy in nonionizing radiation or in providing modest kinetic energies to large amounts of gas near the end of their expansion phase. Hence, supernovas cannot power the diffuse ionized gas. Other potential sources of ionization, such as very hot, highly evolved stars of various types, such as Wolf-Rayet stars, white dwarf stars, or neutron stars, all fall far short. Cosmic rays are very energetic particles rather inefficiently accelerated by supernovas and so are less able to provide the required power than supernovas themselves. Only normal galactic stars of types O and B, similar to those that ionize diffuse nebulae, are viable candidates.

Unlike H II regions, the diffuse ionized gas is found far from the galactic plane as well as close to it. Pulsars occasionally occur at large distances from the galactic plane. The pulses of radio radiation emitted by these objects are slowed in their passage through the interstellar medium by electrons from the ionized hydrogen. The delays of the pulses of various radio frequencies show that the electrons (and hence H^+) extend about 3,000 light-years above and below the plane, indicating a much greater distance than the 300-light-year thickness of the neutral hydrogen, diffuse nebulae, or O and B stars in general. In the diffuse ionized gas, the comparatively low stages of ionization of the common elements (O^+, N^+, S^+) are much more abundant relative to higher stages (O^{++}, N^{++}, S^{++}) as compared to typical diffuse nebulae. Such an effect is caused by the extremely low density of the diffuse ionized gas; in this case, even hot stars fail to produce high stages of ionization. Thus, it seems possible to explain the peculiar ionization of the diffuse ionized gas with ionization powered by O and B stars. However, there is a major problem associated with this explanation: the ionizing radiation must be able to reach the diffuse ionized gas from the stars, which are typically surrounded by neutral hydrogen clouds that should prevent any ionizing radiation from penetrating through them. Apparently the O and B stars are able to ionize passages through the clouds enveloping them, and a substantial part of the ionizing radiation can escape into the regions far from the galactic plane. No other explanation seems plausible.

Ionization powered by O and B stars

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(J.S.M.)

Nepal

The Kingdom of Nepal (Nepāli: Nepāl Adhirājya), lying along the southern slopes of the Himalayan mountain ranges, is a landlocked country located between India to the east, south, and west and the Tibet Autonomous Region of China to the north. Its territory, which has an area of 56,827 square miles (147,181 square kilometres), extends roughly 500 miles (800 kilometres) from east to west and 90 to 150 miles from north to south. Nepal, long under the rule of hereditary prime ministers favouring a policy of isolation, remained closed to the outside world until a palace revolt in 1950 restored the crown's authority in 1951; the country gained admission to the United Nations in 1955. In 1991 the kingdom established a multiparty parliamentary system.

Wedged between two giants, India and China, Nepal seeks to keep a balance between the two countries in its foreign policy—and thus to remain independent. A factor that contributes immensely to the geopolitical importance of the country is the fact that a strong Nepal can deny China access to the rich Gangetic Plain; Nepal thus marks the southern boundary of the Chinese sphere north of the Himalayas in Asia.

As a result of its years of geographic and self-imposed isolation, Nepal is one of the least developed nations of the world. In recent years many countries, including India, China, the United States, the United Kingdom, Japan, Denmark, Germany, Canada, and Switzerland, have provided economic assistance to Nepal. The extent of foreign aid to Nepal has been influenced to a considerable degree by the strategic position of the country between India and China.

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Physical and human geography

THE LAND

Relief. Nepal contains some of the most rugged and difficult mountain terrain in the world. Roughly 75 percent of the country is covered by mountains. From the south to the north, Nepal can be divided into four main physical belts, each of which extends east to west across the country. These are, first, the Tarai, a low, flat, fertile land adjacent to the border of India; second, the forested Churia foothills and the Inner Tarai zone, rising from the Tarai plain to the rugged Mahābhārat Range; third, the mid-mountain region between the Mahābhārat Range and the Great Himalayas; and, fourth, the Great Himalaya Range, rising to more than 29,000 feet (some 8,850 metres).

The Tarai forms the northern extension of the Gangetic Plain and varies in width from less than 16 to more than 20 miles, narrowing considerably in several places. A 10-mile-wide belt of rich agricultural land stretches along the southern part of the Tarai; the northern section, adjoining the foothills, is a marshy region in which wild animals abound and malaria is endemic.

The Churia Range, which is sparsely populated, rises in almost perpendicular escarpments to an altitude of more than 4,000 feet. Between the Churia Range to the south and the Mahābhārat Range to the north, there are broad basins from 2,000 to 3,000 feet high, about 10 miles wide, and 20 to 40 miles long; these basins are often referred to as the Inner Tarai. In many places they have been cleared of the forests and savanna grass to provide timber and areas for cultivation.

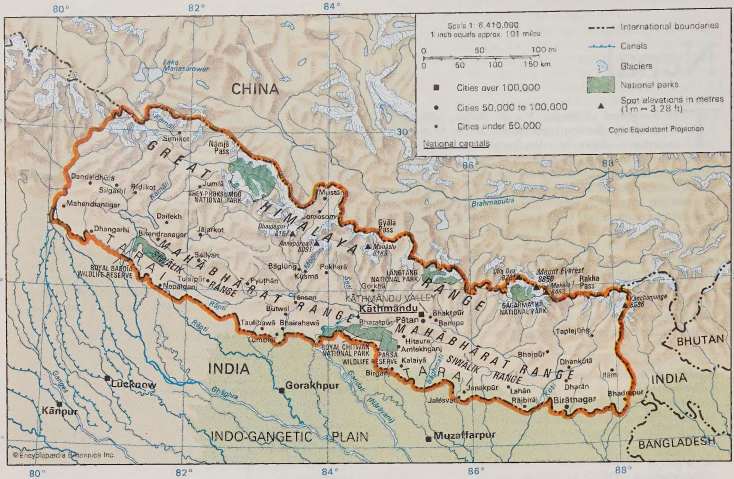
A complex system of mountain ranges, some 50 miles in width and varying in elevation from 8,000 to 14,000 feet, lie between the Mahābhārat Range and the Great Himalayas. The ridges of the Mahābhārat Range present a steep escarpment toward the south and a relatively gentle slope toward the north. To the north of the Mahābhārat Range, which encloses the valley of Kāthmāndu, are the more lofty ranges of the Inner Himalaya (Lesser Himalaya), rising to perpetually snow-covered peaks. The Kāthmāndu and the Pokharā valleys lying within this mid-mountain region are flat basins, formerly covered with lakes, that were formed by the deposition of fluvial and fluvioglacial material brought down by rivers and glaciers from the enclosing ranges during the four glacial and intervening warm phases of the Pleistocene Epoch (from about 1,600,000 to 10,000 years ago).

The Great Himalaya Range, ranging in elevation from 14,000 to more than 29,000 feet, contains many of the world's highest peaks—Everest, Kānchenjunga I, Lhotse I, Makālu I, Cho Oyu, Dhaulāgiri I, Manāslu I, and Annapūrna I—all of them above 26,400 feet. Except for scattered settlements in high mountain valleys, this entire area is uninhabited.

The Kāthmāndu Valley

Drainage. The Kāthmāndu Valley, the political and cultural hub of the nation, is drained by the Bāghmati River, flowing southward, which washes the steps of the sacred temple of Paśupatinātha (Pashupatinath) and rushes out of the valley through the deeply cut Chhobar gorge. Some sandy layers of the lacustrine beds act as aquifers (water-bearing strata of permeable rock, sand, or gravel), and springs occur in the Kāthmāndu Valley where the sands outcrop. The springwater often gushes out of dragon-shaped mouths of stone made by the Nepalese; it is then collected in tanks for drinking and washing and also for raising paddy nurseries in May, before the monsoon. Drained by the Seti River, the Pokharā Valley, 96 miles west of Kāthmāndu, is also a flat lacustrine basin. There are a few remnant lakes in the Pokharā basin, the largest being Phewa Lake, which is about two miles long and nearly a mile wide. North of the basin lies the Annapūrna massif of the Great Himalaya Range.

The major rivers of Nepal—the Kosi, Nārāyani (Gandak), and Karnāli, running southward across the strike of the Himalayan ranges—form transverse valleys with deep



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gorges, which are generally several thousand feet in depth from the crest of the bordering ranges. The watershed of these rivers lies not along the line of highest peaks in the Himalayas but to the north of it, usually in Tibet.

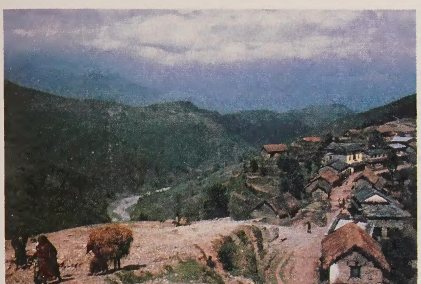
The rivers have considerable potential for development of hydroelectric power. Two irrigation-hydroelectric projects have been undertaken jointly with India on the Kosi and Nārāyani rivers. Discussions have been held to develop the enormous potential of the Karnāli River. A 60,000-kilowatt hydroelectric project at Kulekhani, funded by the World Bank, Kuwait, and Japan, began operation in 1982.

In the upper courses of all Nepalese rivers, which run through mountain regions, there are little or no flood problems. In low-lying areas of the Tarai plain, however, serious floods occur.

The rivers and small streams of the Tarai, especially those in which the dry season discharge is small, are polluted by large quantities of domestic waste thrown into them. Towns and villages have expanded without proper provision for sewage disposal facilities, and more industries have been established at selected centres in the Tarai. The polluted surface water in the Kāthmāndu and Pokharā valleys, as well as in the Tarai, are unacceptable for drinking.

Climate. Nepal's climate, influenced by elevation as well as by its location in a subtropical latitude, ranges from subtropical monsoon conditions in the Tarai, through a warm temperate climate between 4,000 and 7,000 feet in the mid-mountain region, to cool temperate conditions in the higher parts of mountains between 7,000 and 11,000 feet, to an Alpine climate at altitudes between 14,000 and 16,000 feet along the lower slopes of the Himalaya mountains. At altitudes above 16,000 feet the temperature is always below freezing and the surface covered by snow and ice. Rainfall is ample in the eastern portion of the Tarai (which receives from 70 to 75 inches [1,800 to 1,900 millimetres] a year at Biratnagar) and in the mountains, but the western portion of Nepal (where from 30 to 35 inches a year fall at Mahendranagar) is drier.

In Kāthmāndu Valley, average temperatures range from 50° F (10° C) in January to 78° F (26° C) in July, and the lowest and highest temperatures recorded have been 27° Temperatures



Naudanda village in the Annapūrna Range of the Himalayas, Nepal.
Cathlyn Melloan; EB, Inc.

and 99° F (−3° and 37° C). The average annual rainfall is about 55 inches, most of which falls in the period from June to September. At Pokharā the temperature ranges from 40° F (4° C) in January to approximately 100° F (38° C) in June, just before the monsoon. In winter, temperatures during the day rise to 70° F (21° C), creating pleasant conditions, with cool nights and warm days. Because warm rain-bearing monsoon winds discharge most of their moisture as they encounter the Annapūrna range, rainfall is quite heavy (about 100 inches) in the Pokharā Valley.

Vegetation zones

Plant life. The natural vegetation of Nepal follows the pattern of climate and altitude. A tropical, moist zone of deciduous vegetation occurs in the Tarai and the Churia Range. These forests consist mainly of khair (*Acacia catechu*), a spring tree with yellow flowers and flat pods; sissoo (*Dalbergia sissoo*), an East Indian tree yielding dark brown durable timber; and sal (*Shorea robusta*), an East Indian timber tree with foliage providing food for lac insects (which deposit lac, a resinous substance used for the manufacture of shellac and varnishes, on the tree's twigs). On the Mahābhārat Range, at elevations between 5,000 and 10,000 feet, vegetation consists of a mixture of many species, chiefly pines, oaks, rhododendrons, poplars, walnuts, and larch. Between 10,000 and 12,000 feet, fir mixed with birch, as well as rhododendron, abound. In the mid-mountain region of Nepal a fairly dense population has cleared all but the most inaccessible parts of the forest, which are restricted to areas of steep slopes and rocky terrain. Similarly, all readily accessible parts of valuable sal forest in the Tarai have been devastated by overcutting and depletive practices. The vast forested area below the timber line in the Great Himalaya Range bears some of the most valuable forests in Nepal, containing spruce, fir, cypress, juniper, and birch. Alpine vegetation occupies higher parts of the Great Himalaya Range. Just below the snow line, between 14,000 and 15,000 feet, grassy vegetation affords favourable grazing ground in summer.

(P.P.K.)

Animal life. The forested areas of the Tarai are the home of tigers and leopards, gaurs (wild ox), occasional elephants and buffalo, and many deer; the deer include chital, or axis, deer (which have white-spotted bodies), sambar (a large Asiatic deer with coarse hair on the throat and strong antlers), and swamp deer. The Lesser Rāpti Valley, in south-central Nepal, is one of the last homes of the great Indian rhinoceros (*Rhinoceros unicornis*). Much poaching has gone on, as the horn of the rhinoceros is reputed to be valuable as an aphrodisiac, but in the 1960s the Nepal government organized protective measures.

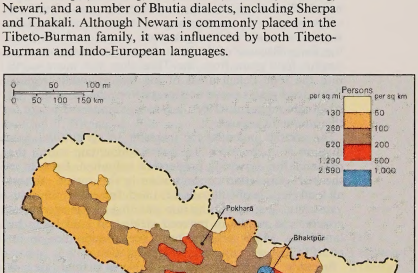
There are few wild animals in the central zone because of the clearing of forests. Occasional leopards, bears, and smaller carnivores inhabit the forests and ravines, and muntjacs (a kind of small deer, also called the barking deer) are found in the woods. In the Alpine zone are musk deer, widely hunted for the musk pods they carry, the tahr (a Himalayan beardless wild goat), the goral (any of several goat antelopes, closely related to the Rocky Mountain goat), and wild sheep, which are preyed upon by wolves and snow leopards. Pheasant are common. The Yeti (bear-man, or Abominable Snowman) is said by the Sherpa to inhabit the high snow mountains but has eluded discovery by several expeditions. Strange tracks are often found in the snow, but it is believed that they are probably made by bears. River wildlife includes the mahseer, a large freshwater food and sport fish.

(R.R.Pr./M.Zu.)

THE PEOPLE

The large-scale migrations of Mongoloid groups from Tibet and Indo-Aryan people from northern India, which accompanied the early settlement of Nepal, have produced a diverse linguistic, ethnic, and religious pattern. Nepalese of Indo-Aryan ancestry comprise the people of the Tarai, the Pahari, the Newar, and the Tharus—the great majority of the total population. Indo-Aryan ancestry has been a source of prestige in Nepal for centuries, and the ruling families have been of Indo-Aryan and Hindu background. Most of the Tibeto-Nepalese groups—the Tamang, Rai, Limbu, Bhutia (including the Sherpa), and Sunwar—live in the north and east, while the Magar and Gurung inhabit west-central Nepal. The bulk of the famous Gurkha contingents in the British army have come from the Magar, Gurung, and Rai groups.

The principal and official language of Nepal is Nepāli (Gorkhali), spoken in the Tarai and the mid-mountain region. Nepāli, a derivative of Sanskrit, belongs to the Indo-Aryan branch of the Indo-European family. There are a number of regional dialects found in the Tarai and mountain areas. The languages of the north and east belong predominantly to the Tibeto-Burman family. These include Magar, Gurung, Rai, Limbu, Sunwar, Tamang, Newari, and a number of Bhutia dialects, including Sherpa and Thakali. Although Newari is commonly placed in the Tibeto-Burman family, it was influenced by both Tibeto-Burman and Indo-European languages.



Population density of Nepal.

In Nepal a vast majority of the population is Hindu, but a small percentage follows Buddhism or other religious faiths. Hindus and Buddhists tend to be concentrated in areas where Indian and Tibetan cultural influences, respectively, have been dominant.

Settlement patterns

Almost all Nepalese live in villages or in small market centres. Outside of Kāthmāndu, there are no major cities. Smaller urban centres (Birātnagar, Nepālganj, and Birganj) are located in the Tarai along the Indian border, and Pokharā is situated in a valley in the mid-mountain region. In addition, a few townships—such as Hitaura, Būtwal, and Dharān—have begun to emerge in the foothills and hill areas, where economic activity has developed.

THE ECONOMY

Landlocked, lacking substantial resources for economic development, and hampered by an inadequate transportation network, Nepal is one of the least developed nations in the world. The economy is heavily dependent on imports of basic materials and on foreign markets for its forest and agricultural products. Nepal imports essential commodities, such as fuel, construction materials, fertilizers, metals, and most consumer goods, and exports such products as rice, jute, timber, and textiles.

The political and administrative system of Nepal has not made those changes in trade, investment, and related economic policies that would expedite economic development and attract foreign capital. The government's development programs, which are funded by foreign aid, also have failed to respond directly to the needs of rural people.

Resources. Nepal's mineral resources are small, scattered, and barely developed. There are known deposits of coal (lignite), iron ore, magnesite, copper, cobalt, pyrite (used for making sulfuric acid), limestone, and mica. Nepal's great river systems provide immense potential for hydroelectric development. If developed and utilized within the country and exported to India (the principal market for power generated in Nepal), it could become a mainstay of the country's economy.

Agriculture. Agriculture—primarily the cultivation of rice, corn (maize), and wheat—engages most of Nepal's population and accounts for well over half of the country's export earnings. Yet agricultural productivity is very low. The low yields result from shortages of fertilizers and improved seed and from the use of inefficient techniques. Because only a tiny percentage of Nepal's cultivated land area is under irrigation, output depends upon the vagaries of the weather. Potatoes, sugarcane, and millet are other major crops. Cattle, buffalo, goats, and sheep are the principal livestock raised.

On the whole, Nepal has a small surplus in food grains. There are, however, major dislocations in supply and demand. Periods of shortage between harvests of various crops occur in the mountain areas. At the same time, substantial amounts of food grain are moved to India from the Tarai. Because of the lack of adequate transportation, surplus food grain from the Tarai does not move north into the food deficit areas of the mid-mountain region. Some food grains move northward from the Tarai and the mountain areas into Tibet, however, despite a shortage in the mountain regions.

The greatest potential for increases in agricultural production is in the Tarai. In the mid-mountain region the potential for increasing production is limited. Because of the high population concentration in this region, almost all land capable of cultivation is tilled. Increasing the cultivated land area by cutting into standing forests aggravates erosion and results in reduced yields and land losses by landslides. Major projects have been undertaken in an effort to halt soil erosion and deforestation.

Forestry. About one-third of Nepal's total area is forested; most of this area is state-owned. In spite of overcutting and poor management, timber represents one of the country's most valuable resources and is a major source of potential revenue. Exports of forest products constitute an important source of Indian rupees. Almost all timber is exported to India. The sawmills of the Timber Corporation of Nepal, a government-owned lumber-processing concern, supply Kāthmāndu Valley with construction and furniture wood.

Industry and trade. Industrial production represents a small but growing segment of economic activity. Most industries are small, localized operations based on the processing of agricultural products. The jute industry, centred in Birātnagar, is an important earner of foreign exchange. Sugar factories are located in Birātnagar, Birganj, and Bhairahawā. There are a sawmill and a meat-processing plant in Hitaura and a number of rice and oil mills in the Tarai. Other industries include brick and tile manufacture; processing of construction materials, paper, and food grain; cigarette manufacture; cement production; and brewing of beer. In general, there are more industrial enterprises in the private than in the public sector, although most of these are cottage industries. The main areas of manufacturing concentration are Birātnagar, the Birganj–Hitaura corridor, and the Kāthmāndu Valley.

Tourism

Tourism represents a small but expanding industry. Foreign tourism is primarily confined to the Kāthmāndu Valley, which is the only area equipped with the necessary hotels, food supplies, roads, and international transport services. There are, however, many areas outside the Kāthmāndu Valley with potential for the development of tourism; these include Pokharā, the Mount Everest area, and the Nārāyani area (where big game exists).

For geographic and historical reasons, nearly all of Nepal's trade is with India. Attempts have been made to diversify trade through agreements with such countries as Japan, South Korea, Pakistan, the United States, Germany, Poland, and China. The state trading agency, National Trading Limited, has expanded its activities by fostering the development of commercial entrepreneurial activity. Large-scale commercial activity has hitherto been in the hands of foreigners, primarily Indians.

Nepal's foreign trade and balance of payments have suffered setbacks, and exports have not increased enough to pay for imports of consumer goods and basic supplies. Nepal's dependence on the Indian market for most of its imports and exports and on the port of Calcutta for its access to the sea has been the source of periodic friction between the two countries.

Transportation. Transport facilities in Nepal are very limited; few independent nations in the world of comparable size have such little road mileage and so few motor vehicles. Construction of new roads has been undertaken since the 1970s with aid from India, China, Great Britain, and the United States. The main means of transportation has been the network of footpaths, which interlace the mountain terrain and valleys. Trails have evolved into main trade routes, which tend to follow the river systems.

The meagre road-transport facilities in Nepal are supplemented by only a few railway and air-transport links. Increased use of road transport has reduced the significance of the two narrow-gauge railroads that run from Amlekhganj to Raxaul (India) and from Janakpūr to Jaynagar (India). The Royal Nepal Airline Corporation, an autonomous government agency, is the only commercial airline. Together with Indian Airlines, it operates flights from Kāthmāndu to various points in India and other nearby countries. Domestic air service within the country has been expanded. The United States built the Kāthmāndu–Hitaura aerial ropeway in the 1950s, and it is still used for carrying goods into the capital. (L.E.R.)

Air transport

ADMINISTRATION AND SOCIAL CONDITIONS

Government. Although reforms in the 1950s began to move the kingdom toward a democratic political system, the crown dissolved Parliament in 1960 and subsequently banned political parties. Thereafter, Nepal became only nominally a constitutional monarchy, and the constitution of 1962 (amended 1967, 1976, and 1980) effectively gave the king autocratic control over a multitiered system of panchayats (local bodies, or councils). In the 1980s, political restrictions were eased, and organizations such as the Nepali Congress Party, the Communist Party of Nepal, numerous small left-leaning student groups, and several radical Nepalese antimonarchist groups were allowed to operate more or less openly. Political parties, however, were not again legalized until 1990, when nationwide unrest forced King Birendra to accept the formation of a multiparty parliamentary system.

A new constitution promulgated on Nov. 9, 1990, greatly reduced the power of the monarchy. The king remained the head of state, but effective executive power was given to the Council of Ministers, headed by the prime minister. Appointed by the king, the prime minister is required to be either the leader of the majority party in the House of Representatives (the lower house of Parliament) or, if there is no majority party, a representative who can form a coalition majority.

The king is constitutionally also a part of Parliament and is charged with giving assent to bills that have been passed by both legislative chambers—the House of Representa-

tives and the National Council (the upper house). The House of Representatives consists of 205 members popularly elected to five-year terms. The 60 members of the National Council hold six-year terms; 10 are nominated by the king, 35 are elected by the House of Representatives (of which 3 must be women), and 15 are selected by an electoral college. The constitution gives the House of Representatives considerably more power than the National Council.

All Nepalese citizens 18 and older are eligible to vote. Because most voters in Nepal are illiterate, candidates are chosen by party symbol (*e.g.*, a tree for the Nepali Congress Party and a sun for the United Marxist-Leninist Party of Nepal). Some voters, moreover, must travel long distances, in some cases for hours along mountain paths, in order to reach a polling station.

Prior to 1990 the country was divided for administrative purposes into 5 development regions, 14 zones, and 75 districts; in addition, there were corresponding regional, zonal, and district courts, as well as a Supreme Court. The 1990 constitution mandated the elimination of the regional and zonal courts, which were to be replaced by appellate courts. The administrative divisions themselves continued to exist as provisional units. (Ed.)

Armed forces and police. Nepal's armed forces consist of the Royal Nepalese Army, predominantly an infantry force. The Army Flight Department operates all aircraft. Except for a few simple weapons, all military supplies are imported. Nepal is famous for the fighting qualities of its Gurkha soldiers; nearly 10,000 of these serve in British Gurkha units, and 50,000 in Indian Gurkha units. The British maintain a recruiting centre at Dharān. Gurkha veterans are a valuable human resource of Nepal.

For police purposes the country is divided into three zones: eastern, central, and western, with headquarters at Birātnagar, Kāthmāndu, and Nepālganj, respectively. Each zonal headquarters, under a deputy inspector general of police, is responsible for several subsections composed of four to five police districts operating under a superintendent of police. A district superintendent is in charge of police stations in his area, and each station normally is supervised by a head constable.

Health and education. The Ministry of Health is responsible for the support and administration of public health services, including hospitals and health clinics. Although the government has taken steps to improve existing health centres and to establish new ones, health care remains inadequate. Malaria, tuberculosis, cholera, and typhoid are prevalent in spite of government projects to control or eradicate them. Ayurvedic medicine, the traditional Hindu system of medicine, is popular in Nepal.

The Ministry of Education and Culture is responsible for administration and supervision of all elementary and secondary education. Higher education has developed relatively recently. The first college was established in 1918, and Tribhuvan University in Kāthmāndu, with faculties of arts, sciences, commerce, and education, was chartered in 1959. The University Senate has sole legal responsibility for higher education and the authority to grant academic recognition to colleges but is largely dependent upon the Ministry of Education for funds.

Higher education

CULTURAL LIFE

The relaxation of censorship that followed the overthrow of Rana rule in 1951 encouraged a revival of artistic and intellectual expression. In literature and poetry, Nepāli works emphasize the cultural renaissance and national patriotism. King Mahendra, a poet whose Nepāli lyrics have been published in English translation under the name of M.B.B. Shah (for Mahendra Bir Bikram Shah), did much to promote the revival of arts and literature.

The cultural heritage of Nepal, particularly contributions made by the Newar of Kāthmāndu Valley to sculpture, painting, and architecture, is a source of great pride. Hindu and Buddhist religious values have provided the basic source of inspiration to Newar artisans. The themes of most artistic works have been primarily religious; the lives of the gods, saints, and heroes and the relationship of man to society and to the universe are expounded in sculpture, architecture, and drama. In Kāthmāndu Valley some 2,500 temples and shrines display the skill and highly developed aesthetic sense of Newar artisans.

Music and dance are favourite pastimes among the Nepalese. Religious ceremonies require the use of drums and wind instruments preserved from ancient times. Important in most religious and family occasions are devotional songs that have elements of both classical and folk music and that have been used by some contemporary musical revivalists in their attempt to bridge the gap between the two. The government-owned Radio Nepal broadcasts programs in Nepālī and English. The country's first television station, at Kāthmāndu, began broadcasting in 1986.

Newspapers and periodicals are published in Nepālī and in English. Newspapers are frequently sensational in tone and are poorly staffed and financed. *Gorkha Patra,* published by the government, occupies a commanding position in the Nepalese press. Nepalese newspaper readers rely on the foreign press, particularly Indian newspapers, which are flown daily into Kāthmāndu, for more sophisticated coverage of world and national news.

After 1960 King Mahendra required newspapers to obtain official clearance for all reports of political activity. Subsequently the government increased its censorship, and in 1985 the publication of many newspapers was suspended. In 1990, reflecting the change in the country's political climate, freedom of the press was restored. (P.P.K.)

For statistical data on the land and people of Nepal, see the *Britannica World Data* section in the BRITANNICA BOOK OF THE YEAR.

History

PREHISTORY AND EARLY HISTORY

Nepal's rich prehistory consists mainly of the legendary traditions of the Newar, the indigenous community of Nepal Valley (now usually called Kāthmāndu Valley). There are usually both Buddhist and Brahmanic Hindu versions of these various legends. Both versions are accepted indiscriminately in the festivals associated with legendary events, a tribute to the remarkable synthesis that has been achieved in Nepal between the two related but divergent value systems.

References to Nepal Valley and Nepal's lower hill areas are found in the ancient Indian classics, suggesting that the Central Himalayan hills were closely related culturally and politically to the Gangetic Plain at least 2,500 years ago. Lumbini, Gautama Buddha's birthplace in southern Nepal, and Nepal Valley also figure prominently in Buddhist accounts. There is substantial archaeological evidence of an early Buddhist influence in Nepal, including a famous column inscribed by Aśoka (emperor of India, 3rd century BC) at Lumbinī and several shrines in the valley.

The Licchavi dynasty

A coherent dynastic history for Nepal Valley becomes possible, though with large gaps, with the rise of the Licchavi dynasty in the 4th or 5th century AD. Although the earlier Kirati dynasty had claimed the status of the Kshatriya caste of rulers and warriors, the Licchavis were probably the first ruling family in that area of plains Indian origin. This set a precedent for what became the normal pattern thereafter—Hindu kings claiming high-caste Indian origin ruling over a population much of which was neither Indo-Aryan nor Hindu.

The Licchavi dynastic chronicles, supplemented by numerous stone inscriptions, are particularly full from AD 500 to 700; a powerful, unified kingdom also emerged in Tibet during this period, and the Himalayan passes to the north of the valley were opened. Extensive cultural, trade, and political relations developed across the Himalayas, transforming the valley from a relatively remote backwater into the major intellectual and commercial centre between South and Central Asia. Nepal's contacts with China began in the mid-7th century with the exchange of several missions. But intermittent warfare between Tibet and China terminated this relationship; and, while there were briefly renewed contacts in subsequent centuries, these were reestablished on a continuing basis only in the late 18th century.

MIDDLE PERIOD

The Malla dynasty

The middle period in Nepalese history is usually considered coterminous with the rule of the Malla dynasty (10th–18th century) in Nepal Valley and surrounding areas. Although most of the Licchavi kings were devout Hindus, they did not impose Brahmanic social codes or values on their non-Hindu subjects; the Mallas perceived their responsibilities differently, however, and the great Malla ruler Jaya Sthiti (reigned *c.* 1382–95) introduced the first legal and social code strongly influenced by contemporary Hindu principles.

Jaya Sthiti's successor, Yakṣa Malla (reigned *c.* 1429–*c.* 1482), divided his kingdom among his three sons, thus creating the independent principalities of Kāthmāndu, Pātan, and Bhaktpūr (Bhādgāon) in the valley. Each of these states controlled territory in the surrounding hill areas, with particular importance attached to the trade routes northward to Tibet and southward to India that were vital to the valley's economy. There were also numerous small principalities in the western and eastern hill areas, whose independence was sustained through a delicate balance of power based upon traditional interrelationships and, in some cases, common ancestral origins (or claims thereto) among the ruling families. By the 16th century virtually all these principalities were ruled by dynasties claiming high-caste Indian origin whose members had fled to the hills in the wake of Muslim invasions of northern India.

In the early 18th century one of the principalities—Gorkha (also spelled Gurkha), ruled by the Shah family—began to assert a predominant role in the hills and even to pose a challenge to Nepal Valley. The Mallas, weakened by familial dissension and widespread social and economic discontent, were no match for the great Gorkha ruler Prithvi Narayan Shah. He conquered the valley in 1769 and moved his capital to Kāthmāndu shortly thereafter, providing the foundation for the modern state of Nepal.

MODERN PERIOD

The Shah dynasty

The Shah (or Sah) rulers faced tremendous and persistent problems in trying to centralize an area long characterized by extreme diversity and ethnic and regional parochialism. They established a centralized political system by absorbing dominant regional and local elites into the central administration at Kāthmāndu. This action neutralized potentially disintegrative political forces and involved them in national politics, but it also severely limited the centre's authority in outlying areas because local administration was based upon a compromise division of responsibilities between the local elites and the central administration.

From 1775 to 1951, Nepalese politics was characterized by confrontations between the royal family and several noble families. The position of the Shah dynasty was weakened by the fact that the two kings who ruled successively between 1777 and 1832 were minors when they ascended the throne. The regents and the nobility competed for political power, using the young rulers as puppets; both factions wanted a monopoly of political offices and power for their families, with their rivals exterminated, exiled to India, or placed in a subordinate status. This was achieved by the Thapa family (1806–37) and, even more extensively, by the Rana family (1846–1951). In these periods, the Shah ruler was relegated to an honorary position without power, while effective authority was concentrated in the hands of the leading members of the dominant family. Although intrafamilial arrangements on such questions as the succession and the distribution of responsibilities and spoils were achieved, no effective national political institutions were created. The excluded noble families had only two alternatives—to accept inferior posts in the administration and army or to conspire for the overthrow of the dominant family. Until 1950 and to some extent thereafter, Nepalese politics was basically conspiratorial in character, with familial loyalty taking precedence over loyalty to the crown or nation.

External relations, 1750–1950. Prithvi Narayan Shah (reigned 1742–75) and his successors established a unified state in the central Himalayas and launched an ambitious and remarkably vigorous program of expansion, seeking to bring the entire hill area, from Bhutan to Kashmir, under their authority. They made considerable progress, but successive setbacks in wars with China and Tibet (1788–92), with the Sikh kingdom in the Punjab (1809), with British India (1814–16), and again with Tibet (1854–56) frustrated Nepal and set the present boundaries of the kingdom.

Alliance with Great Britain

The British conquest of India in the 19th century posed a serious threat to Nepal—which expected to be another victim—and left the country with no real alternative but to seek an accommodation with the British to preserve its independence. This was accomplished by the Rana family regime after 1860 on terms that were mutually acceptable, if occasionally irritating, to both. Under this de facto alliance, Kāthmāndu permitted the recruitment of Nepalese for the highly valued Gurkha units in the British Indian Army and also accepted British "guidance" on foreign policy; in exchange, the British guaranteed the Rana regime against both foreign and domestic enemies and allowed it virtual autonomy in domestic affairs. Nepal, however, was also careful to maintain a friendly relationship with China and Tibet, both for economic reasons and to counterbalance British predominance in South Asia.

The British withdrawal from India in 1947 deprived the Ranas of a vital external source of support and exposed the regime to new dangers. Anti-Rana forces, composed mainly of Nepalese residents in India who had served their political apprenticeship in the Indian nationalist movement, formed an alliance with the Nepalese royal family, led by King Tribhuvan (reigned 1911–55), and launched a revolution in November 1950. With strong diplomatic support from New Delhi, the rebels accepted a settlement with the Ranas under which the sovereignty of the crown was restored and the revolutionary forces, led by the Nepali Congress Party, gained an ascendant position in the administration.

Constitutional government

Nepal since 1950. The introduction of a democratic political system in Nepal, a country accustomed to autocracy and with no deep democratic tradition or experience, proved a formidable task. A constitution was finally approved in 1959, under which general elections for a national assembly were held. The Nepali Congress won an overwhelming victory and was entrusted with the formation of Nepal's first popular government. But persistent controversy between the Cabinet and King Mahendra (reigned 1955–72) led the king to dismiss the Nepali Congress government in December 1960 and to imprison most of the party's leaders. The constitution of 1959 was abolished in 1962, and a new constitution was promulgated that established the crown as the real source of authority. King Mahendra obtained both Indian and Chinese acceptance of his regime, and the internal opposition was weak, disorganized, and discouraged. Mahendra died in January 1972 and was succeeded by his son Birendra, who was crowned in 1975.

Throughout the 1970s King Birendra sought to expedite economic development programs while maintaining the "nonparty" political system established by his father. The results were disappointing on both accounts, and by 1979 a systemic crisis was evident. To meet the first serious political challenge to the monarchy since 1960, King Birendra announced in May 1979 that a national referendum would be held to decide between a nonparty and multiparty (by implication, parliamentary) political system. In the referendum, which was held in May 1980, the political groups supporting the existing nonparty system won by the relatively small margin of 55 percent, accurately reflecting the sharp differences in the country on basic political issues.

It was in this context that King Birendra decided in 1980 to retain the 1962 constitution but to liberalize the political system by providing for direct popular election of the National Assembly. The government also permitted the "illegal" political parties, such as the Nepali Congress Party, to function under only minimal constraints. Elections were still formally held on a "partyless" basis, but many candidates ran informally and openly as members of political parties.

This partial movement toward a democratic parliamentary system satisfied neither the supporters of a multiparty

constitutional monarchy nor several more radical leftist factions, and in February 1990 a coalition of centrist and leftist opposition forces began a campaign demanding basic political reforms. A series of protests and strikes followed nationwide, and the royal government's efforts to suppress the movement with force were ineffectual. In April, as the situation in Kāthmāndu Valley worsened, King Birendra lifted the ban on political parties, abrogated the more repressive security ordinances, and on April 16 appointed a coalition interim government headed by the president of the Nepali Congress, K.S. Bhattarai, but also including the moderate faction of the communist movement, the United Leftist Front.

The policy objectives of the interim government were "to maintain law and order, develop a multiparty system on the basis of constitutional monarchy, draft a new constitution, and hold general elections" to a parliament. Within a year, all four tasks were accomplished with remarkable success despite the broad divergence of views among the major political organizations. A draft of the new constitution, prepared by a broadly representative government commission, was submitted to the Palace and the Cabinet on Sept. 10, 1990. In November, following two months of vigorous debate on a number of key issues—including the role of the king, the development of a secular state, emergency powers, and the status of Nepal's many languages—an amended version of the constitution was promulgated by King Birendra that provided for both a constitutional monarchy and a multiparty parliamentary political system.

General elections held on May 12, 1991, gave the Nepali Congress a majority in Parliament (110 of 205 seats), but the moderate United Marxist-Leftist Party (UML), with 69 seats, emerged as a strong opposition party. The two "Pancha" parties usually associated with the old system won only four seats. The elections were thus perceived to constitute a strong endorsement of the 1990 political changes, and G.P. Koirala, the brother of Nepal's first elected prime minister (1959–60), was nominated by the Nepali Congress and appointed by the king to head the new elected government.

Nepal emerged from this period of rapid political change facing a multitude of economic and social problems; among these were a stagnant economy and a variety of regional ethnic and religious movements, some of whose basic demands were not acceptable to the country's Hindu majority. Although overwhelming support existed for the new democratic constitutional monarchy system, at both the party and the public level, the democratic movement itself remained badly fractionalized and antagonistic, making more difficult the new government's attempt to introduce the kind of hard-hitting economic and social policies the panchayat governments had carefully avoided in an effort to mollify several small but important interest groups. (L.E.R.)

The 1990s were a period of political instability in Nepal. In 1994 the UML emerged as the largest party in the legislature and formed a minority government. However, it was defeated on a vote of no confidence the following year and replaced by a Nepali Congress-led coalition. By March 1997 the UML was back in government, though it was ousted again in October. In 1999 the Nepali Congress won a majority in the legislature, winning 110 seats, while the UML dropped to only 68. In late 1999 the Communist Party led a series of general strikes, which resulted in widespread violence. The killing of most members of the royal family by the crown prince (who also died, from self-inflicted wounds) in 2001 heightened tensions and threatened greater political and economic instability. (Ed.)

For later developments in the history of Nepal, see the BRITANNICA BOOK OF THE YEAR.

For coverage of related topics in the *Macropædia* and *Micropædia,* see the *Propædia,* sections 935, 936, 968, and 976, and the *Index.*

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Nerves and Nervous Systems

All living organisms are able to detect changes within themselves and in their environments. Changes in the external environment include those of light, temperature, sound, motion, and odour, while changes in the internal environment include those in the position of the head and limbs as well as in the internal organs. Once detected, these internal and external changes must be analyzed and acted upon in order to preserve the integrity, well-being, and status quo of the organism. As life on Earth evolved and the environment became more complex, the survival of organisms depended upon how well they could respond to changes in their surroundings. One factor necessary for survival was a speedy reaction or response. Since communication from one cell to another by chemical means was too slow to be adequate for survival, a system evolved that allowed for faster reaction. That system was the nervous system, which is based upon the almost instantaneous transmission of electrical impulses from one region of the body to another along specialized nerve cells.

Nervous systems are of two general types, diffuse and centralized. In the diffuse type, found in lower invertebrate animals, there is no brain, and the nerve cells are distributed throughout the organism in a netlike pattern. In the centralized systems of the higher invertebrates and the vertebrate animals, some portion of the nervous system has a dominant role in coordinating information and directing responses. This centralization reaches its apogee in the vertebrates, which have a well-developed brain and spinal cord. Impulses are carried to and from the brain and spinal cord by nerve fibres that make up the peripheral nervous system.

This article begins with a discussion of the general features of nervous systems—that is, their function of responding to stimuli and the rather uniform electrochemical processes by which they carry out their response. Following a discussion of the various types of nervous systems, from the simplest to the most complex, are sections on the anatomy and functions of the human nervous system. The article concludes with a section on the most common neurological diseases and disorders.

For detailed discussion of the biochemical and physiological processes of which the nervous system forms a part, see CELLS; and GROWTH AND DEVELOPMENT, BIOLOGICAL. For description of receptors that initiate nerve impulses, see SENSORY RECEPTION. The organ systems that are supplied by nerves are described in MUSCLES AND MUSCLE SYSTEMS.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, sections 323, 333, 421, and 423, and the *Index*. (S.D.E.)

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FORM AND FUNCTION OF NERVOUS SYSTEMS

Stimulus–response coordination

The simplest type of living response is the direct one-to-one stimulus–response reaction. The change in the environment is the stimulus; the reaction of the organism to it is the response. In the case of single-celled organisms, the response is the result of a property of the cell fluid called irritability. In simple organisms, such as algae, protozoans, and fungi, a stereotyped response in which the organism moves toward or away from the stimulus is termed taxis. In larger and more complicated organisms—those in which response involves the synchronization and integration of events in different parts of the body—a control mechanism, or "controller," is located between the stimulus and the response. In multicellular organisms, this controller consists of two basic mechanisms by which integration is achieved—chemical regulation and nervous regulation.

Two mechanisms of coordination: chemical and nervous

In chemical regulation, substances called hormones are produced by well-defined groups of cells and are either diffused or carried by the blood to other areas of the body where they act on so-called target cells, influencing metabolism or inducing synthesis of other substances. The changes resulting from hormonal action are expressed in the organism as influences on, or alterations in, form, growth, reproduction, and behaviour.

Plants respond to a variety of external stimuli by utilizing hormones as controllers in a stimulus–response system. Directional responses of movement are known as tropisms and are called positive when the movement is toward the stimulus and negative when it is away from the stimulus. When a seed germinates, the growing stem turns upward toward the light, and the roots turn downward away from the light. Thus, the stem shows positive phototropism and negative geotropism, while the roots show negative phototropism and positive geotropism. In this example, light and gravity are the stimuli, and directional growth is the response. The controllers are certain hormones synthesized by cells in the tips of the plant stems. These hormones, known as auxins, diffuse through the tissues beneath the tip and concentrate toward the shade side, causing elongation of these cells and, thus, a bending of the tip toward the light. The end result is that the plant is maintained in an optimal condition with respect to light.

In animals, in addition to chemical regulation via the endocrine system, there is another integrative system called the nervous system. A nervous system can be defined as an organized group of cells, called neurons, specialized for the conduction of an impulse—an excited state—from a sensory receptor through a nerve network to an effector, the site at which the response occurs.

Advantages of nervous coordination

Organisms that possess a nervous system are capable of much more complex behaviour than are organisms that lack one. The nervous system, being specialized for the conduction of impulses, allows rapid responses to stimuli from the environment. Many of the responses mediated by the nervous system are directed toward preserving the status quo, or homeostasis, of the animal. Stimuli that tend to displace or disrupt some part of the organism call forth a response that results in reduction of the adverse effects and a return to a more normal condition. Organisms with a nervous system are also capable of a second group of functions that initiate a variety of behaviour patterns. Animals may go through periods of exploratory or appetitive behaviour, nest building, and migration. Although these activities are beneficial to the survival of the species, they are not always performed by the individual in response to an individual need or stimulus. Finally, learned behaviour can be superimposed on both the homeostatic and initiating functions of the nervous system.

INTRACELLULAR SYSTEMS

All living cells have the property of irritability, or responsiveness to environmental stimuli, which can affect the cell in different ways, producing, for example, electrical, chemical, or mechanical changes. These changes are expressed as a response, which may be the release of secretory products by gland cells, the contraction of muscle cells, the bending of a plant-stem cell, and the beating of whiplike "hairs," or cilia, by ciliated cells.

The responsiveness of a single cell can be illustrated by the behaviour of the relatively simple amoeba. Unlike some other protozoans, an amoeba lacks highly developed structures that function in the reception of stimuli and in the production or conduction of a response. The amoeba behaves as though it had a nervous system, however, because the general responsiveness of its cytoplasm serves the functions of a nervous system. An excitation produced by a stimulus is conducted to other parts of the cell and evokes a response by the animal. An amoeba will move to a region of a certain level of light. It will be attracted by chemicals given off by foods and exhibit a feeding response. It will also withdraw from a region with noxious chemicals and show an avoidance reaction upon contacting other objects.

ORGANELLE SYSTEMS

In more complex protozoans, specialized cellular structures, or organelles, serve as receptors of stimulus and as effectors of response. Receptors include stiff sensory bristles in ciliates and the light-sensitive eyespots of flagellates. Effectors include cilia (slender, hairlike projections from the cell surface), flagella (greatly elongated, whiplike cilia), and other organelles associated with drawing in food or with locomotion. Protozoans also have subcellular cytoplasmic filaments that, like muscle tissue, are contractile. The vigorous contraction of the stalked protozoan *Vorticella,* for example, is the result of contraction of a threadlike structure called a myoneme in the stalk.

Although protozoans clearly have specialized receptors and effectors, it is not certain that there are special conducting systems between the two. In a ciliate such as *Paramecium,* the beating of the cilia—which propels it along—is not random, but coordinated. Beating of the cilia begins at one end of the animal and moves in regularly spaced waves to the other end, suggesting that coordinating influences are conducted longitudinally. A system of fibrils connecting the bodies in which the cilia are rooted could provide conducting paths for the waves, but coordination of the cilia could also take place without such a system. Each cilium could respond to a stimulus carried over the cell surface from an adjacent cilium—in which case, coordination would be the result of a chain reaction from cilium to cilium.

Coordination in the *Paramecium*

The best evidence that formed structures are responsible for coordination comes from another ciliate, *Euplotes,* which has a specialized band of ciliary rows (membranelles) and widely separated tufts of cilia (cirri). By means of the coordinated action of these structures, *Euplotes* is capable of several complicated movements in addition to swimming (*e.g.,* turning sharply, moving backward, spinning). The five cirri at the rear are connected to the anterior end in an area known as the motorium. The fibres of the motorium apparently provide coordination between the cirri and the membranelles. The membranelles, cirri, and motorium constitute a neuromotor system.

NERVOUS SYSTEMS

The basic pattern of stimulus–response coordination in animals is an organization of receptor, adjustor, and effector units. External stimuli are received by the receptor cells, which, in most cases, are neurons. (In a few instances, a receptor is a non-nervous sensory epithelial cell, such as a hair cell of the inner ear or a taste cell, which stimulates adjacent neurons.) The stimulus is modified, or transduced, into an electrical impulse in the receptor neuron. This incoming excitation, or afferent impulse, then passes along an extension, or axon, of the receptor to an adjustor, called an interneuron. (All neurons are capable of conducting an impulse, which is a brief change in the electrical charge on the cell membrane. Such an impulse

can be transmitted, without loss in strength, many times along an axon until the message, or input, reaches another neuron, which in turn is excited.) The interneuron-adjustor selects, interprets, or modifies the input from the receptor and sends off an outgoing, or efferent, impulse to an efferent neuron, such as a motor neuron. The efferent neuron, in turn, makes contact with an effector such as a muscle or gland, which produces a response.

In the simplest arrangement, the receptor–adjustor–effector units form a functional group known as the reflex arc. Sensory cells carry afferent impulses to a central interneuron, which makes contact with a motor neuron. The motor neuron carries efferent impulses to the effector, which produces the response. Three types of neurons are involved in this reflex arc, but a two-neuron arc, in which the receptor makes contact directly with the motor neuron, also occurs. There, simple reflexes are prompt, short-lived, automatic, and involve only a part of the body. Examples of simple reflexes are the contraction of a muscle in response to stretch, the blink of the eye when the cornea is touched, and salivation at the sight of food. Reflexes of this type are usually involved in preserving homeostasis.

Simple and complex nervous systems

The differences between simple and complex nervous systems lie not in the basic units but in their arrangement. In higher nervous systems, there are more interneurons concentrated in the central nervous system (brain and spinal cord) that mediate the impulses between afferent and efferent neurons. Sensory impulses from particular receptors travel over specific neuronal pathways to the central nervous system. Within the central nervous system, though, the impulse can travel over multiple pathways formed by numerous neurons. Theoretically, the impulse can be distributed to any of the efferent motor neurons and produce a response in any of the effectors. It is also possible for many kinds of stimuli to produce the same response.

As a result of the integrative action of the interneuron, the behaviour of the organism is more than the simple sum of its reflexes; it is a unitary, integrated whole that exhibits coordination between many individual reflexes. Reflexes can occur in a complicated series or sequence producing elaborate behaviour patterns. Behaviour in such cases is characterized not by inherited, stereotyped responses but by flexibility and adaptability to circumstances. Many automatic, unconditioned reflexes can be modified by or adapted to new stimuli. The remarkable experiments of the Russian physiologist Pavlov, for example, showed that if an animal salivates at the sight of food while another stimulus, such as the sound of a bell, occurs simultaneously, the sound alone can induce salivation after several trials. This response, known as a conditioned reflex, is a form of learning. The animal's behaviour is no longer limited by fixed, inherited reflex arcs but can be modified by experience and exposure to an unlimited number of stimuli. The most evolved nervous systems are capable of even higher associative functions: of other forms of learning, of thinking, and of memory. The complex manipulation of the signals necessary for these functions depends to a great extent on the number and intricacy of arrangement of the pool of interneurons. (T.L.L./S.D.E.)

The nerve cell

The watershed of all studies of the nervous system was an observation made in 1889 by the Spanish scientist Santiago Ramón y Cajal, who reported that the nervous system is composed of individual units that are structurally independent of one another and whose internal contents do not come into direct contact. According to this hypothesis, now known as the neuron theory or neuron doctrine, each nerve cell communicates with others through contiguity rather than continuity. That is, communication between adjacent but separate cells must take place across the space and barriers separating them. It has since been proved that Ramón y Cajal's theory is not universally true, but his central idea—that communication in the nervous system is largely communication between independent nerve cells—has remained an accurate guiding principle for all further study.

There are two basic cell types within the nervous system: neurons and neuroglial cells.

THE NEURON

In the human brain there are approximately 10,000,000,000 neurons. Each neuron has its own identity, expressed by its interactions with other neurons and by its secretions; each also has its own function, depending on its intrinsic properties and location as well as its inputs from other select groups of neurons, its capacity to integrate those inputs, and its ability to transmit the information to another select group of neurons.

Three regions of the neuron

With few exceptions, most neurons consist of three distinct regions: (1) the cell body, or soma; (2) the nerve fibre, or axon; and (3) the receiving processes, or dendrites (Figure 1).

By courtesy of Alan Peters

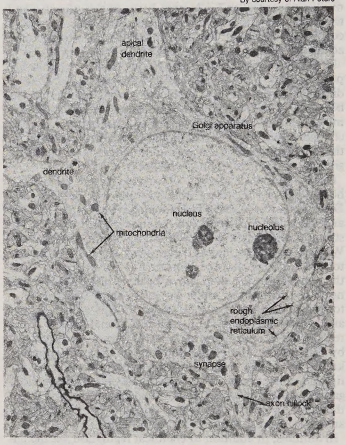


Figure 1: *A neuron from the visual cortex of a rat.*
The centre of the field is occupied by the soma, or cell body, of the neuron. Most of the soma is occupied by the nucleus, which contains a nucleolus. The double membrane of the nucleus is surrounded by cytoplasm, containing elements of the Golgi apparatus lying at the base of the apical dendrite. Mitochondria can be seen dispersed in the cytoplasm, which also contains the rough endoplasmic reticulum. Another dendrite is seen to the side, and the axon hillock is shown at the initial segment of the emerging axon. A synapse impinges onto the neuron close to the axon hillock.

The soma. *The plasma membrane.* The neuron is bounded by a plasma membrane, a structure so thin that its fine detail can be revealed only by high-resolution electron microscopy. About half of the membrane is the so-called lipid bilayer, two sheets of mainly phospholipids with a space between. One end of a phospholipid molecule is hydrophilic, or water attaching, and the other end is hydrophobic, or water repelling. The bilayer structure results when the hydrophilic ends of the phospholipid molecules in each sheet turn toward the watery mediums of both the cell interior and the extracellular environment, while the hydrophobic ends of the molecules turn in toward the space between the sheets. These lipid layers are not rigid structures; the loosely bonded phospholipid molecules can move laterally across the surfaces of the membrane, and the interior is in a highly liquid state.

Embedded within the lipid bilayer are proteins, which also "float" in the liquid environment of the membrane. These include glycoproteins containing polysaccharide chains, which function, along with other carbohydrates, as adhesion sites and recognition sites for attachment and

chemical interaction with other neurons. The proteins provide another basic and crucial function: those which penetrate the membrane can exist in more than one conformational state, or molecular shape, forming channels that allow ions to pass between the extracellular fluid and the cytoplasm, or internal contents of the cell. In other conformational states, they can block the passage of ions. This action is the fundamental mechanism that determines the excitability and pattern of electrical activity of the neuron.

A complex system of proteinaceous intracellular filaments are linked to the membrane proteins. This so-called cytoskeleton includes thin neurofilaments containing actin, thick neurofilaments similar to polymerized myosin, and microtubules composed of tubulin. The filaments are probably concerned with movement and translocation of the membrane proteins, while microtubules may anchor the proteins to the cytoplasm.

The nucleus. Each neuron contains a nucleus defining the location of the soma. The nucleus is surrounded by a double membrane, called the nuclear envelope, that fuses at intervals to form pores allowing molecular communication with the cytoplasm. Within the nucleus are the chromosomes, the genetic material of the cell, through which the nucleus controls synthesis of proteins and the growth and differentiation of the cell into its final form. Proteins synthesized in the neuron include enzymes, receptors, hormones, and structural proteins for the cytoskeleton.

Organelles of the cell. The endoplasmic reticulum (ER) is a widely spread membrane system within the neuron that is continuous with the nuclear envelope. It consists of series of tubules, flattened sacs called cisternae, and membrane-bounded spheres called vesicles. There are two types of ER.

Synthesis of protein in the neuron

The rough endoplasmic reticulum (RER) has rows of knobs called ribosomes on its surface. Ribosomes synthesize proteins that, for the most part, are transported out of the cell. The RER is found only in the soma.

The smooth endoplasmic reticulum (SER) consists of a network of tubules in the neuron soma that connects the RER with the Golgi apparatus. The tubules can also enter the axon at its initial segment and extend to the axon terminals.

The Golgi apparatus is a complex of flattened cisternae arranged in closely packed rows. Located close to and around the nucleus, it receives proteins synthesized in the RER and transferred to it via the SER. Once arrived at the Golgi apparatus, the proteins are attached to carbohydrates. The glycoproteins so formed are packaged into vesicles that leave the complex to be incorporated into the cell membrane.

The axon. The axon arises from the soma at a region called the axon hillock or initial segment. This is the region where the plasma membrane generates nerve impulses; the axon conducts these impulses away from the soma or dendrites toward other neurons. Large axons (arising from large somas) acquire an insulating myelin sheath and are known as myelinated or medullated fibres. Myelin is composed of 80 percent lipid and 20 percent protein; cholesterol is one of the major lipids, along with variable amounts of cerebrosides and phospholipids. Concentric layers of these lipids separated by thin layers of protein give rise to a high-resistance, low-capacitance electrical insulator interrupted at intervals by gaps called nodes of Ranvier, where the nerve membrane is exposed to the external environment. In the central nervous system, the myelin sheath is formed from glial cells called oligodendrocytes, while in peripheral nerves it is formed from Schwann cells (see below *The neuroglia*).

While the axon mainly conducts nerve impulses from the soma to the terminal, the terminal itself secretes chemical substances called neurotransmitters. The synthesis of these substances can occur in the terminal itself, but the synthesizing enzymes are formed by ribosomes in the soma and must be transported down the axon to the terminal. This process is known as axoplasmic flow; it occurs in both directions along the axon and may be facilitated by microtubules.

At the terminal of the axon, and sometimes along its length, are specialized structures that form junctions with other neurons and with muscle cells. These junctions are called synapses. Presynaptic terminals, when seen by light microscopy, look like small knobs; when examined under high-resolution electron microscopy, they are seen to contain many organelles. The most numerous of these are synaptic vesicles, which, filled with neurotransmitters, are often clumped in areas of the terminal membrane that appear to be thickened. The thickened areas are known as presynaptic dense projections, or active zones.

Axon terminals at the synapse

The presynaptic terminal is unmyelinated and is separated from the neuron or muscle cell onto which it impinges by a gap called the synaptic cleft, across which the neurotransmitters diffuse when released from the vesicles. In nerve–muscle junctions the synaptic cleft contains a structure called the basal lamina. This structure holds an enzyme that destroys neurotransmitters and thus regulates the amount that reaches the postsynaptic receptors on the receiving cell. Most knowledge of postsynaptic neurotransmitter receptors comes from studies of the receptor on muscle cells. This receptor, called the end plate, is a glycoprotein composed of five subunits. Other neurotransmitter receptors do not have the same structure, but they are all proteins and probably have subunits with a central channel that is activated by the neurotransmitter.

While the chemically mediated synapse described above forms the majority of synapses in nervous systems of vertebrates, there are other types of synapses in vertebrate brains and, in especially great numbers, in invertebrate and fish nervous systems. At these synapses there is no synaptic gap; instead, there are so-called gap junctions, direct channels between neurons that establish a continuity between the cytoplasm of adjacent cells and a structural symmetry between the pre- and postsynaptic sites. Rapid neuronal communication at these junctions is probably not chemical but electrical in nature. (For further discussion, see below *Transmission of information in the nervous system: Transmission at the synapse.*)

The dendrites. Besides the axon, neurons have other branches called dendrites. These are usually shorter than axons and are unmyelinated. Traditionally, dendrites are thought to form receiving surfaces for synaptic input from other neurons. In many dendrites these surfaces are provided by specialized structures called dendritic spines, which, by providing discrete regions for the reception of nerve impulses, isolate changes in electrical current from the main dendritic trunk.

The traditional view of dendritic function presumes that only axons conduct nerve impulses and only dendrites receive them, but it has been shown that dendrites can form synapses with dendrites and that axons and even somata can receive impulses. Indeed, some neurons have no axon; in these cases nervous transmission is carried out by the dendrites.

THE NEUROGLIA

Neurons form a minority of the cells in the nervous system. Exceeding them in number by at least 10 to 1 are neuroglial cells, which exist in the nervous systems of invertebrates as well as vertebrates. Neuroglia can be distinguished from neurons by the lack of axons and the presence of only one type of process. In addition, they do not form synapses, and they retain the ability to divide throughout their life span. While neurons and neuroglia lie in close apposition to one another, there are no direct junctional specializations, such as gap junctions, between the two types. Gap junctions do exist between neuroglial cells, raising questions about their functions and properties.

Differences between neuroglia and neurons

Types of neuroglia. Apart from conventional histological and electron-microscopic techniques, immunologic techniques are used to identify different neuroglial cell types. By staining the cells with antibodies that bind to specific protein constituents of different neuroglia, neurologists have been able to discern two (in some opinions three) main groups: (1) astrocytes, subdivided into fibrous and protoplasmic types; (2) oligodendrocytes, subdivided into interfascicular and perineuronal types; and sometimes (3) microglia.

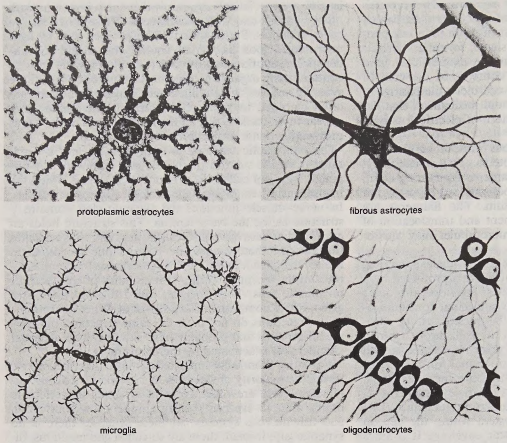


Figure 2: Neuroglial cells.
After del Rio-Hortega in W. Bloom and D.W. Fawcett, *A Textbook of Histology* (1986), W.B. Saunders Co., Philadelphia; reprinted by permission

Fibrous astrocytes are prevalent among myelinated nerve fibres in the white matter of the central nervous system. Organelles seen in the somata of neurons are also seen in astrocytes, but they appear to be much sparser. These cells are characterized by the presence of numerous fibrils in their cytoplasm. The main processes exit the cell in a radial direction (hence the name astrocyte, meaning "star-shaped cell"), forming expansions and end feet at the surfaces of vascular capillaries.

Unlike fibrous astrocytes, protoplasmic astrocytes occur in the gray matter of the central nervous system. They have fewer fibrils within their cytoplasm, and cytoplasmic organelles are sparse, so that the somata are shaped by surrounding neurons and fibres. The processes of protoplasmic astrocytes also make contact with capillaries.

Oligodendrocytes have few cytoplasmic fibrils but a well-developed Golgi apparatus. They can be distinguished from astrocytes by the greater density of both cytoplasm and nucleus, the absence of fibrils and glycogen in the cytoplasm, and large numbers of microtubules in the processes. Interfascicular oligodendrocytes are aligned in rows between the nerve fibres of the white matter of the central nervous system. In gray matter perineuronal oligodendrocytes are located in close approximation with the somata of neurons. In the peripheral nervous system, neuroglia that are equivalent to oligodendrocytes are called Schwann cells.

Microglial cells are small, crenate cells with dark cytoplasm and a dark nucleus. It is uncertain whether they are merely damaged neuroglial cells or occur as a separate group in living tissue.

Neuroglial functions. The term neuroglia means "nerve glue," and these cells were originally thought to be structural supports for neurons. This is still thought to be plausible, but other functions of the neuroglia are now generally accepted. It has long been known that oligodendrocytes and Schwann cells produce the myelin sheath around neuronal axons. Studies show that some constituent of the axonal surface stimulates Schwann cell proliferation and that the type of axon determines whether there is loose or tight myelination of the axon. In tight myelination a glial cell wraps itself like a rolled sheet around a length of axon until the fibre is covered by several layers. Between segments of myelin wrapping are exposed sections called nodes of Ranvier, which are important in the transmission of nerve impulses. Myelinated nerve fibres are found only in vertebrate animals, leading biologists to conclude that they are an adaptation to transmission over relatively long distances.

Formation of myelin

Another well-defined role of neuroglial cells is in repair following injury to the central nervous system. It has been well documented that astrocytes divide after injury to the nervous system and that they occupy the spaces left by injured neurons. The role of oligodendrocytes after injury is not so clear, but evidence suggests that they can proliferate and form myelin sheaths.

When neurons of the peripheral nervous system are cut, they undergo a process of degeneration followed by regeneration, the fibres regenerating in such a way that they return to their original target sites. Schwann cells that remain after nerve degeneration apparently mark the route. This route direction is also performed by astrocytes during development of the central nervous system. In the developing cerebral cortex and cerebellum of primates, astrocytes project long processes to certain locations, and neurons migrate along these processes to arrive at their final locations. Thus, neuronal organization is brought about to some extent by the neuroglia.

Functions in synaptic transmission

Astrocytes are also believed to have high-affinity uptake systems for neurotransmitters such as glutamate and gamma-aminobutyric acid (GABA). This function is important in the modulation of synaptic transmission. Uptake systems tend to terminate neurotransmitter action at the synapses and perhaps also act as storage systems for the neurotransmitters when they are needed. For instance, when motor nerves are cut, the nerve terminals degenerate and their original sites are occupied by Schwann cells. It has been found not only that electrical signals can be recorded on muscle cell receptors in the absence of any form of stimulation but also that currents applied to the Schwann cells evoke neurotransmitter release. Apparently, the synthesis of neuro-transmitters by neurons also requires the presence of neuroglial cells in the vicinity.

In the past it was thought that neuroglia were not electrically excitable, but it has been shown that neuroglial cells in vitro have voltage-sensitive properties similar to those of excitable neurons. If electrical activity similar to that occurring in neurons were generated in neuroglial cells in vivo, the implications for glial–neuronal interaction would be enormous. Such proof is not available, however.

Finally, the environment surrounding neurons in the brain consists of a network of very narrow extracellular clefts. In 1907 the Italian biologist Emilio Lugaro suggested that neuroglial cells exchange substances with the extracellular fluid and in this way exert control on the neuronal environment. It has since been shown that glucose, amino acids, and ions—all of which influence neuronal function—are exchanged between the extracellular space and neuroglial cells. After high levels of neuronal activity, for instance, neuroglial cells can take up and spatially buffer potassium ions and thus maintain normal neuronal function.

Transmission of information in the nervous system

In the nervous systems of animals at all levels of the evolutionary scale, the signals containing information about a particular stimulus are electrical in nature. In the past the nerve fibre and its contents were compared to a metal wire, while the membrane was compared to insulation around the wire. This comparison was erroneous for a number of reasons. First, the charge carriers in nerves are ions, not electrons, and the density of ions in the axon is much less than that of electrons in a metal wire. Second, the membrane of an axon is not a perfect insulator, so that the movement of current along the axon is not complete. Finally, nerve fibres are smaller than most wires, so that the currents they can carry are limited in amplitude.

THE IONIC BASIS OF ELECTRICAL SIGNALS

Ions are atoms or groups of atoms that gain an electrical charge by losing or acquiring electrons. For example, in the reaction that forms salt from sodium and chlorine, each sodium atom "donates" an electron, which is negatively charged, to a chlorine atom. The result is sodium chloride (NaCl), composed of one positively charged sodium ion (Na^+) and one negatively charged chloride ion (Cl^-).

Positive and negative charge

A positively charged ion is called a cation; a negatively charged ion, an anion. The number of charges carried by an ion is called its valence. Na^+ and Cl^-, which respectively lose and acquire one electron, have a valence of one, while calcium ions (Ca^{2+}), which lose two electrons, have a valence of two.

The electrical events that constitute signaling in the nervous system depend upon the distribution of ions on either side of the nerve membrane. Underlying these distributions and their change are crucial physicochemical principles.

Distribution of ions across a membrane. *Diffusion of uncharged molecules.* Molecules in solution move randomly, the energy for their movement being derived from thermal energy. When a permeable membrane (a membrane that allows molecules to cross it) divides a heavily concentrated solution from a lightly concentrated solution, there occurs a diffusion of molecules through the membrane and down their concentration gradient—that is, from the fluid with the higher concentration to that with the lower concentration. The number of molecules moving per unit of time is called the flow rate, or flux rate. Diffusion continues until the concentrations on both sides of the membrane are equal. A condition of no net flux is then established with an equal, random diffusion of molecules in both directions. This is called the equilibrium state.

A membrane with pores allowing passage of molecules of only a particular size is called a semipermeable membrane. The semipermeable membrane imposes a condition of restricted diffusion. In that case the flux rate of the diffusing material is controlled by the permeability of the membrane, which in turn is dictated by the size of the pores and is given a unit of measure called the permeability coefficient.

Diffusion of water. The water molecule, like other molecules, diffuses down its concentration gradient. If a rigid vessel contains water on one side of a semipermeable membrane and an impermeant substance (a substance that cannot cross the membrane) on the other side, the water tends to cross the membrane, diluting the substance and increasing the hydrostatic pressure on the other side (Figure 3). The pressure then will tend to push water back across the membrane in opposition to the net flux. When the pressure built up equals the diffusion of water in the opposite direction, no net flux occurs and equilibrium is established. The migration of water (or any solvent) across a membrane is called osmosis, and the pressure necessary to establish equilibrium is called osmotic pressure. Water moves from a region of low osmotic pressure to a region of high osmotic pressure.

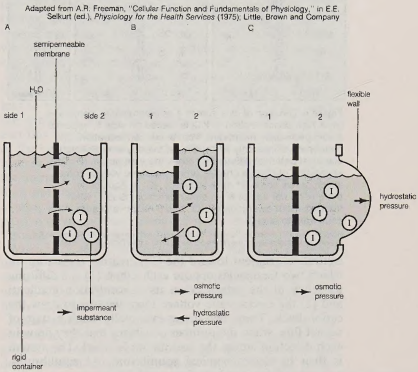


Figure 3: *Diffusion of water across a semipermeable membrane.* (A) Water diffuses down its concentration gradient from side 1 to side 2 of a rigid container. (B) The net flux of water creates a hydrostatic pressure, tending to force the water back to side 1. (C) If the wall of side 2 is flexible, the hydrostatic pressure causes an increase in the volume of side 2.

The above example refers to water in a container with rigid walls. The neuron, however, has somewhat flexible walls, so that as water enters it, the cell tends to increase in volume, or swell. There is a direct relation between osmotic pressure across the plasma membrane and the final volume of a cell at equilibrium, so that if the osmotic pressure of the cell exterior is halved, the equilibrium volume of the cell will be twice its original.

Diffusion of ions. When potassium chloride (KCl) is placed into solution, the elements separate into potassium cations (K^+) and chloride anions (Cl^-). The ions follow much the same principles of diffusion as uncharged molecules. For example, if a highly concentrated solution of KCl is separated from a lower concentration by a semipermeable membrane—one that is permeable to cations only—then K^+ from the higher concentration diffuses across the membrane, following its concentration gradient to the region of lower concentration (Figure 4). Cl^-, being blocked by the membrane, remains behind. At this point the diffusion of ions creates conditions quite different from the diffusion of uncharged molecules and water molecules. The movement of cations toward the less concentrated solution creates a separation of electrical charge across the membrane—that is, a greater number of positively charged ions will have moved to the side with the less concentrated solution of KCl, and the side of the membrane with the higher concentration will have a more negative charge. This separation of charge—actually a difference in electrical potential—is called the potential difference, and it is the starting point of all electrical events in nervous systems. When present in the plasma membrane of the neuron, it transforms the neuron into an electrolytic cell that is capable, upon stimulation, of generating and transmitting electrical impulses.

Separation of electrical charge

Complicating the ionic diffusion process is the phenomenon that opposite charges attract. This means that, in the example above, some of the K^+ diffusing across the membrane is electrostatically drawn back up its con-

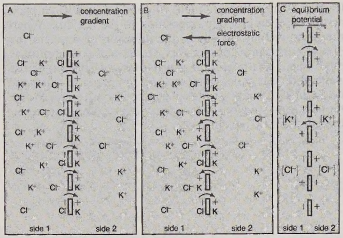


Figure 4: *Diffusion of ions across a semipermeable membrane.* (A) A high concentration of KCl is placed on side 1, opposite a semipermeable membrane from a low concentration. The membrane allows only K^+ to diffuse, thereby establishing an electrical potential difference across the membrane. (B) The separation of charge creates an electrostatic voltage force, which draws some K^+ back to side 1. (C) At equilibrium, there is no net flux of K^+ in either direction. Side 1, with the higher concentration of KCl, has a negative charge compared to side 2.

Adapted from A.R. Freeman, "Cellular Function and Fundamentals of Physiology," in E.E. Selkurt (ed.), *Physiology for the Health Services* (1975). Little, Brown and Company

centration gradient toward the Cl^-, creating a situation in which two tendencies oppose each other: (1) the diffusing tendency of the cation down its concentration gradient; and (2) the electrostatic voltage force tending to draw the cation back. These two forces eventually reach a state of no net flux, when the number of cations that they draw in each direction across the membrane is equal. The system is then in electrochemical equilibrium. At equilibrium, one side of the membrane may still have a more negative charge than the other. In that case the potential difference is called the equilibrium potential. (It is also called the Nernst potential, after Walther Nernst, the German physical chemist who, in the late 19th century, developed equations for calculating the electrical potential at which there is no longer a net flux of a specific ion across a membrane.)

The law of electroneutrality states that in any single ionic solution a sum of negative electrical charges attracts an equal sum of positive electrical charges. If a solution of KCl is divided into two parts by a membrane, permeable to both ions, then the equal concentration of KCl across the membrane preserves chemical equilibrium between the two sides, while the equal concentrations of K^+ and Cl^- on each side preserve electroneutrality on each side as well (Figure 5). This equilibrium can be upset by the addition to side 1 of a large number of K^+ and an equal charge of impermeant anions (that is, negatively charged ions other than Cl^- that cannot permeate the membrane). In that case electroneutrality on side 1 is preserved, since the sum of positive charges added to that side is equaled by the sum of added negative charges. However, chemical equilibrium between side 1 and side 2 is not preserved, since side 1 now has a greater concentration of ions than side 2. Therefore, K^+ diffuses down its concentration gradient, crossing the membrane to side 2 while drawing Cl^- with it to preserve electroneutrality. Diffusion continues until a new state of electrochemical equilibrium is reached. Researchers have found that this occurs at a point at which the ratio of K^+ concentration on side 2 to that on side 1 is equal to the ratio of Cl^- concentration on side 1 to that on side 2. Stated mathematically, equilibrium is reached when

$$\frac{[K^+]_{\text{side 2}}}{[K^+]_{\text{side 1}}} = \frac{[Cl^-]_{\text{side 1}}}{[Cl^-]_{\text{side 2}}}.$$

This is known as the Donnan equilibrium, after Frederick George Donnan, the British chemist who in 1911 first measured the changes brought about by adding an impermeant substance to one side of a divided solution at equilibrium.

In the new state of equilibrium, both side 1 and side 2 are electrically neutral, since the impermeant anions added to side 1 are equaled by the added K^+, and the K^+ that has diffused to side 2 is balanced by the Cl^- electrostatically drawn along with it. But the entire solution is not at osmotic equilibrium, because the larger amount of ions on side 1 tends to draw water from side 2. Osmotic equilibrium can be established by the addition of ions to side 2. Indeed, in the neuron, osmotic equilibrium is maintained partly because large amounts of K^+ and impermeant anions inside the cell are balanced by large amounts of salt outside.

The neuronal membrane. The principles outlined above can be applied to the neuron and its ionic contents.

The plasma membrane of the neuron is semipermeable, being highly permeable to K^+ and slightly permeable to Cl^- and Na^+. In the extracellular fluid, electroneutrality is preserved by a balance between a high concentration of Na^+ on the one hand and a high concentration of Cl^- as well as small quantities of impermeant anions such as bicarbonate, phosphate, and sulfate on the other. In the cytoplasm, where K^+ concentration is high, the concentration of Cl^- is much below that necessary to balance the sum of the positive charges. Electroneutrality is maintained there by negatively charged impermeant proteins and phosphates. Osmotic balance is maintained between the extracellular fluid and the cytoplasm by movement of water through the plasma membrane when the total concentration of particles on one side is not equal to that on the other.

The electrical potential of the neuron

These three characteristics of the neuron—semipermeability of the membrane, osmotic balance, and electroneutrality on each side—create an equilibrium electrical potential at which the inside of the membrane is more negative than the outside. In most neurons this potential, called the membrane potential, is between −60 and −75 millivolts (mV; the minus sign indicates that the inner surface is negative). When the inside of the plasma membrane has a negative charge compared to the outside, the neuron is said to be polarized. Any change in membrane potential tending to make the inside even more negative is called hyperpolarization, while any change tending to make it less negative is called depolarization.

As stated above, the Nernst potential is the potential difference that exists across a membrane when a particular ion, having reached equilibrium between the tendency to diffuse down its concentration gradient and the tendency to be drawn back by other ions, is in a state of no net flux. Given such information as the energy of the dissolved substances, the temperature of the solution, and the concentrations of ions on each side of the membrane, researchers using the Nernst equation can predict the potential difference that will exist if the membrane is permeable to any one of the ions in solution. The plasma membrane of the neuron is highly permeable to K^+, and in fact the recorded membrane potential of most neurons (−60 to −75 millivolts) is close to that predicted by the Nernst equation for K^+. However, it is not exactly the

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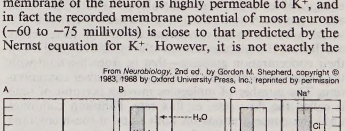


Figure 5: *Establishment of electrochemical and osmotic equilibrium.*
(A) A solution of KCl divided by a permeable membrane reaches electrochemical equilibrium, with both sides maintaining equal concentrations of KCl and each side maintaining equal positive (K^+) and negative (Cl^-) charges. (B) With the addition to side 1 of K^+ and an anion (A^-) that cannot permeate the membrane, equilibrium is upset. K^+ diffuses to side 2, drawing an equal charge of Cl^-. A new electrochemical equilibrium is reached at which each side maintains equal positive and negative charges, but side 1 has a higher concentration of ions than side 2. This causes the osmosis of water (H_2O) from side 2 to side 1. (C) Osmotic equilibrium is established by the addition of salt (NaCl) to side 2, creating an equal concentration of ions across the membrane.

same, because K^+ is not the only ion affecting the membrane potential. The membrane is also slightly permeable to Na^+ and Cl^-. The permeability to Na^+ may be low, but the high concentration of this cation outside the cell and the slightly negative electric charge inside the cell tend to drive Na^+ inward. This in turn causes the inside of the cell to depolarize, placing K^+ out of equilibrium. As a consequence, K^+ leaves the cell until an equilibrium state is reached in which the leak inward of Na^+ is equaled by the leak outward of K^+ and there is no net flux of ions. There is also a tendency for Cl^- to permeate the membrane, since that ion is at higher concentration outside the neuron than inside. Therefore, for an equilibrium state to be produced, the sum of all three net currents must equal zero.

Given the concentrations of all three ions on each side of the membrane and the relative permeability of the membrane to each ion, researchers can calculate the combined effect of K^+, Na^+, and Cl^- on the membrane potential by using the so-called constant-field equation. This equation, by including relative permeability as an important factor, takes into account the phenomenon that the more permeable a membrane is to a particular ion, the greater is the influence of that ion on membrane potential. The permeance of Na^+, for example, is only a fraction of that of K^+, and the permeance of Cl^- is lower yet; therefore, while the membrane potential is highly sensitive to changes in the concentration of K^+, it is less affected by changes in Na^+ and almost unaffected by changes in Cl^-.

TRANSMISSION IN THE NEURON

The discussion above demonstrates that the electrical potential existing in neurons is based on the distribution of ions across the plasma membrane and that this distribution comes about through permeation of the membrane. In fact, ions are almost always hydrated in the form of ion–water complexes, which have great difficulty in penetrating the hydrophobic lipid bilayer of the plasma membrane. Permeation actually occurs through protein structures embedded in the lipid bilayer and spanning the membrane from cytoplasm to extracellular fluid. Sometimes pumping ions from one side to the other and sometimes merely providing channels through which diffusing ions can flow past the lipid molecules, these structures maintain the ionic distribution that keeps the membrane polarized, and they also allow the abrupt changes in distribution that create nerve impulses. The protein structures are described in detail in *Ion transport.* Following is a discussion of the electrical events, created by movement of ions, that lead to nervous transmission in the neuron.

Resting potential. The electrical potential across the nerve membrane can be measured by placing one microelectrode within the neuron (usually in the soma) and a second microelectrode in the extracellular fluid. The microelectrode consists of a sharp-tipped glass capillary tube filled with a conducting solution. Upon penetration of the neuron, the potential at the tip of the electrode becomes electrically negative in relation to the outside electrode. As described above, the value of this negative charge is usually between −60 and −75 millivolts. This is the membrane potential of the neuron at rest (*i.e.,* when it is not generating a nerve impulse), and for this reason it is called the resting potential.

The resting potential is maintained by the sodium–potassium pump, which steadily discharges more positive charge from the cell than it allows in, and by the relatively high permeance of K^+, which leaks out of the cell through its membrane channels faster than Na^+ leaks in.

Localized potential. When a physical stimulus such as touch, taste, or colour acts on a sensory receptor cell specifically designed to respond to that stimulus, then the energy of the stimulus (*e.g.,* mechanical, chemical, light) is transduced, or transformed, into an electrical response. This response is the receptor potential, a type of local potential that, when it reaches high enough amplitude, generates the nerve impulse. (Another type of local potential is the postsynaptic potential, which originates in chemical receptors at the synaptic cleft. See below *Transmission at the synapse: Chemical transmission.*)

Response to stimulation

Sensory receptors transduce stimuli into electrical responses by activating ion channels in their membranes. For example, in the stretch receptors of neurons attached to muscle cells, the stretching action of the muscle is thought to put a mechanical stress on protein filaments of the cytoskeleton, which in turn alter the shape of ion channels, inducing them to open and allowing cations to diffuse into the cell. Receptor cells sensitive to chemical and light energy, on the other hand, activate ion channels through the so-called second-messenger system. Under this system, stimulated receptor molecules on the surface of the cell membrane catalyze a series of enzymatic reactions within the cytoplasm; these reactions in turn release energy, which activates the ion channels.

By permitting a flux of Na^+ into the cell, the opening of ion channels slightly depolarizes the membrane. The extent to which the membrane is depolarized depends upon the extent to which the sodium channels are activated, and this in turn depends upon the strength and duration of the original stimulus at the receptor. If depolarization reaches what is called the threshold potential, it triggers the nerve impulse, or action potential (see below). If it does not reach that amplitude, then the neuron remains at rest, and the local potential, through a process called passive spread, diffuses along the nerve fibre and back out through the membrane.

When it is of the postsynaptic type, the local potential usually begins in the dendrites and spreads toward the soma and axon. It is at the initial segment of the axon where, if the local potential is of threshold amplitude, the nerve impulse is generated.

Action potential. *Depolarization.* Because it varies in amplitude, the local potential is said to be graded. The greater the influx of positive charge—and, consequently, depolarization of the membrane—the higher the grade. Beginning at the resting potential of a neuron (for instance, −75 millivolts), a local potential can be of any grade up to the threshold potential (for instance, −58 millivolts). At threshold, voltage-dependent sodium channels become fully activated, and Na^+ pours into the cell. Almost instantly, the membrane actually reverses polarity, the inside acquiring a positive charge in relation to the outside. This reverse polarity constitutes the nerve impulse. It is called the action potential because the positive charge then flows through the cytoplasm, activating sodium channels the entire length of the nerve fibre. This series of activations,

Generation of the nerve impulse

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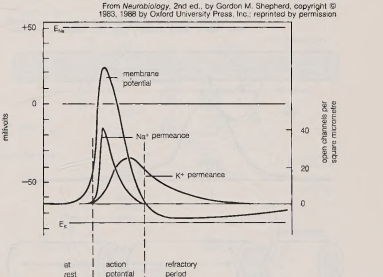


Figure 6: *Changes in ion permeance underlying the action potential.*
Electrical potential is graded at left in millivolts, ion permeance at right in open channels per square micrometre of membrane. At rest, with no channels open, the membrane potential is close to E_K, the equilibrium potential of K^+. When sodium channels open, the membrane depolarizes. Generation of the action potential brings the membrane potential close to E_{Na}, the equilibrium potential of Na^+. When sodium channels close (lowering Na^+ permeance) and potassium channels open (raising K^+ permeance), the membrane repolarizes. During the refractory period, while potassium channels remain open, the membrane is hyperpolarized.

by propagating the action potential along the fibre with virtually no reduction in amplitude, gives the nerve impulse its regenerative property.

Researchers call the nerve impulse an "all-or-none" reaction, since between threshold potential and fully activated potential there are no gradations. The neuron is either at rest with a polarized membrane, or it is conducting a nerve impulse at reverse polarization. The reverse polarity of active neurons is measured at about +30 millivolts. This is close to the Nernst potential for Na^+—that is, the membrane potential at which electrochemical equilibrium would be established if the membrane were completely permeable to Na^+.

Repolarization. As instantaneous as the opening of sodium channels at threshold potential is their closing at the peak of the action potential. This is called sodium inactivation, and it is caused by gates within the channel that are sensitive to depolarization. Following sodium inactivation is the opening of potassium channels, which allows the diffusion of K^+ out of the cell. The combined effect of sodium inactivation, which blocks the influx of cations, and potassium activation, which causes the efflux of other cations, is the immediate return of the cell membrane to a polarized state, with the inside negative in relation to the outside. After repolarization there is a period during which a second action potential cannot be initiated, no matter how large a stimulus current is applied to the neuron. This is called the absolute refractory period, and it is followed by a relative refractory period, during which another action potential can be generated, but only by a greater stimulus current than that originally needed. This period is followed in turn by the return of the neuronal properties to the threshold levels originally required for the initiation of action potentials.

Conduction. The sequence of sodium activation–sodium inactivation–potassium activation creates a nerve impulse that is brief in duration, lasting only a few milliseconds, and that travels down the nerve fibre like a wave, the membrane depolarizing in front of the current and repolarizing behind. Because nerve impulses are not graded in amplitude, it is not the size of the action potential that is important in processing information within the nervous system; rather, it is the number and frequency with which the impulses are fired.

As stated above, the action potential is propagated along the axon without any decrease in amplitude with distance. However, the velocity of conduction along the

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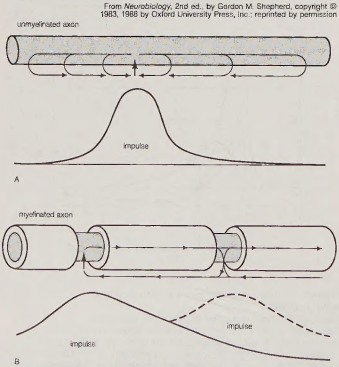


Figure 7: *Conduction of the action potential.*
(A) Passive spread in an unmyelinated axon. The impulse fades along the fibre as it diffuses back through the membrane to the original depolarized region. (B) Saltatory conduction in a myelinated axon. The impulse jumps along the fibre as it is regenerated at each node of Ranvier.

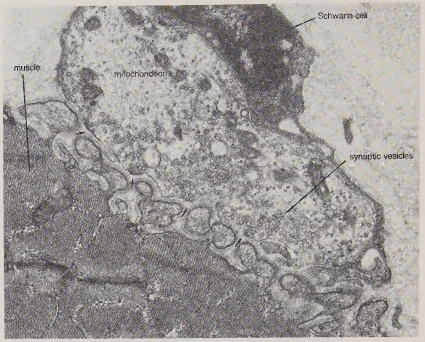


Figure 8: *Electron micrograph of the neuromuscular junction of the frog.*
The motor nerve terminal at the end-plate region contains synaptic vesicles. Active zones (arrows) are located opposite troughs in the postsynaptic membrane of the muscle. A Schwann cell partially covers the terminal.
By courtesy of A. Stieber, N. Gonatas, and S.D. Erulkar

nerve fibre is dependent upon several factors. First is the outside diameter of the nerve fibre. The fastest conduction velocity occurs in the largest diameter nerve fibres. This phenomenon has formed the basis for classifying mammalian nerve fibres into groups in order of decreasing diameter and decreasing conduction velocity. Another factor is the temperature of the nerve fibre. Conduction velocity increases at high temperature and decreases at low. Indeed, nerve conduction can be blocked by the local application of cold to a nerve fibre. Conduction velocity is also affected by myelination of the nerve fibre. Since ions cannot cross the lipid content of the myelin sheath, they spread passively down the nerve fibre until reaching the unmyelinated nodes of Ranvier. The nodes of Ranvier are packed with a high concentration of ion channels, which, upon stimulation, propagate the nerve impulse to the next node. In this manner the action potential jumps quickly from node to node along the fibre in a process called saltatory conduction (from Latin *saltare,* "to jump"; see Figure 7).

Factors affecting the velocity of transmission

TRANSMISSION AT THE SYNAPSE

Once an action potential has been generated at the axon hillock, it is conducted the length of the axon until it reaches the terminals, the fingerlike extensions of the neuron that abut other neurons and muscle cells (see above *The nerve cell: The neuron*). At this point there exist two methods for transmitting the action potential from one cell to the other. In electrical transmission, the ionic current flows directly through channels that couple the cells. In chemical transmission, a chemical substance called the neurotransmitter passes from one cell to the other, stimulating the second cell to generate its own action potential.

Electrical transmission. This method of transmitting nerve impulses, while far less common than chemical transmission, has been found in the nervous systems of invertebrates and lower vertebrates as well as in the central nervous systems of some mammals. Transmission takes place through so-called gap junctions, which are protein channels that link the cellular contents of adjacent neurons. Direct diffusion of ions through these junctions allows the action potential to be transmitted with little or no delay and distortion, in effect synchronizing the response of an entire group of neurons. The channels often allow ions to diffuse in both directions, but some gated channels restrict transmission to only one direction.

Gap junctions

Chemical transmission. There are two classic preparations for the study of chemical transmission at the synapse.

One is the vertebrate neuromuscular junction, and the other is the giant synapse of the squid *Loligo*. These sites have the advantage of being readily accessible for recording by electrodes—especially the squid synapse, which is large enough that electrodes can be inserted directly into the presynaptic terminal and the postsynaptic fibre. In addition, only a single synapse is involved at these sites, whereas a single neuron of the central nervous system may have many synapses with many other neurons, each with a different neurotransmitter.

Neurotransmitter release. Two factors are essential for the release of the neurotransmitter from the presynaptic terminal: (1) depolarization of the terminal and (2) the presence of calcium ions (Ca^{2+}) in the extracellular fluid. The membrane of the presynaptic terminal contains voltage-dependent calcium channels that open when the membrane is depolarized by a nerve impulse, allowing Ca^{2+} to diffuse into the terminal along its concentration gradient (see Figure 9). Following the entrance of Ca^{2+} is the release of neurotransmitter. The scheme may be depicted as follows:

depolarization → calcium entry → neurotransmitter release

What happens in the time between Ca^{2+} entry and transmitter release is uncertain. Ca^{2+} is known to be sequestered by certain organelles within the terminal, including the endoplasmic reticulum. The ions may attach to the membranes of synaptic vesicles, in some way facilitating their fusion with the nerve terminal membrane. They may also be removed from the terminal by exchange with extracellular Na^+—a mechanism known to occur at some neuronal membranes. What is certain is that when the concentration of Ca^{2+} is increased within the terminal, then the probability of transmitter release is also increased.

Release of neurotransmitter in synaptic vesicles

Neurotransmitter substances are packed into small, membrane-bound spheres called synaptic vesicles. Each vesicle contains thousands of neurotransmitter molecules, and there are thousands of vesicles in each axon terminal. Once stimulated by Ca^{2+}, the vesicles move through the cytoplasm and fuse their membranes with the plasma membrane of the terminal. The transmitter molecules are then expelled from the vesicles into the synaptic cleft. This expulsion process is called exocytosis. Vesicle membranes are then recovered from the plasma membrane through endocytosis. In this process the membranes are surrounded by a protein coat at the lateral margins of the synapse and are then transferred to cisternae, which form in the terminal during nerve stimulation. There the vesicles lose their coats, are probably refilled with neurotransmitter, and pinch off from the cisternae to become synaptic vesicles once more.

Because the neurotransmitter chemicals are packed into separate, almost identically sized vesicles, their release into the synaptic cleft is said to be quantal—that is, rather than flowing from the terminal in a growing stream, they are expelled in parcels, each vesicle adding its contents incrementally to the contents released from other parcels. This quantal release of neurotransmitter has a critical influence on the electrical potential created in the postsynaptic membrane.

Postsynaptic potential. After neurotransmitter is released from the presynaptic terminal, it diffuses across the synaptic cleft and binds to receptor proteins on the postsynaptic membrane. Some receptors are ion channels that open or close when their molecular configuration is altered by the binding action of the neurotransmitter. Others are membrane proteins that, upon activation, catalyze second-messenger reactions within the postsynaptic cell; these reactions in turn open or close the ion channels. Whether acting upon ion channels directly or indirectly, the neurotransmitter molecules bring about a sudden change in the membrane's permeability to specific ions. Exactly which ions now permeate the membrane vary according to the neurotransmitters and their receptors (see below *Neurotransmitters and neuromodulators*), but the net result of a change in ion diffusion is a change in electrical potential across the membrane. This change is called the postsynaptic potential, or PSP. (In reference to the neuromuscular synapse, it is also called the end-plate potential, or EPP.)

Excitatory and inhibitory postsynaptic potentials

The most common potential change is depolarization, caused by a net influx of cations (usually Na^+). Because this infusion of positive charge brings the membrane potential toward the threshold at which the nerve impulse is generated, it is called an excitatory postsynaptic potential (EPSP). Other neurotransmitters stimulate a net efflux of positive charge (usually in the form of K^+ diffusing out of the cell), leaving the inside of the membrane more negative. Because this hyperpolarization draws the membrane potential farther from threshold, making it more difficult to generate a nerve impulse, it is called an inhibitory postsynaptic potential (IPSP). The interaction of competing EPSPs and IPSPs at the hundreds or even thousands of synapses on a single neuron determines whether the nerve impulse arriving at the presynaptic terminals will be regenerated in the postsynaptic membrane.

The PSP is a type of local potential, having properties similar to the electrical potential set up at sensory receptor neurons (see above *Transmission in the neuron: Localized potential*). Like the receptor potential, the PSP is a graded response, varying in amplitude according to the duration and amount of stimulation by neurotransmitter substances. At the neuromuscular junction, brief depolarizations measuring no more than one millivolt can be observed in the postsynaptic muscle membrane, even when it is at rest. These tiny electrical events, called miniature end-plate potentials (MEPPs) or miniature postsynaptic potentials (MPSPs), are caused by the random release of single quanta of neurotransmitter from a resting presynaptic terminal. The EPP is actually made up of multiple MEPPs, which arise when an activated terminal releases hundreds of neurotransmitter quanta. A series of EPPs, or a number of them stimulated simultaneously at many synapses, can then bring the cell to the threshold of the action potential. This combined action of EPPs is called summation.

In contrast to electrical transmission, which takes place with almost no delay, chemical transmission shows what is called the synaptic delay. Recordings from squid synapses and neuromuscular junctions of the frog reveal a delay of from 0.5 to 4.0 milliseconds between the onset of action

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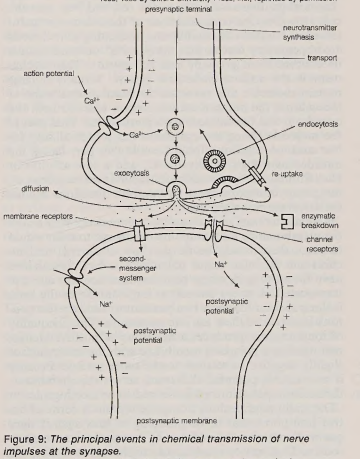


Figure 9: *The principal events in chemical transmission of nerve impulses at the synapse.*
The arrival of the nerve impulse at the presynaptic terminal stimulates the release of neurotransmitter into the synaptic gap. Before inactivation, the neurotransmitter molecules stimulate the regeneration of the impulse in the postsynaptic membrane.

potential at the nerve terminal and action potential at the postsynaptic site. This may be accounted for by three factors. First, diffusion of the neurotransmitter across the synaptic cleft takes approximately 0.05 millisecond. Second, the response of the postsynaptic receptor takes about 0.15 millisecond. This leaves 0.30 to 3.80 milliseconds for other processes. A third process, called mobilization of the transmitter, is traditionally postulated as taking up the remaining time, but evidence suggests that the time is occupied at least partially by the opening of calcium channels to allow the entry of Ca^{2+} into the presynaptic terminal.

Brief duration of the nerve impulse

Inactivation. A series of nerve impulses arriving in rapid succession at the axon terminal is accurately reproduced as a series in the postsynaptic cell because the quanta of neurotransmitter released by each impulse are inactivated as soon as they stimulate the receptor proteins. Neurotransmitter inactivation is carried out by a combination of three processes. First, the neurotransmitter molecules simply diffuse out of the narrow synaptic cleft. Second, they are taken back into the presynaptic terminal by transmitter-sensitive transport molecules. Third, they are metabolized into inactive compounds by enzymes in the synaptic cleft.

ION TRANSPORT

As was stated above, the lipid bilayer of the neuronal membrane tends to repel electrically charged, hydrated ions, making virtually impossible the movement across the membrane that is necessary for the generation of nerve impulses. The transmembrane movement of ions is actually carried out by molecular mechanism—specifically, by protein molecules embedded in the lipid layers. One mechanism, the sodium–potassium pump, maintains the resting potential, and another, the various ion channels, helps create the action potential.

Active transport: the sodium–potassium pump. Since the plasma membrane of the neuron is highly permeable to K^+ and slightly permeable to Na^+, and since neither of these ions is in a state of equilibrium (Na^+ being at higher concentration outside the cell than inside and K^+ at higher concentration inside), then a natural occurrence should be the diffusion of both ions down their electrochemical gradients—K^+ out of the cell and Na^+ into the cell. However, the concentrations of these ions are maintained at constant disequilibrium, indicating that there is a compensatory mechanism moving Na^+ outward against its concentration gradient and K^+ inward. This mechanism is the sodium–potassium pump. Actually a large protein molecule that traverses the plasma membrane of the neuron, the pump presents receptor areas to both the cytoplasm and the extracellular environment. That part of the molecule facing the cytoplasm has a high affinity for Na^+ and a low affinity for K^+, while that part facing the outside has a high affinity for K^+ and a low affinity for Na^+. Stimulated by the action of the ions on its receptors, the pump transports them in opposite directions against their concentration gradients.

If equal amounts of Na^+ and K^+ were transported across the membrane by the pump, the net charge transfer would be zero; there would be no net flow of current and no effect on the membrane potential. In fact, researchers have found that in many neurons three sodium ions are transported for every potassium ion; sometimes the ratio is three sodium for every two potassium, and in a few neurons it is two sodium for one potassium. This inequality of ionic transfer produces a net efflux of positive charge, maintaining a polarized membrane with the inner surface slightly negative in relation to the outer surface. Because it creates this potential difference across the membrane, the sodium–potassium pump is said to be electrogenic.

Maintaining a polarized membrane

The sodium–potassium pump carries out a form of active transport—that is, its pumping of ions against their gradients requires the addition of energy from an outside source. That source is adenosine triphosphate (ATP), the principal energy-carrying molecule of the cell. ATP is formed by an inorganic phosphate molecule held in high-energy linkage with a molecule of adenosine diphosphate (ADP). When an enzyme in the pump, called sodium–potassium–ATPase, splits the phosphate from the ADP, the energy released powers the transport action of the pump.

Passive transport: membrane channels. The sodium–potassium pump sets the membrane potential of the neuron by keeping the concentrations of Na^+ and K^+ at constant disequilibrium. The sudden shift from a resting to an active state, when the neuron generates a nerve impulse, is caused by a sudden movement of ions across the membrane—specifically, a flux of Na^+ into the cell. Given the relative impermeability of the plasma membrane to Na^+, this influx itself implies a sudden change in permeability. Beginning in the 19th century, researchers puzzled over the mechanism by which this change could occur. The idea arose that there must exist pores, or channels, through which the ions could diffuse, passing the barrier posed by the lipid bilayer. However, for years only the gross currents accompanying ionic movement could be measured, and it was only by inference that the presence of membrane channels could be postulated.

The breakthrough came in the 1970s and '80s with the development of the patch-clamp technique, which enabled investigators to directly measure currents flowing across single ion channels in the membrane. The patch-clamp technique electrically isolates a small patch of neuron or muscle cell membrane by applying the tip of a micropipette filled with conducting solution to the membrane and forming a tight seal with it. As single channels in the patch undergo various transitional states between fully open and fully closed, the times of opening and closing are recorded and the amplitudes and duration of the currents are measured.

Since the pioneering studies, the electrical and biochemical properties of certain channels have been characterized. Known as "voltage dependent" when activated by changes in the membrane potential and "neurotransmitter sensitive" when activated by neurotransmitter substances, these channels are protein structures that span the membrane from the extracellular space to the cytoplasm. They are believed to be cylindrical, with a hollow, water-filled pore wider than the ion passing through it except at one region called the selectivity filter. This filter makes each channel specific to one type of ion.

The sodium channel. Voltage-sensitive sodium channels have been characterized with respect to their subunit structure and their amino acid sequences. The principal protein component is known to be a glycoprotein containing 1,820 amino acids. Four similar "transmembrane domains," of about 300 amino acids each, surround a central aqueous pore through which the ions pass. The selectivity filter is a constriction of the channel ringed by negatively charged carbonyl oxygens, which repel anions but attract cations. Also within the channel are thought to be two types of charged particles forming the gates that control the diffusion of Na^+. One gate closes at polarization and opens at depolarization; the other closes at depolarization.

Structure of a channel protein

Investigators believe that the resting, activated, and inactivated states of the sodium channel are due to voltage-dependent conformational changes in the glycoprotein component. These changes result from effects of the electrical field on the charges and dipoles of the amino acids within the protein. With a large electrical field applied to it, the protein has been observed to change its conformation from a stable, closed resting state to a stable, open state in which the net charge or the location of the charge on the protein is changed.

The potassium channel. There are several types of voltage-dependent potassium channels, each having its own physiological and pharmacological properties. A single neuron may contain more than one type.

The best-known flow of K^+ is the outward current following depolarization of the membrane. This occurs through the so-called delayed rectifier channel (I_{DR}), which, activated by the influx of Na^+, counteracts the effect of that cation by allowing the discharge of K^+. By repolarizing the membrane in this way, the I_{DR} channel restricts the duration of the nerve impulse and participates in the regulation of repetitive firing of the neuron.

Another outward K^+ current, occurring with little delay after depolarization, is the so-called A current. The I_A channels are opened by depolarization following hyperpolarization. By increasing the interval between action potentials, they help a neuron fire repetitively at low frequencies.

Another type of potassium channel, the $I_{K(Ca)}$ channel, is activated by high concentrations of intracellular Ca^{2+}. The opening of these channels results in hyperpolarization of the membrane, so that they appear to slow the repetitive firing of nerve impulses.

The I_M channel is opened by depolarization but is deactivated only by the neurotransmitter acetylcholine. This property may serve to regulate the sensitivity of neurons to synaptic input.

A final type of potassium channel is the anomalous, or inward, rectifier channel (I_{IR}). This channel closes with depolarization and opens with hyperpolarization. By allowing an unusual inward diffusion of K^+, the I_{IR} channel prolongs depolarization of the neuron and helps produce long-lasting nerve impulses.

The calcium channel. As with potassium channels, there is more than one type of calcium channel. The inward calcium current has been shown to be slower than the sodium current. Studies show the presence of at least two types in certain neurons of the central nervous system—a long-lasting current activated at positive potential and a transient current activated at more negative potential. Patch-clamp studies show two corresponding types of calcium channel: a large conductance channel that gives rise to a long-lasting current at positive membrane potentials and a low conductance channel that gives rise to a transient current at more negative potentials. In some neurons a third channel current has been measured that is transient and can only be activated at high negative potential.

Anion channels. Evidence points to channels that pass anions such as Cl^-, but their existence is difficult to prove. Single-channel recordings of cultured tissue have shown selective Cl^- channels that are voltage dependent and of high conductance. Channels with lower conductance have been demonstrated in reconstituted artificial membranes as well as in neurons.

NEUROTRANSMITTERS AND NEUROMODULATORS

The traditional models for the study of neurotransmitter release are either the neuromuscular junction of the frog, crayfish, and rat or the giant synapse of the squid. These synapses are relatively simple in their structure, with a single axon terminal forming an identifiable synapse at the postsynaptic membrane of a muscle fibre or neuron. Recordings can be obtained from these single-synaptic junctions in response to the release of a single neurotransmitter. At neurons of the central nervous system, on the other hand, the situation is more complex. Each central neuron has several synapses with other neurons at various locations, such as on the dendrites, soma, and initial segment of the axon. Several neurotransmitters, therefore—some excitatory and others inhibitory—may be involved in the final integrated response of a central neuron, making their identities difficult to determine.

Further complicating the study of neurotransmitter action is the presence not only of multiple transmitter substances but also of neuromodulators. These are substances that do not directly activate ion-channel receptors but that, acting in concert with neurotransmitters, enhance the excitatory or inhibitory responses of the receptors. It is often impossible to discern, in the presence of many substances, which are transmitters and which are modulators. Such is the case with many of the neuropeptides (see below *Neuroactive peptides*).

The second-messenger system

In addition to the multiplicity of transmitters and modulators is a multiplicity of receptors. Some receptors directly open ion channels, while others activate the second-messenger system. This is any of a number of reactions that take place in the cytoplasm or plasma membrane and indirectly act upon the ion channels. One second-messenger system involves the activation by receptor proteins of so-called linking proteins, which move across the membrane, bind to channel proteins, and open the channels. Another system is the cyclic adenosine monophosphate (cAMP) system. In this chain reaction, receptor proteins activate linking proteins, which then activate the enzymes that synthesize cAMP. The cAMP molecules activate other enzymes that, in turn, activate ion channels.

Whether they activate channels directly or through a second-messenger system, neurotransmitters are considered to be primary messengers. Criteria have been defined that, when fulfilled, allow an investigator to identify a substance as a true neurotransmitter for a specific neuron. In many situations, all the criteria are not satisfied. While this does not necessarily mean that the substance is not a neurotransmitter, it does mean that the argument for its being so is considerably weakened. The criteria are as follows:

1. The presynaptic neuron.
   - *a.* Enzymes should be present for synthesis of the neurotransmitter.
   - *b.* The neurotransmitter should be released in pharmacologically identifiable form.
   - *c.* Enzymes that destroy the neurotransmitter may be present in the synaptic gap. Because some neurotransmitters are inactivated by uptake back into the presynaptic terminal or into surrounding glial cells, the presence of catabolic enzymes is not a mandatory requirement.
2. The postsynaptic site.
   - *a.* Application of the substance under experimental conditions must be able to reproduce the specific events of normal transmission.
   - *b.* Under experimental conditions the action of the substance must be mimicked or facilitated by the same agents that are known to elicit identical responses in nerve stimulation. Conversely, the action of chemicals that block the substance must be the same in actual nerve stimulation as they are in experimental application of the suspected neurotransmitter.

Described below are the principal proved or suggested neurotransmitters of the mammalian nervous system and their corresponding receptors.

Acetylcholine. This was the first neurotransmitter whose actions were proved to fulfill the criteria given above. Although early studies of acetylcholine were undertaken at neuromuscular junctions, where it is especially concentrated, the concept leading to the identification of the substance as a neurotransmitter of the central nervous system is a landmark in neuroscience. The concept is called Dale's principle after Sir Henry Dale, a British physiologist who, in 1935, stated that a neurotransmitter released at one axon terminal of a neuron can be presumed to be released at other axon terminals of the same neuron. (Dale's principle refers only to the presynaptic neuron, as the responses of different postsynaptic receptors to a single neurotransmitter can vary in the same or different neurons.) The first application of Dale's principle was at the mammalian spinal cord, from which motor neurons send their axons to striated muscles, where the terminals are observed to release acetylcholine. According to Dale's principle, all of the branches of a single motor neuron axon should release acetylcholine—including the terminals in the spinal cord. In fact, it was found that some collateral branches leave the motor axons and reenter the gray matter of the spinal cord, where they synapse onto spinal interneurons. The neurotransmitter released at these terminals is acetylcholine. High concentrations of the acetylcholine-synthesizing enzyme, choline acetyltransferase, and the enzyme for its breakdown, acetylcholinesterase, are also found in motor neuron regions of the spinal cord.

Cholinergic receptors

Acetylcholine receptors (also called cholinergic receptors) appear in clusters on muscle-cell membranes opposite the active zones of presynaptic terminals. Their density at these receptor regions is between 7,000 and 30,000 sites per square micrometre. The number drops drastically even a few nanometres (billionths of a metre) away from the receptor region, so that sensitivity to acetylcholine is about 50 to 100 times less one millimetre from the receptor region than it is at the receptor site itself. Cholinergic receptors also exist on the presynaptic terminals of neu-

rons that release acetylcholine as well as on terminals that release other neurotransmitters. These receptors are called autoreceptors, and they probably regulate the release of neurotransmitter at the terminal.

There are two main categories of cholinergic receptor, nicotinic and muscarinic. In the first years of the 20th century, they were differentiated by their responses to the alkaloids nicotine and muscarine, but advanced biochemical techniques have shown a more fundamental difference. The nicotinic receptor is a channel protein that, upon binding by acetylcholine, opens to allow diffusion of cations. The muscarinic receptor, on the other hand, is a membrane protein; upon stimulation by neurotransmitter, it causes the opening of ion channels indirectly, through a second messenger. For this reason, the action of a muscarinic synapse is relatively slow. Muscarinic receptors predominate at higher levels of the central nervous system, while nicotinic receptors, which are much faster acting, are more prevalent at neurons of the spinal cord and at neuromuscular junctions in skeletal muscle.

The nicotinic receptor channel has been purified and shown to be a glycoprotein composed of five subunits (Figure 10). Two so-called alpha- (α-) subunits contain the two acetylcholine-binding sites associated with the channel. Three other subunits—a beta- (β-) subunit, a gamma- (γ-) subunit, and a delta- (δ-) subunit—complete the protein. High-resolution electron microscopy with optical image reconstruction, as well as freeze-fracture electron microscopy, reveal a highly symmetrical structure, looking from the top somewhat like a life belt, with the presumed channel in the centre. About one-third of the protein protrudes from the plasma membrane, while the rest is embedded in the membrane or protruding into the cell.

Patch-clamp techniques give information on single channel currents and, hence, on the conductance and kinetics of the cholinergic receptor channel. At the neuromuscular junction, approximately 20,000 univalent ions carry the charge across a single activated channel, and a quantum of acetylcholine activates about 1,500 channels. The time constant for the decay of the MEPP is the same as that for channel closing. The time constant for channel closing is voltage dependent, with depolarization shortening the duration of open channels and hyperpolarization lengthening the duration.

Studies show that nicotinic acetylcholine-activated channels allow cations to permeate the membrane with no specificity—that is, all cations can diffuse through the channels indiscriminately. Because the resting membrane is already near the equilibrium potential of K^+, this means that much more Na^+ and Ca^{2+} diffuse into the cell than K^+ out, causing depolarization and excitation of the neuron or muscle cell. However, in certain molluscan neurons, nicotinic acetylcholine receptors can also activate Cl^- channels, causing hyperpolarization of the postsynaptic membrane and inhibition of the cell's excitability. With respect to muscarinic receptors, the situation is not clear. Second messengers may be involved, and potassium channels may be activated.

Epinephrine and norepinephrine. These related hormones, also called adrenaline and noradrenaline, act to increase the heart rate, blood pressure, and levels of sugar and fat in the blood. They are secreted into the bloodstream by the adrenal glands in response to stress, but they are also synthesized and released as neurotransmitters by axon terminals in the central nervous system and in sympathetic fibres of the autonomic system.

Adrenergic receptors

Receptors sensitive to norepinephrine and epinephrine are called adrenergic receptors. They are divided into two types, α and β. These are further classified into subtypes α_1, α_2, β_1, and β_2.

Both types of adrenergic receptor produce changes in the postsynaptic membrane potential by acting upon ion channels specific to K^+ and Ca^{2+}. They differ in the mechanisms that, upon stimulation by neurotransmitter, they employ to activate those channels. Stimulated β_1 receptors bind to linking proteins that in turn bind to calcium channels, changing their shape and altering their permeability to the cation. More important, the linking proteins stimulate the synthesis of cAMP, which, through another

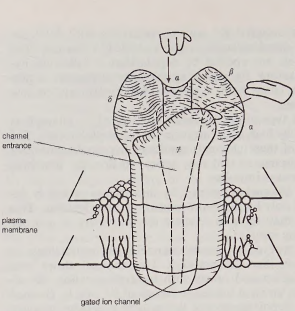


Figure 10: *The cholinergic channel receptor.*
The two α-subunits and the β-, γ-, and δ-subunits are arranged symmetrically around a central channel.
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series of reactions, opens potassium channels. The efflux of K^+ tends to hyperpolarize the postsynaptic membrane, inhibiting the generation of a nerve impulse. The β_2 receptor has been found on glial cells.

The α_2 receptor activates potassium channels in both the postsynaptic and presynaptic membranes, probably via linking proteins and the synthesis of cAMP. The α_1 receptor acts on calcium channels through a series of reactions linked to the lipid molecules of the plasma membrane.

Both epinephrine and norepinephrine are terminated by uptake back into the presynaptic terminals, where they are enzymatically degraded or inactivated.

For a discussion of the effects of adrenergic transmission on organs and muscles, see below *Functions of the human nervous system: The autonomic system.*

Dopamine. This precursor of norepinephrine acts as a neurotransmitter at certain synapses of the brain. Disorders at these synapses have been implicated in schizophrenia and Parkinson's disease.

There are two types of dopaminergic receptor, called the D_1 and the D_2. The former catalyzes the synthesis of $cAMP$, and the latter inhibits its synthesis. These reactions then regulate calcium and potassium channels in the postsynaptic membrane. Dopaminergic receptors also exist on the presynaptic membrane. The neurotransmitter is terminated by uptake into the presynaptic terminal.

Serotonin (5-hydroxytryptamine). Although the brain has only a small percentage of the serotonin found in the body, there appears to be a strong relationship between the levels of this neurotransmitter at some regions of the brain and certain behavioral patterns, including sleep, sexual urge, and mood. At synapses of the peripheral nervous system, it seems to prime muscle cells for an excitatory response to other neurotransmitters.

Serotonin receptors, or 5HT receptors, activate calcium and potassium channels through linking proteins and the cAMP second-messenger systems. After acting on the postsynaptic receptors, the neurotransmitter is taken up by the presynaptic terminal and enzymatically degraded.

Amino acids. Several amino acids exist in the central nervous system in extremely high concentrations, but their ubiquity makes their identification as true neurotransmitters difficult. Furthermore, because some of them are essential components of metabolic reactions, their presence within a neuron does not prove that they function as neurotransmitters. Nevertheless, there is enough evidence that some amino acids act as either excitatory or inhibitory transmitters. The excitatory amino acids include glutamic acid (or glutamate) and aspartic acid (or aspartate), and the inhibitory amino acids include gamma-aminobutyric acid (GABA) and glycine.

Excitatory amino acids. Glutamate is the most abundant amino acid in the brain. Unlike acetylcholine, glu-

Excitatory neurotransmitter in the spinal cord

tamate does not vary greatly in concentration from one region to the next. However, the dorsal gray matter of the spinal cord, which contains terminals of incoming dorsal roots, has large concentrations of glutamate. Aspartate, on the other hand, is believed to be concentrated in the interneurons of the ventral gray matter.

At postsynaptic receptor sites glutamate depolarizes the membrane by opening nonspecific cation channels, which allow a net influx of Na^+ and Ca^{2+}. Of the excitatory amino acid receptors, the N-methyl-D-aspartic acid (NMDA) receptor has been thoroughly characterized. Patch-clamp studies show that this receptor is influenced by the presence of magnesium ions (Mg^{2+}). In the absence of Mg^{2+}, activated NMDA receptors open nonspecific cationic channels with no variation when the voltage is changed. With Mg^{2+} added to the extracellular medium, though, the frequency of channel openings is reduced when the membrane is hyperpolarized. Both glutamate and aspartate are probably inactivated by uptake systems at the presynaptic terminals and at glial cells surrounding some of the synaptic junctions.

Inhibitory amino acids. GABA and glycine are proved to cause hyperpolarization of the postsynaptic membrane. GABA is widely distributed in the brain, being especially prevalent at higher levels of the central nervous system. It is produced from glutamate by the enzyme glutamic acid decarboxylase (GAD). Consequently, the concentrations of GABA and GAD parallel each other in the nervous system.

At postsynaptic receptor sites GABA opens chloride channels, causing in most cells a hyperpolarization of the membrane as Cl^- diffuses inward to reach its equilibrium potential. It must be pointed out, however, that GABA inhibits presynaptic nerve fibres as well. At certain synaptic junctions the release of neurotransmitter is modulated by the binding to presynaptic receptors of neurotransmitter released from other neurons. A classic example of this is at the axon terminals of incoming dorsal roots in the dorsal gray matter. Projecting onto these terminals are other terminals that release GABA. Although GABA causes an increased Cl^- conductance at these terminals, the result is depolarization, not hyperpolarization, of the membrane. This is because the resting membrane potential of the receiving nerve terminal is much more negative than the Cl^- equilibrium potential. This means that as Cl^- flows into the terminal to reach equilibrium, the membrane is actually depolarized. The effect at the terminal is a decrease in neurotransmitter release.

Unlike GABA, glycine is found mostly at lower levels of the central nervous system, including the spinal cord, medulla oblongata, and pons. It is a major inhibitor released by interneurons to suppress motoneuronal activity. Like GABA, glycine acts by increasing Cl^- conductance at the postsynaptic membrane, although it acts at a clearly different receptor.

It appears that at least two molecules of glycine and GABA must bind to their respective receptors to activate a chloride channel. The action of both neurotransmitters is terminated by uptake back into the presynaptic terminal or into surrounding glial cells.

Histamine. The main difficulty in proving that this substance acts as a neurotransmitter is the lack of adequate techniques for identification. There is little doubt that histamine exists in the brain, but it appears to be present in at least two distinct compartments—in mast cells (non-neuronal connective-tissue cells) and in nerve endings. The actions of histamine are unclear; it is reported to act as a depressor of neuronal activity at some sites and as an excitor at others.

Adenosine triphosphate. ATP may also be a neurotransmitter, particularly at primary sensory endings in the spinal cord. However, its ubiquitous distribution and participation in many energy-conversion reactions makes its role as a neurotransmitter difficult to establish.

Neuroactive peptides. Neuroactive peptides are sequences of amino acids, usually longer than amino acid neurotransmitters yet shorter than hormones or proteins. Unlike the classic neurotransmitters described above, which are formed by enzymes near the presynaptic terminals, neuroactive peptides are assembled by ribosomes attached to the endoplasmic reticulum. From there they are transferred to the Golgi apparatus, where they are packed into secretory vesicles and transported to the terminals. Some peptides are secreted by so-called neuroendocrine cells of the hypothalamus or pituitary gland. Because they are released into the capillary system of the bloodstream and act at distant sites of the body, these are called neurohormones. Other peptides are released into the synaptic cleft between neurons of the central nervous system (including the hypothalamus). Many of these so-called neuropeptides fulfill some criteria of neurotransmitters, evoking excitatory or inhibitory responses in postsynaptic ion channels, yet it is still uncertain to what extent they act as true neurotransmitters or as neuromodulators.

Distinction between neurotransmitters and neuropeptides

Distinguishing neuropeptides from the classic neurotransmitters is the longevity of their action. While acetylcholine, for example, acts upon synaptic receptors for only a few milliseconds, neuropeptides have a course of action lasting from several seconds to several days. Also, neuropeptides are released in much lower concentrations than are transmitter substances, although the peptides have a much higher potency.

The list of neuropeptides is not yet complete. Among those peptides known to affect synaptic transmission are substance P, neurotensin, somatostatin, vasoactive intestinal peptide, cholecystokinin, and the opioid peptides. The best studied are the opioid peptides, so called because opiate drugs such as morphine are known to bind to their receptors and mimic their pain-killing and mood-altering actions. All opioid peptides belong to three genetically distinct families: the β-endorphins, the enkephalins, and the dynorphins.

It has long been known that opioids and opiate drugs have varied and powerful effects on pain, mood, sleep, sedation, and the cough reflex—apart from effects on the gastrointestinal tract and the cardiovascular system. It is not surprising, therefore, that there are multiple receptors for these substances. There may in fact be as many as eight different types of opioid receptor, but the four best described are designated mu (μ), kappa (κ), delta (δ), and sigma (σ). The μ receptors, which readily bind morphine, are believed to mediate euphoria, respiratory depression, and physical addiction and to block pain pathways in the brain. The κ receptors bind preferentially to dynorphin and are believed to mediate analgesia and sedation at the spinal cord. The δ receptors, located primarily in the limbic portions of the brain, bind enkephalin. They may be responsible for dysphoria (extreme depression), hallucination, and respiratory and vasomotor stimulation. The σ receptors are perhaps involved in alterations of affective behaviour, but their functions are unclear. They are found in the hippocampus.

Inhibitory mechanisms of opioid receptors

The opioid receptors mediate their effects mainly by inhibiting regeneration of the nerve impulse at the postsynaptic membrane. They do this by opening potassium channels or closing calcium channels, causing a net outflow of positive charge that keeps the postsynaptic membrane from reaching threshold potential. As with other neuropeptides, it is not known whether all the opioid receptors are activated by the opioids alone or by a combination of opioid and other transmitter substances. For this reason it is uncertain whether the opioid peptides are true neurotransmitters or are neuromodulators.

The presence of peptides within certain structures of the central nervous system is well established; more important, peptides are often found in the same neurons with classic neurotransmitters or with other peptides. For example, substance P can be found in the same neurons of the brain stem as serotonin. In the sympathetic system, norepinephrine is found with somatostatin in some neurons and with enkephalin in others.

Because some neuropeptides and transmitters are stored in the same vesicles and secreted together in response to stimulation, a form of interaction between the substances appears likely. The interaction could take place at presynaptic terminals, altering the release of neurotransmitter, or it could take place postsynaptically, altering the effect of neurotransmitter. At the neuromuscular junction of the

lobster, for example, the neurotransmitters serotonin and octopamine and the neuropeptide proctolin can act presynaptically to alter the amounts of GABA or glutamate released from the nerve terminals. In a similar manner, at some regions of the central nervous system opioid peptides inhibit the release of norepinephrine, acetylcholine, dopamine, and substance P.

The discovery of more than one type of neuroactive substance in one set of axon terminals has disproved an assumption implied by Dale's principle—that a single neuron synthesizes and secretes a single neurotransmitter. Also called into doubt is another assumption—that a single neuron secretes a single set of neurotransmitters at all of its synapses. Researchers are finding evidence that different synapses of the same neuron act somewhat independently. This may mean that different areas of a single neuron synthesize different neuroactive substances. Such a phenomenon would be another example of the metabolic and functional complexity of the nervous system.

(S.D.E.)

EVOLUTION AND DEVELOPMENT OF THE NERVOUS SYSTEM

The study of the evolutionary development of the nervous system traditionally concentrated on the structural differences that exist at various levels of the phylogenetic scale, but certain functional characteristics, including biochemical and biophysical processes laid down early in evolution and amazingly well conserved to the present, can no longer be ignored. Two basic aspects of the evolution of the nervous system must be considered: first, how primitive systems serve newer functions, and, second, how the formation of new systems serves newer functional requirements.

Early theories on the evolutionary origin of the nervous system argued for a three-stage process: first, the development of non-nervous "independent effectors," such as muscle cells; second, the appearance of non-nervous receptors responding to certain modalities in a receptor-effector mechanism; and finally, the formation of a "protoneuron," from which primitive nerves and ganglia evolved. This model is no longer considered valid. In primitive systems there appear to be many examples of non-nervous electrical conduction. For instance, large areas of epithelium covering the swimming bells in the hydrozoan order Siphonophora (which contains certain families of jellyfish) contain neither nerve nor muscle, yet depolarizing potentials between cells of the epithelium have been recorded. Similar examples from other systems in related orders suggest that the evolution of the nervous system may have begun with non-nervous epithelial tissue. The conduction of electrical potentials from one epithelial cell to the next may well have been via so-called tight junctions, in which the plasma membranes of adjacent cells fuse to form sheets of cells. Tight junctions have low electrical resistance and high permeability to molecules. They also occur in great numbers in embryos, suggesting that the electrical potentials of cells joined in this manner serve as a driving force for the movement of ions and even nutritive substances from one cell to the next. These phenomena suggest that electrically mediated junctional transmission is older than chemically mediated synaptic transmission, which would require that some epithelial cells secrete chemical substances.

Possible origin of nerve cells

Many investigators believe that neurons originated from endothelial secretory cells that could secrete chemical substances, respond to stimulation, and conduct impulses. Specialization may then have brought about an outer receptor surface and an inner conducting fibre. In fact, neurosecretory cells can propagate action potentials, and many neurons secrete chemical substances, called neurohormones, that influence the growth and regeneration of cells at other sites of the body. Some researchers suggest that neurons first appeared as neurosecretory growth-regulating cells in which elongated processes were later adapted to rapid conduction and chemical transmission by release of transmitters at their endings.

There is an amazing consistency in neurotransmitters present in different organisms of a given phylum, although different phyla may show striking differences. Thus, in vertebrates, including fishes, amphibians, reptiles, birds, and mammals, the motor neurons (neurons whose fibres innervate striated muscle) are always cholinergic; in arthropods, on the other hand, they are not cholinergic, although the sensory neurons do secrete acetylcholine. The number of known neurotransmitter substances in the animal kingdom is indeed small, and their presence in more primitive organisms as well as in nervous systems of later vertebrates shows a striking conservation of these substances throughout evolution.

Natural selection of nervous systems

If later organisms evolved from single-celled ancestors, then there must have been some system for the transmission of information from one evolutionary stage to the next. These conditions have been defined as: (1) a stable means for encoding, transmitting, and decoding characteristics from one generation to the next, (2) the possibility of alterations in the code taking place by mutation or sexual recombination, and (3) a means of selecting only those characteristics for transmission that are favourable for survival. As mentioned above (see *Stimulus–response coordination*), protozoans (single-celled organisms) move toward places that are favourable for survival, such as areas with optimal conditions of light and temperature. As the metazoans (multicelled organisms) developed, entire groups of cells probably tended to move toward favourable conditions, and when the number of cells became very large, a system of internal communication—in effect, a nervous system—developed. Two general types developed: the diffuse nervous system and the centralized nervous system.

Diffuse nervous systems

The diffuse nervous system is the most primitive nervous system. In diffuse systems nerve cells are distributed throughout the organism, usually beneath the outer epidermal layer. Large concentrations of nerve cells—as in the brain—are not found in these systems, though there may be ganglia, or small local concentrations of neurons. Diffuse systems are found in cnidarians (hydroids, jellyfish, sea anemones, corals) and in ctenophores, or comb jellies. However, the primitive nervous systems of these animals do not preclude prolonged and coordinated responses and integrated behaviour to the simplest stimuli. An example is the movement of the sea anemone *Calliactis* onto the shell of the hermit crab *Pagurus* in response to a factor present in the outer layer of the empty mollusk shell occupied by the crab. This movement requires integration of the highest order.

Most cnidarians, such as those of the genus *Hydra*, have what is called a nerve net—a meshlike system of individual and separate nerve cells and fibres dispersed over the organism (Figure 11A). Species of *Hydra* have two nets, one located between the epidermis and the musculature and the second associated with the gastrodermis. Connections occur at various points between the two nets, with individual neurons making contact but not fusing, thereby forming structures similar to the chemically mediated synapses of vertebrates. Several specializations occur within various species. In *Hydra* the neurons are slightly more concentrated in a ring near the pedal disk and the hypostome (the "mouth"), but in jellyfish of a related genus the nerve fibres form a thick ring at the margin of the bell to form "through" conduction pathways.

The nervous systems of cnidarians correspond to their radially symmetrical bodies, in which similar parts are arranged symmetrically around a hollow gut cavity called

the coelenteron. In some species nerve fibres course along the radial canals, where there may be arranged sensory bodies, called rhopalia, which contain ganglionic concentrations of neurons. In the sea anemone *Metridium* some of the nerve fibres are seven to eight millimetres long and form a system for fast conduction of nerve impulses. Such specializations may have allowed the evolution of different functions. Certainly the rapid coordination of swimming movements requires a fast-conducting pathway, while feeding relies on the nerve net. Integrative activity is likely to occur at the sensory ganglia, which may represent the first forms of a centralized nervous system.

Comparison with mammalian nervous transmission

The terminals forming synapselike structures in nerve nets contain synaptic vesicles that are believed to be packed with neurotransmitters and neuroactive peptides. Peptides present in *Hydra* nervous systems also exist in mammalian systems as neuromodulators, neurohormones, or even possible neurotransmitters.

Transmission in the nerve net is relatively slow compared with that in other nervous systems (0.04 metre per second in radial fibres of *Calliactis* compared with 100 metres per second in some fibres of the dog). Many repetitive stimuli may be required to elicit responses at these synapses. Long refractory periods are also characteristic of nerve nets, having durations about 150 to 300 times those seen at mammalian nerve fibres.

Finally, pacemaker systems are present in animals with nerve nets. In the sea anemone *Metridium* these systems are expressed in a series of spontaneous rhythmic movements that occur in the absence of any detectable stimulus. The question remains whether the movements originate from a "command" neuron or group of neurons or whether they arise without neuronal stimulation. It has been postulated that pacemaking cells were present in epithelial conducting systems known not to be nervous but that eventually evolved into neuronal tissue.

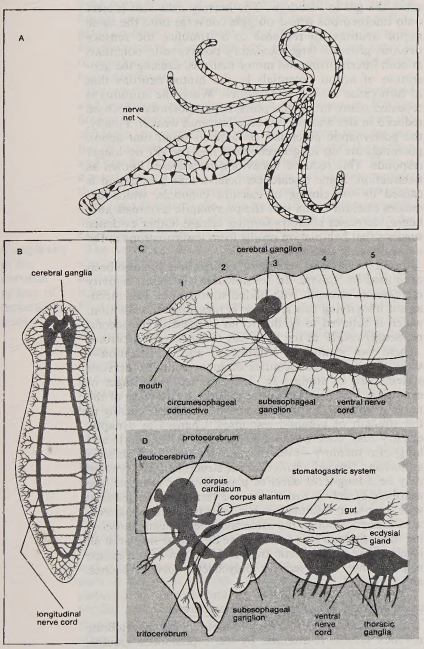


Figure 11: *Invertebrate nervous systems.* (A) The nerve net of *Hydra*, (B) central nervous system of a flatworm, composed of a brain (cerebral ganglia) and longitudinal nerve cords, (C) annelid, moderately cephalized with a brain, ventral nerve cord, and ventral ganglia, and (D) arthropod, highly cephalized and compartmentalized.

Centralized nervous systems

The development of the nerve net allowed an organism to engage in several different behaviours, including feeding and swimming. The development in the net of rapidly conducting bundles of fibres and of pacemaker systems allowed rapid withdrawal and rhythmic swimming activities, respectively, in some cnidarians. However, it is at the level of the flatworms (phylum Platyhelminthes) that there appears a longitudinal nerve cord and an anterior collection of nerve cells that can be called a brain (Figure 11B). Furthermore, there are well-defined sensory and motor pathways as well as coordinating interneurons. Although nerve nets and pacemaker activity are still present in the flatworms, the presence of ganglia or a brain concentrated at the cephalic (head) end of the organisms represents a simple beginning to the complex centralized systems that develop at higher levels of the phylogenetic tree.

SIMPLE BILATERAL SYSTEMS

The flatworms were the first invertebrates to exhibit bilateral symmetry and also the first to develop a central nervous system with a brain. The nervous system of a free-living flatworm such as *Planaria* consists of a brain, longitudinal nerve cords, and peripheral nerve plexuses (interlacing networks of peripheral nerves; from Latin *plectere,* "to braid"). Located in the anterior portion of the animal, the brain is composed of two cephalic ganglia joined by a broad connection called a commissure. Longitudinal nerve cords, usually three to five pairs, extend posteriorly from the brain; they are connected by transverse commissures, and smaller, lateral nerves extend from the cords. The lateral nerves give rise to the peripheral nerve plexuses. The submuscular nerve plexus, consisting of sensory cells, ganglion cells, and their processes, is situated in the loose tissue (mesenchyme) below the subepidermal musculature. A much finer subepidermal plexus is located at the bases of the epithelial cells above the muscular layer.

Rudimentary brain of the flatworm

Planaria are richly supplied with sensory receptors. Single sensory cells in the nerve plexuses are widely scattered over the animal. Sensory organs also are present and include ciliated pits and grooves, auricles, the frontal organ, statocyst, and eyes. The ciliated pits and grooves contain chemical receptors, or chemoreceptors, which permit the animal to detect food. The statocyst is responsible for balancing and such reactions as rising to the surface of the water or sinking. The eyes, or ocelli, may occur as a pair situated anteriorly or may be scattered abundantly over the head region depending on the species. Short optic nerves connect the eyes with the brain.

Seven types of nerve cell bodies and two types of neuroglia have been described in *Planaria.* Removal of the brain results in the abolition of such functions as food finding and recognition and severe deficits in locomotion. However, the nerve cords by themselves can mediate a certain amount of locomotion as well as righting and avoidance reactions.

Nematodes (phylum Aschelminthes) have a high degree of centralization, with three-quarters of all nerve cells concentrated in a group of anteriorly placed ganglia and no peripheral plexuses or nets. They usually have eight longitudinal cords, commissures between dorsal and ventral cords, six cephalic nerves, a few special ganglia and nerves in the tail, and two sympathetic systems (one anterior and one posterior).

MODERATELY CEPHALIZED SYSTEMS

Basic similarities in the nervous systems of the annelid worms, mollusks, and arthropods include an anteriorly situated brain, connectives running from the brain around the esophagus and joining paired longitudinal cords, and

ventral nerve cords with ganglia along their length. The trend toward greater centralization and cephalization of nervous functions is continued within these groups, reaching its peak in the higher mollusks and arthropods.

Annelids. The brain of most annelids (phylum Annelida, segmented worms, including the leeches and terrestrial earthworms) is relatively simple in structure (Figure 11C). The earthworm brain is a bilobed mass lying above the pharynx in the third body segment. Sensory nerves leave the brain and run forward into the prostomium (extreme anterior end) and first segment. The brain of the active, predatory polychaetes (a class of marine worms) is more complicated. In some, the brain can be divided into a forebrain, midbrain, and hindbrain; a single pair of circumesophageal or circumpharyngeal connectives leave the brain, surround the anterior gut, and connect with the ventral nerve cord.

Divided brain of the segmented worm

The most primitive annelids have a pair of ventral nerve cords joined by transverse connectives; the most advanced forms have the cords fused to form a single cord. A ganglionic swelling of the cord is found in each body segment, with the most anterior ganglion, the subpharyngeal ganglion, being the most prominent. Two to five pairs of lateral nerves leave each ganglion to innervate the body wall of that segment. A subepidermal nerve plexus occurs over the whole body. Another plexus, called the enteric, stomodaeal, or sympathetic system, is found in the wall of the gut.

Giant axons, usually few in number, are found running the length of the cord. They may belong to one cell or be composed of many neurons. These axons are capable of very rapid conduction of impulses to the segmental muscles; their main function is to permit the worm to contract very rapidly as a defense against predators.

The usual slow crawling movements of worms are mediated by a series of reflex arcs. During crawling, the contraction of muscles in one segment stimulates stretch receptors in the muscle. Impulses are carried over sensory nerves to the cord, causing motor neurons to send impulses to the longitudinal muscles, which then contract. The longitudinal pull activates stretch receptors in the following segment, and a wave of contraction moves along the worm.

Studies of the nervous systems of annelids show certain behavioral capabilities, including perception, motor coordination, and learning. Because the neuronal organization behind these capabilities can be deduced, they may give an indication of the mechanisms underlying similar patterns of activity and behaviours at other levels of the phylogenetic scale.

Rhythmic nerve impulses in the leech

Two rhythmic movements generated by the leech, the heartbeat and swimming rhythm, have been extensively studied. The coordinated heartbeat rhythm is produced by heart excitor motor neurons, which show rhythmic activity in which bursts of action potentials alternate with bursts of inhibitory synaptic potentials derived from rhythmically firing inhibitory interneurons. The heartbeat appears to be produced by a central rhythm generator. The swimming movement, on the other hand, is generated by a neuronal network requiring many more cells. These neuronal oscillators may in fact form the basis for neuronal generators of rhythmic movements in other animals at higher levels of the phylogenetic scale.

Simple mollusks. The nervous systems of the more primitive mollusks (snails, slugs, and bivalves such as clams and mussels) conform to the basic annelid plan but are modified to conform with the unusual anatomy of these animals. In snails a pair of cerebral ganglia constitutes the brain, which overlies the esophagus. Nerves leave the brain anteriorly to supply the eyes, tentacles, and a pair of buccal ganglia. These last ganglia, also called the stomatogastric head ganglia, innervate the pharynx, salivary glands, and a plexus on the esophagus and stomach. Other nerve cords—the pedal cords—leave the cerebral ganglia ventrally and terminate in a pair of pedal ganglia, which innervate the foot muscles. Another pair of nerve cords—the visceral cords—leave the brain and run posteriorly to the visceral ganglia. The pleural ganglion, supplying the mantle, or fleshy lining of the shell, and the parietal ganglion, innervating the lateral body wall and mantle, are located along the visceral nerves. Intestinal ganglia connected with the pleural ganglia innervate the gills, osphradium (a chemical sense organ), and mantle. Because of the torsion that occurred during the evolutionary history of the snails, some components of the nervous system are twisted and located in asymmetrical positions. In addition, there has been some migration forward and fusion of ganglia. Sense organs of snails include eyes, tentacles, statocysts, and osphradia.

In the bivalves, a cerebropleural ganglion is situated on either side of the esophagus. An upper pair of nerve cords leaves these ganglia and runs posteriorly to the visceroparietal (visceral) ganglia. The visceral ganglia supply the mantle, adductor muscles (which close the shell), and internal organs. A second pair of nerve cords runs ventrally to the pedal ganglia. Most of the sense organs are found at the edge of the mantle. In the scallop, for example, the eyes are set in a row. They are well developed and consist of a cornea, a lens, and a retina, in which the photoreceptor cells are not placed superficially (an arrangement much like that in the vertebrate retina).

Elementary forms of learning and memory have been studied at a cellular level by analysis of the neuronal activity of the marine snail *Aplysia californica.* This simple mollusk withdraws its gill and siphon in response to a mild tactile stimulus. The neural circuit for this reflex consists of a sensory component from the siphon that forms single-synapse junctions with motor neurons that cause the gill to withdraw. The sensory cells also project onto interneurons whose outputs converge onto the same motor neurons. In response to a stimulus, the sensory neurons generate large excitatory postsynaptic potentials at both interneurons and motor neurons, causing the generation of action potentials in the motor neurons that in turn cause the gill to withdraw. When the stimulus is repeated many times, the postsynaptic potentials become reduced in size and the response becomes weaker. Finally, the postsynaptic potentials become so small that action potentials are no longer generated and the gill no longer responds. This reduced behavioral response is known as habituation. Some researchers believe that habituation is caused by the closing of calcium channels, which decreases calcium influx into the presynaptic terminals and, hence, decreases neurotransmitter release. Other evidence suggests that habituation results from fewer neurons in the network being activated.

Synaptic transmission in the snail

Another behavioral paradigm, sensitization, has also been examined in *Aplysia.* In sensitization the reflex activity increases in strength with added stimulation. The mechanism underlying this response is presynaptic facilitation, which is believed to be due to an increase in the second messenger cAMP in the terminals of the sensory neurons.

These two examples—habituation and sensitization—show that important features of more complex nervous systems can be studied in organisms at lower stages of evolution. First is what can be called the plasticity of the nervous system, the phenomenon of changes occurring in the strength of synaptic responses. Changes in synaptic efficacy may underlie certain mechanisms for short- and long-term memory—even in more complex animals such as humans. Second, changes in the structure of the synapse may be a long-term effect of plasticity. For example, the numbers of active zones at nerve terminals are reduced with long-term habituation but increased with long-term sensitization. Finally, the molecular mechanisms underlying these changes may be the same or at least similar at all levels of the phylogenetic tree. Habituation of the escape response has been seen in polychaete worms, roaches, and crayfish.

COMPLEXLY COMPARTMENTALIZED SYSTEMS

The highest degree of development of the invertebrate nervous system is attained by the cephalopods (squids, cuttlefishes, and octopuses) among the mollusks and by the insects and spiders among the arthropods. Although the basic plan of these nervous systems is similar to that of the annelids, there are several advances. First, there is a high degree of cephalization, with nervous functions con-

centrated in the head region of the animal. In addition, ganglia are fused and farther forward, and nerve cells, less abundant in the peripheral nervous system, are situated in the brain or ganglia so that the nerve cords consist only of nerve fibres. Finally, control and coordination of specific functions, such as locomotion and feeding, are compartmentalized in particular parts of the nervous system.

Complex mollusks. The complex nervous system of the cephalopods is correlated with the active movement and predatory habits of these animals. Most of the ganglia typical of mollusks are concentrated or fused in a brain that encircles the esophagus. Nerves extend from the brain to ganglia at the base of the arms or tentacles and from the ganglia the length of the arms. A pair of large pallial nerves connects the brain with a pair of stellate ganglia on the inner surface of the mantle. The stomatogastric ganglia supply nerves to the digestive tract.

A great variety of body functions are centralized in the brain and compartmentalized to specific brain regions. These activities may be local, simple, and uncoordinated with other regions or may be extensive, complex, and coordinated, involving large groups of muscles. The highest centres of the cephalopod brain are the associative areas, which are believed to be concerned with discrimination between objects, learning, and memory.

Giant-fibre system of the squid

The giant-fibre system—also seen in earthworms and insects—is very well developed in the squid. The diameter of giant fibres is many times greater than the diameter of most other nerve fibres. Giant neurons in the brain send fibres to the retractor muscles of the head and the funnel or to the stellate ganglion. Fibres from the stellate ganglion fuse to form giant fibres that innervate the mantle. Because of their large size, these fibres are capable of rapid conduction, which, in turn, permits extremely rapid movement.

The eyes of cephalopods are especially well developed and bear close resemblance to the vertebrate eye. The eye fits into a socket of cartilaginous plates separate from the cartilages that protect the brain, and external muscles permit its movement. A transparent cornea covers the surface and can be focused for both near and far objects. There is a pupil formed by an iris diaphragm, which can regulate the amount of light reaching the retina. The retina contains light-sensitive cells. The axons of the photoreceptors, or rod cells, form the optic nerves, which terminate in the extremely large optic lobes of the brain.

Complexity of the nervous system of cephalopods

The cephalopods are strikingly different in many respects from other molluscan classes. The nervous system as described above is more highly developed and, consequently, the behavioral repertoire much more complex. First, the animals are predators; they move, they use their eyes in search of food, they use receptors in their arms for detection of tactile or chemical stimuli, and they have exceptionally fast muscle action. Second, they have an enormous flexibility of response, discriminating between palatable and unpalatable prey and "learning" to attack or not to attack. They can also change colour to blend into their environment if needed.

The mollusks as a whole provide an important link in the developing complexity of the nervous system. Indeed, the presence in their systems of vertebrate as well as natural molluscan neuroactive peptides may give some clue to the true place of these animals in the phylogenetic scale.

Arthropods. The other complex compartmentalized nervous system is found in arthropods (Figure 11D). The arthropodan brain consists of three main regions: the protocerebrum, deutocerebrum, and tritocerebrum. The anterior protocerebrum, which receives the nerves of the eyes and other organs forward, contains centres or neuropils such as the optic centres and bodies known as corpora pedunculata. The neuropils function as integrative systems for the anterior sense organs, especially the eyes, and in control of movement; they also are the centres for the initiation of complex behaviour. The deutocerebrum contains the association centres for the first antennae. The posterior tritocerebrum contains association neuropils for the second antennae (of crustaceans) and gives rise to nerves that innervate the mouthparts and the anterior digestive canal. The latter constitute the stomatogastric system, which regulates the intake of food and the movement of the gut necessary for digestion. This system bears a resemblance to the vertebrate autonomic system (see below).

The ventral nerve cord, connected to the brain by the circumesophageal connectives, is composed of a double row of ganglia connected longitudinally by connectives and transversely by commissures. Different groups of arthropods exhibit different degrees of fusion of the ganglia. In insects the first ganglion, the subesophageal, is formed by fusion of three pairs of ganglia; it sends nerves to the mouthparts and to the salivary glands. The segmental ganglia in the thorax and abdomen provide nerves to the appendages, dorsal muscles, sense organs, and heart. Insects have 3 pairs of thoracic ganglia and up to 10 abdominal ganglia.

The most common sensory receptors in arthropods are the cuticular hairs, many of which are mechanoreceptors, sensitive to touch, vibration, water currents, or sound waves; some hairs are chemoreceptors, which detect odours or chemicals in the water. Hairs situated near the joints are stimulated by body movements and thus provide a sense of the position of the joint or appendage during locomotion or flight. Many sensory cells and organs are concentrated in the antennae, and a statocyst is found at the base of each antenna.

Spiders have several pairs of simple eyes with cup-shaped retinas. Crustaceans and insects, however, have a pair of well-developed compound eyes, each consisting of a large number of visual units called ommatidia. Each ommatidium contains six to eight sensory receptors arranged under a cornea and refractile cone and is surrounded by pigment cells, which adjust the intensity of light. Each ommatidium can act as a separate eye, capable of responding to its own visual field. Such an arrangement seems particularly well suited for detecting movement across a wide visual field.

Specialized neurons in insects

In spite of the small size of insects, some of their nerve cells and axons are larger in diameter than any neuron in the human nervous system. The number of insect neurons is relatively small, so that each neuron must be capable of dealing with a maximum amount of information. Evasive behaviour requires mechanisms of this sort—as exemplified by the jumping muscle of the grasshopper, which is supplied by only a few motor axons, while those muscles of a human required for a similar purpose have tens of thousands of axons. Another example is the ear of a noctuid moth. Each ear is essentially a tympanic membrane forming the outer wall of an air-filled cavity in the thorax. A five-tissue strand, the acoustic sensillum, runs from the centre of the tympanic membrane across the tympanic cavity to a nearby skeletal support. This sensillum has two acoustic sensory receptors, called A cells. From the central end of each A cell, an axon passes within the sensillum to the skeletal support and then in the tympanic nerve to the thoracic ganglia of the moth.

The A cells encode the intensity of ultrasound by the frequency with which they fire action potentials. Each ear is capable of responding differently to different stimuli, so that differences between the two ears in the duration of the action potentials and response times could allow for binaural detection of the source of a sound. The impulses are conducted to the pterothoracic ganglion, where they must then influence muscles used for avoidance of predators. The important point here is that two A cells provide enough information with speed to allow the moth to take evasive behaviour.

Clearly, simplicity of the neural circuitry is required for speedy response; while some information may be sacrificed, escape will not be compromised. In fact, the quick evasion of predators has probably influenced the evolution of the giant-fibre systems of worms and squid as well as crustaceans and insects. These giant fibres conduct impulses at much higher conduction velocities than do smaller axons, while the information-handling capacity of many small axons acting together is far greater than that of giant axons. Under these circumstances it is clear that different systems evolved in the invertebrate nervous system in response to different qualities of stimuli in the environment to which the organism had to react—one responsible for survival and the other for information.

Neurosecretory cells in crustaceans and arthropods

Neurosecretory cells, which have been identified in all the major invertebrate groups, reach their highest degree of development in the arthropods. The principal system of insects consists of neurosecretory cells in the protocerebrum of the brain. The axons of these cells form nerves that innervate structures called corpora cardiaca, situated just posterior to the brain. A corpus cardiacum is an organ in which neurosecretory products are stored in the nerve terminals for later release into the vascular system.

The neurosecretory cells of the protocerebrum manufacture a hormone called ecdysiotropin, or brain hormone. Sensory nerve impulses reaching the brain regulate the release of the hormone from the nerve endings into the blood within the corpora cardiaca. The hormone then stimulates a non-neural endocrine gland, the ecdysial gland, located in the thorax. The ecdysial glands in turn release a hormone, ecdysone, which initiates molting during larval development and also stimulates differentiation into adult tissues. Another hormone, however, the juvenile hormone, keeps tissue in a juvenile or larval form. This hormone is released by the corpora allata, another pair of non-neural endocrine glands, located behind the corpora cardiaca. The successive life stages in insect development are, therefore, determined by the varying levels of ecdysone and juvenile hormone.

The vertebrate system

The nervous system of vertebrates has two main divisions: the central nervous system, consisting of the brain and spinal cord, and the peripheral nervous system, which in humans includes 12 pairs of cranial nerves, 31 pairs of spinal nerves, and the autonomic, or involuntary, nervous system. Because the arrangement of nerve cells and their fibres is so complex, it is helpful to understand some basic terms used in describing the vertebrate nervous system.

Anatomical structures such as the nervous system are described according to their position. In four-legged animals the upper (back) surface is called dorsal and the lower (belly) surface ventral. The terms anterior, cranial, cephalic, or rostral refer to the head end of the body; posterior, or caudal, to the tail end. In humans, since they stand erect, the situation is more complicated: dorsal becomes equivalent to posterior, and ventral is the same as anterior; cranial is often called superior, and caudal inferior. Objects near the middle plane of the body are medial and those farther away are lateral. Proximal refers to structures nearest the central bulk of a structure and distal to ones away from it. In referring to another structure, if it is located on the same side of the body, it is known as ipsilateral; if it is on the opposite side, it is contralateral.

Neurons are often gathered into localized masses. In the peripheral nervous system these accumulations are called ganglia; in the central nervous system they are called nuclei. Portions of the central nervous system in which unmyelinated neurons and neuroglia predominate are called gray matter; areas in which myelinated neurons dominate are called white matter. Efferent, or motor, nerve fibres carry impulses away from the central nervous system; afferent, or sensory, fibres carry impulses toward the central nervous system. Visceral fibres innervate the viscera such as the heart and intestine, and somatic fibres innervate the body-wall structures such as skin and muscle. In the central nervous system the nerve fibres are organized in bundles called tracts, or fasciculi. Ascending tracts carry impulses along the spinal cord toward the brain, and descending tracts carry them from the brain or higher regions in the spinal cord to lower regions. The tracts are often named according to their origin and termination; for example, the corticospinal tract consists of fibres running from the cerebral cortex in the brain to the spinal cord.

THE PRIMITIVE CONDITION

Predecessors of the spinal cord

The vertebrates constitute an advanced subdivision of the phylum Chordata. All chordates at some time in their life history have a rodlike bar called the notochord running the length of the body. Lower chordates (acorn worms, tunicates, and amphioxus), which lack a vertebral column, illustrate the most primitive features of the chordate nervous system. In these animals the nerve cord is a rather uniform-appearing dorsally placed tube with a hollow cavity, which corresponds roughly to the spinal cord of the vertebrates, suggesting that the spinal cord is the most primitive component of the central nervous system.

In amphioxus and in the lowest vertebrates such as lampreys, the sensory fibres and motor fibres leave the cord in dorsal and ventral roots to supply the adjacent body segments (myotomes). The dorsal and ventral roots remain separate nerves and arise at alternate positions along the cord. In lower fishes there is still alternation of dorsal and ventral roots, but the roots unite in a single spinal nerve. In higher vertebrates the two roots unite in a single spinal nerve and leave the cord at the same level, one above the other. Each spinal nerve supplies a single myotome. When appendages (fins, wings, arms, and legs) develop from several myotomes, the nerves continue to supply their original segments, and branches of the spinal nerves become interwoven to form plexuses.

The brain of vertebrates developed by the accumulation of nerve cells at the cephalic end of the nerve cord. At first this diffuse collection of nerve cells regulated the reflex activity of spinal motor neurons. These cells are comparable to the reticular formation occupying the brain stem of higher vertebrates. The brain stem, thus, is the oldest portion of the brain.

ENCEPHALIZATION

Early in the evolution of vertebrates, a special sensory system became associated with each major part of the brain: the olfactory organs with the forebrain, the eye with the midbrain, and the ear and related organs with the hindbrain. Each of the three sections, furthermore, developed dorsal outgrowths of gray matter forming, respectively, the cerebrum, the midbrain roof, or tectum, and the cerebellum. With these developments the three-part brain stem was then transformed into a brain of five regions: telencephalon, diencephalon, mesencephalon, metencephalon, and myelencephalon (Figure 12). The addition of these nerve centres to the primitive brain stem allowed greater coordination and association between the sensory and motor fibres.

In tracing the development of the parts of the brain in the different vertebrate classes, some general features are apparent (Figure 13). There is a correlation between the

From A. Romer, *The Vertebrate Body*, 3rd ed. (1962); W.B. Saunders Company, Philadelphia

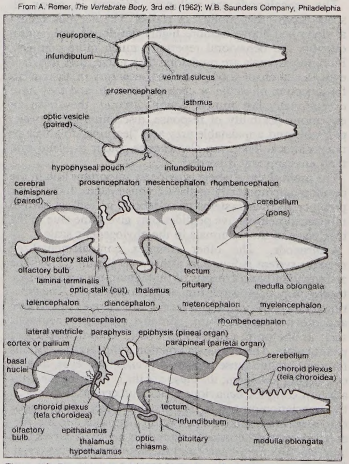


Figure 12: Development of principal vertebrate brain divisions.

size of a particular part of the brain and its importance in the life of the animal in question. Some neural structures (*e.g.*, olfactory bulb) have considerable size and importance in more primitive forms but are less conspicuous in most recent forms. Progressing from primitive to recent forms, there is a gradual cephalic shift of function from the lower brain stem to the higher cerebral cortex.

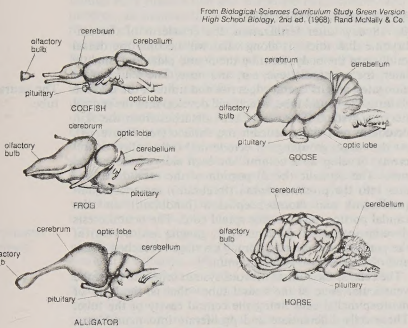


Figure 13: Representative series of vertebrate brains illustrating the evolutionary development of the brain.

The hindbrain is comparable to an enlarged, anterior section of the spinal cord. In the gray matter are dorsal sensory and ventral motor columns similar to those present in the cord. The longitudinal continuity of these columns is preserved in the earlier vertebrates, but in more recent vertebrates the columns break up into discrete nuclei that serve some of the cranial nerves. The hindbrain exerts partial control over the spinal motor neurons through the reticular formation. Fish and tailed amphibians, in addition, have a pair of giant cells called the cells of Mauthner, which exert some control over the local spinal-cord reflexes responsible for the rhythmic swimming undulations and the flip-tail escape response characteristic of these animals.

The hindbrain is the area of reception of one of the main sensory systems, the acoustico-lateralis system, which consists of the ear (hearing and equilibrium) and the lateral-line organs (vibration and pressure). The latter, situated in rows along the head and body, are retained in fish but disappear in the land vertebrates.

The cerebellum originated as a specialized part of the acoustico-lateralis area. The oldest part of the cerebellum—the archicerebellum—is concerned with equilibrium and connected with the inner ear and the lateral-line system. The anterior lobe of the cerebellum represents the paleocerebellum, an area that regulates equilibrium and muscle tone; it constitutes the main mass of the cerebellum in fish, reptiles, and birds. In mammals the development of the cerebral cortex and its connections with the cerebellum are correlated with the appearance of the large cerebellar hemispheres. This new part of the cerebellum, or neocerebellum, coordinates skilled movements initiated at cortical levels. In mammals a great mass of fibres connects the brain stem to the cerebellum; this region forms the pons, which, together with the cerebellum, constitutes the metencephalon. The caudal part of the hindbrain remains as the medulla (myelencephalon).

The midbrain (mesencephalon) and diencephalon constitute the anterior portion of the brain stem. Sensory and motor nuclei for cranial nerves extend from the hindbrain to the midbrain. The roof of the midbrain, or tectum, developed as the primary visual centre. The optic lobes, especially prominent in fish and birds, are a part of this area. In fish and amphibians the tectum is the major centre of the nervous system and wields the greatest influence on body activity. While this area is still significant in reptiles and birds, it is supplanted in importance by the cerebral hemispheres. In mammals the midbrain is greatly reduced in importance. Instead, most of the optic sensations are relayed to the cerebral cortex. With development of the cerebral cortex, the thalamus becomes less significant as an association area and more important as a relay centre for sensory impulses. Centres for visceral sensations and visceral motor responses become established in the hypothalamus.

DOMINANCE OF THE CEREBRUM

Original function of the cerebral hemispheres

Ascending the vertebrate scale, the cerebral hemispheres become more and more important as association centres. The cerebral hemispheres begin their development as paired outgrowths of the forebrain and serve as centres of olfactory reception. In the older vertebrates the forebrain is divided into the olfactory bulb—where the olfactory nerve fibres end—and the cerebral hemisphere. The hemisphere at this time, referred to as the paleopallium, is merely an olfactory lobe serving as an association area for olfactory impulses. The olfactory lobes are prominent in animals such as amphibians, but in birds and primates in which sense of smell is less important the lobes are reduced in extent. In amphibians the hemispheres consist of three parts: the paleopallium (olfactory lobe), archipallium, and basal nuclei. These areas of gray matter are located deep to the surface. All three areas receive olfactory stimuli and discharge impulses to the brain stem. The archipallium is a correlation centre and forerunner of the mammalian hippocampus. The basal nuclei are equivalent to the corpus striatum and function as association areas with connections with the thalamus. In primitive reptiles the basal nuclei have moved to the inner part of the hemisphere, whereas the other areas of gray matter have moved toward the surface. In advanced reptiles a new association centre, the neopallium, appears between paleopallium and archipallium. In birds there is nothing corresponding to the neopallium, but the basal ganglia (that is, the corpus striatum) are enormously expanded. In mammals the neopallium becomes greatly enlarged to exceed all the other parts of the brain in size. This region assumes more and more of the higher types of neural activity in correlation, association, and learning. At first the neopallium expands to envelop the other brain structures. The archipallium becomes folded into a small area on the median part of the hemispheres, where it remains as the hippocampus. The paleopallium (olfactory lobes) constitutes a small ventral region on the hemisphere, the pyriform lobe. The corpus striatum (old basal nuclei) becomes a central part of the hemisphere. Further expansion of the neopallium in primates and humans causes extensive folding and results in a very convoluted surface of the brain. (T.L.L./S.D.E.)

ANATOMY OF THE HUMAN NERVOUS SYSTEM

Development

Almost all neurons are generated during prenatal life, and they are not replaced by new neurons during postnatal life. Morphologically, the nervous system first appears about 18 days after conception, with the genesis of the neural plate. Functionally, it appears with the first sign of reflex activity during the second prenatal month, when stimulation by touch of the upper lip has been shown to evoke an avoidance-withdrawal response of the head. Many reflexes of the head, trunk, and extremities can be elicited in the third month.

During its development the nervous system undergoes remarkable changes to attain its complex organization. In order to produce the estimated one trillion neurons present in the mature brain, an average of 2.5 million neurons

must be generated per minute during the entire prenatal life. This includes the formation of neuronal circuits comprising 100 trillion synapses, as each potential neuron is ultimately connected with either a selected set of other neurons or specific targets such as sensory endings. Moreover, synaptic connections with other neurons are made at precise locations on the cell membranes of the target neurons. The totality of these events is not thought to be the exclusive product of the genetic code, for there are simply not enough genes to account for such complexity. Rather, the differentiation and subsequent development of embryonic cells into mature neurons and glial cells are achieved by two sets of influences: (1) specific subsets of genes, and (2) environmental stimuli from within and outside the organism. Genetic influences are critical to the development of the nervous system in ordered and temporally timed sequences. Cell differentiation, for example, depends on a series of signals that regulate transcription; this is the process in which DNA molecules give rise to RNA molecules, which in turn express the genetic messages that control cellular activity. Environmental influences derived from the embryo itself include cellular signals that consist of diffusible molecular factors (see below *Neuronal development*). External environmental factors include nutrition, sensory experience, social interaction, and even learning. All of these latter are essential for the proper differentiation of individual neurons and for fine-tuning the details of synaptic connections. Thus, the nervous system requires continuous stimulation over an entire lifetime in order to sustain optimal functional activity.

NEURONAL DEVELOPMENT

The embryonic disk

In the second week of prenatal life, the rapidly growing blastocyst (the bundle of cells into which a fertilized ovum divides) flattens into what is called the embryonic disk. This soon acquires three layers: the ectoderm (outer layer), endoderm (inner layer), and mesoderm (middle layer). Within the mesoderm grows the notochord, an axial rod that serves as a temporary backbone. Both the mesoderm and notochord release a chemical molecular factor that instructs and induces adjacent undifferentiated ectoderm cells to form the neural plate. This includes a population of neural precursor cells, known as neuroepithelial cells, which develop into the neural tube (see below *Morphologic development*). Neuroepithelial cells then commence to divide, diversify, and give rise to immature neurons and neuroglia, which in turn migrate from the neural tube to their final location. Each neuron forms dendrites and an axon; axons elongate and form branches, the terminals of which form synaptic connections with a select set of target neurons or muscle fibres.

The remarkable events of this early development involve an orderly migration of billions of neurons, the growth of their axons (many of which extend widely throughout the brain), and the formation of thousands of synapses between individual axons and their target neurons. This migration and growth are dependent, at least in part, on chemical and physical guidance cues. The growing tips of axons (called growth cones) apparently recognize and respond to various molecular cues, which guide axons and some branches to their appropriate targets but eliminate other branches that try to synapse with inappropriate targets. Once a synaptic connection has been established, a target cell releases a so-called trophic factor (some of which have been identified) that is essential for the survival of the neuron synapsing with it. One example is nerve growth factor (NGF), a diffusable protein essential for the survival of sensory and sympathetic neurons. Physical guidance cues are seen in the migration of immature neurons along a preexistent scaffold of glial fibres through a process called contact guidance.

In some regions of the nervous system, initial synaptic contacts are precise and stable, indicative of an initial specificity of neuronal recognition. In other regions the initial contacts are not precise and stable and are followed later by an ordered reorganization, including the elimination of many synapses. The instability of some synaptic connections persists until a so-called critical period, prior to which environmental influences have a significant role in fine-tuning many connections. Following the critical period, synaptic connections become stable and are unlikely to be altered by environmental influences. This suggests that certain skills and sensory activities can be influenced during development (including postnatal life), and for some intellectual skills this adaptability presumably persists into adulthood and old age.

MORPHOLOGIC DEVELOPMENT

By 18 days after fertilization, the ectoderm of the embryonic disk thickens along what will become the dorsal midline of the body, forming the neural plate and, slightly later, the primordial eye, ear, and nose. The neural plate elongates, and its lateral edges rise and unite in the midline to form the neural tube, which will develop into the central nervous system. The neural tube detaches from the skin ectoderm and sinks beneath the surface (see Figure 14). At this stage, groupings of ectodermal cells, called neural crests, develop as a column on each side of the neural tube. The cephalic (head) portion of the tube differentiates into the prosencephalon (forebrain), mesencephalon (midbrain), and rhombencephalon (hindbrain), and the caudal portion becomes the spinal cord. The neural crests develop into most elements (*e.g.*, ganglia and nerves) of the peripheral nervous system. This stage is reached at the end of the first embryonic month.

The neural tube

The cells of the central nervous system originate from the ventricular zone of the neural tube—that is, the layer of neuroepithelial cells lining the central cavity of the tube. These cells differentiate and proliferate into neuroblasts, which are the progenitors of neurons, and glioblasts, from which neuroglia develop. With a few exceptions, the neuroblasts, glioblasts, and their derived cells do not divide and multiply once they have migrated from the ventricular zone into the gray and white matter of the nervous system. With some exceptions, all neurons are generated

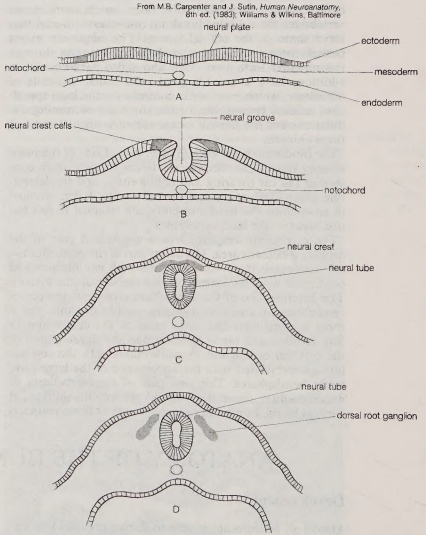


Figure 14: *Cross section of the embryonic disk, showing formation of the neural tube.*
(A) Thickening of the neural plate. (B) Infolding of the neural groove. (C) Closure of the neural groove to form the neural tube. (D) Development of the neural crests into dorsal root ganglia.

before birth, although all are not fully differentiated. This effectively implies that an individual is born with a full complement of nerve cells. (One exception is that the neurons of the olfactory nerve are generated and replaced continuously throughout life.)

By mid-fetal life the slender primordial brain of the neural-tube stage differentiates into a globular-shaped brain. Although fully mature size and shape are not attained until puberty, the main outlines of the brain are recognizable by the end of the third fetal month. This early development is the product of several factors: the formation of three flexures (cephalic, pontine, and cervical; see Figure 15); the differential enlargement of various regions, especially the cerebrum and cerebellum; the massive growth of the cerebral hemispheres over the sides of the midbrain and of the cerebellum at the hindbrain; and the formation of convolutions (sulci and gyri) in the cerebral cortex and of folia in the cerebellar cortex. The central and calcarine sulci are discernible by the fifth fetal month, and all major gyri and sulci are normally present by the seventh month. Many minor sulci and gyri appear after birth. By two years after birth, the size of the brain and the proportion of its parts are basically those of the adult.

Postnatal growth

The postnatal growth of the human brain is rapid and massive, especially during the first two years. The typical brain of a full-term infant weighs 350 grams (12 ounces) at birth, 1,000 grams at the end of the first year, about 1,300 grams at puberty, and about 1,500 grams at adulthood. This increase is attributable mainly to the growth of preexisting neurons, new glial cells, and the myelination of axons. The trebling of weight during the first year (a growth rate unique to humans) may be an adaptation that is essential to the survival of human beings as a species with a large brain. Birth occurs at a developmental stage when the infant is not so helpless as to be unable to survive yet is small enough to be delivered out of the maternal pelvis. If the brain were much larger (enough, say, to support intelligent behaviour), normal delivery would not be possible.

Between the ages of 20 and 75, it is estimated that an average of 50,000 neurons atrophy or die each day. In a healthy person, this loss is roughly equal to 10 percent of the original neuronal complement. Indeed, by the age of 75, the weight of the brain is reduced from its maximum at maturity by about one-tenth, the flow of blood through the brain by almost one-fifth, and the number of functional taste buds by about two-thirds. A loss of neurons does not necessarily imply a comparable loss of function, however; some loss may be compensated for by the formation from viable neurons of new branches of nerve fibres and by the formation of new synapses. (C.R.N.)

The central nervous system

The central nervous system consists of the brain and spinal cord, both derived from the embryonic neural tube. Both parts are invested by protective membranes called the meninges, and both float in a crystal-clear cerebrospinal fluid. The brain is encased in a bony vault, the neurocranium, while the cylindrical and elongated spinal cord lies in the vertebral canal, which is formed by successive vertebrae connected by dense ligaments.

THE BRAIN

The brain is a relatively small organ, weighing about 1,500 grams and constituting about 2 percent of total body weight. Three major divisions of the brain are recognized: (1) the massive, paired cerebral hemispheres (cerebrum), derived from the telencephalon; (2) the brain stem, from which all true cranial nerves emerge, consisting of the thalamus and hypothalamus, the midbrain, the pons, and the medulla oblongata (also known as the diencephalon, the mesencephalon, the metencephalon, and the myelencephalon); and (3) the cerebellum ("little brain"), derived from the pons, or metencephalon. The terms telencephalon, diencephalon, mesencephalon, metencephalon, and myelencephalon denote five distinct embryonic subdivisions derived from separate vesicles in the rostral neural tube (see Figure 15).

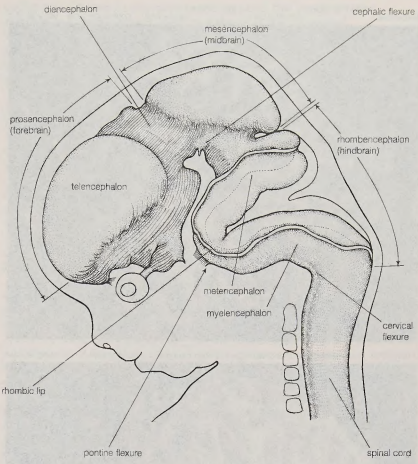


Figure 15: Profile of the brain of a human fetus at 10 weeks.
From G.J. Romanes (ed.), *Cunningham's Textbook of Anatomy*, 12th ed. (1981); Oxford University Press

The cerebral hemispheres

Telencephalon. The paired cerebral hemispheres are mirror-image duplicates composed of a gray cellular mantle called the cerebral cortex, an underlying mass of white matter composed of myelinated nerve fibres, and collections of subcortical neuronal masses known as the basal ganglia. Each hemisphere receives impulses conveying the senses of touch and vision largely from the contralateral half (that is, the opposite side) of the body, while auditory input comes from both sides. Pathways conveying the senses of smell and taste to the cerebral cortex are ipsilateral (that is, they do not cross to the opposite hemisphere). In turn, each cerebral hemisphere supplies motor function to the opposite side of the body, the side from which it receives sensory input.

In spite of this arrangement, the cerebral hemispheres are not functionally equal. In each individual, one hemisphere is dominant, the dominant hemisphere being concerned with language, mathematical and analytical functions, and handedness. The nondominant hemisphere is concerned with simple spatial concepts, recognition of faces, some aspects of music, and emotion. (For further discussion of cerebral dominance, see below *Functions of the human nervous system: Higher cerebral functions*.)

The hemispheres are partially separated from each other by the longitudinal fissure (see Figure 16), but in central regions this fissure extends only as deep as a broad interhemispheric commissure called the corpus callosum. It is through the corpus callosum that corresponding regions of the cerebral hemispheres are connected by various nerve projections.

Lobes of the cerebral cortex. The cortical mantle is highly convoluted; the crest of a single convolution is known as a gyrus, while the fissure between two gyri is known as a sulcus. Sulci and gyri form a more or less constant pattern, on the basis of which each cerebral hemisphere is divided into six so-called lobes: (1) frontal, (2) parietal, (3) temporal, (4) occipital, (5) central (or insular), and (6) limbic. Two important sulci located on the lateral aspect (that is, the side surface) of each hemisphere help to distinguish these lobes. The central sulcus separates the frontal and parietal lobes, and the deeper lateral sulcus forms the boundary between the temporal lobe and the frontal and parietal lobes (see Figure 16).

The frontal lobe, largest of all the lobes of the brain,

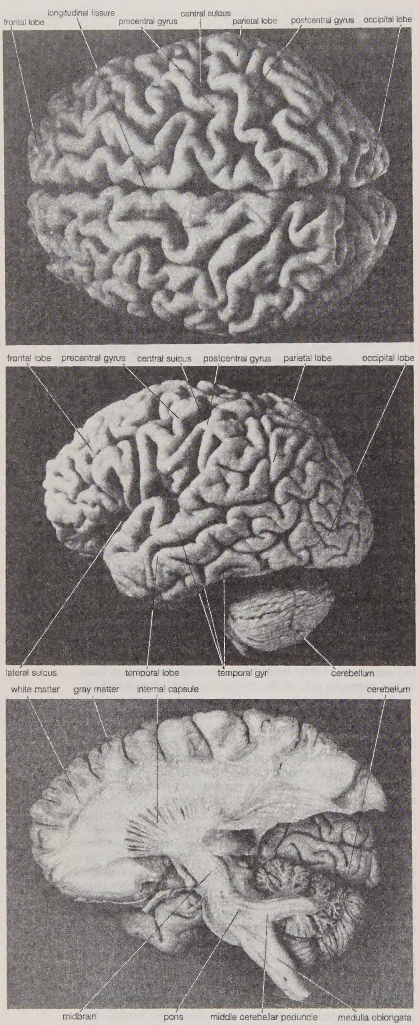


Figure 16: *Photographs of the human brain.*
(Top) Upper surface, showing division of the cerebrum into two hemispheres by the longitudinal fissure. (Centre) Left lateral surface, showing various lobes of the hemisphere. (Bottom) Dissection of the left hemisphere, showing internal capsule and middle cerebellar peduncle.

From (top and centre) N. Ghilchegovic and T.H. Williams, *The Human Brain: A Photographic Guide* (1960). J.B. Lippincott Co./Harper & Row; (bottom) original preparation by J. Klingler, Anatomical Museum, Basel, Switz.

lies rostral to the central sulcus (that is, toward the nose from the sulcus). The precentral gyrus, located rostral to the central sulcus, constitutes the primary motor region of the brain; when parts of this gyrus are given electrical stimulation in conscious patients (operated upon under local anesthesia), they produce localized movements on the opposite side of the body that are interpreted by the patients as voluntary. Injury to parts of this gyrus results in paralysis on the contralateral half of the body.

Parts of the inferior frontal lobe (close to the lateral sulcus) constitute Broca's area, a region concerned with neural mechanisms that convert thoughts into speech (see below *Functions of the human nervous system* and Figure 32).

The parietal lobe, posterior to the central sulcus, is divided into three parts: (1) a postcentral gyrus, (2) a superior parietal lobule, and (3) an inferior parietal lobule. The postcentral gyrus receives sensory input, both superficial and deep, from the contralateral half of the body. The sequential representation is the same as in the primary motor area, with sensations from the head area being represented in inferior parts of the gyrus and impulses from the lower extremities represented above. Lesions in the postcentral gyrus result in impaired sensation from cutaneous (surface) and deep parts of the contralateral half of the body. The superior parietal lobule, located caudal to the postcentral gyrus, lies superior to the interparietal sulcus. This lobule is regarded as an association cortex, part of which may be concerned with motor function. The inferior parietal lobule (composed of the angular and supramarginal gyri) is a cortical region concerned with the integration of multiple sensory signals. Lesions in this lobule produce various syndromes of a devastating nature.

Sensory cortex

In the parietal and frontal lobes, each primary sensory or motor area is close to, or surrounded by, a smaller secondary area (see Figure 29). The primary sensory area receives input only from relay nuclei in the thalamus, while the secondary sensory area receives input from the thalamus, the primary sensory area, or both. The motor regions receive input from the thalamus as well as the sensory areas of the cerebral cortex.

The temporal lobe, inferior to the lateral sulcus, fills the middle fossa of the skull. Near the margin of the lateral sulcus, two transverse temporal gyri constitute the primary auditory area of the brain. Audition is represented here in a tonotopic fashion—that is, with different frequencies represented on different parts of the area. The transverse gyri are surrounded by a less finely tuned secondary auditory area (see Figure 31).

A medial, or inner, protrusion near the ventral surface of the temporal lobe, known as the uncus, constitutes a large part of the primary olfactory area. The outer surface of this lobe is an association area made up of the superior, middle, and inferior temporal gyri.

The occipital lobe lies caudal to (that is, below and behind) the parieto-occipital sulcus. As seen on the medial aspect of the hemisphere, this sulcus joins the calcarine sulcus in a Y-shaped formation. Cortex on both banks of the calcarine sulcus constitutes the primary visual area (see Figure 31), which receives input from the contralateral visual field via the optic radiation. The visual field is represented near the calcarine sulcus in a retinotopic fashion—that is, with upper quadrants of the visual field laid out along the inferior bank of the sulcus and lower quadrants of the visual field represented on the upper bank. Central vision is represented most caudally and peripheral vision rostrally. Lesions in the calcarine cortex—or in the optic radiation, which projects to it—produce blindness in the contralateral visual field.

The insular, or central, lobe is an invaginated triangular area on the medial surface of the lateral sulcus; it can be seen in the intact brain only by separating the frontal and parietal lobes from the temporal lobe. Branches of the middle cerebral artery cover the surface of the insula.

The limbic lobe is a synthetic lobe on the medial margin (or limbus) of the hemisphere. Composed of adjacent portions of the frontal, parietal, and temporal lobes that surround the corpus callosum, it is concerned with visceral, autonomic, and related somatic behavioral activities. This

region of the cerebral cortex receives inputs from thalamic nuclei that are connected with parts of the hypothalamus and with the hippocampal formation, a primitive cortical structure within the inferior horn of the lateral ventricle (see Figure 17).

White matter. Beneath the cerebral cortex is a mass of white matter, which is composed of nerve fibres projecting to and from the cerebral cortex, commissural systems connecting the two hemispheres via the corpus callosum, and association fibres connecting different regions of a single hemisphere. Myelinated fibres projecting to and from the cerebral cortex form a concentrated fan-shaped band, known as the internal capsule (see Figure 16). In horizontal sections of the brain (see Figure 18), the internal capsule can be seen to consist of two parts: (1) an anterior limb, between the caudate nucleus and the putamen; and (2) a larger posterior limb, running between the thalamus and the globus pallidus and putamen. These two limbs form an obtuse angle with the apex directed toward the centre of the brain; the junction is called the genu.

The internal capsule

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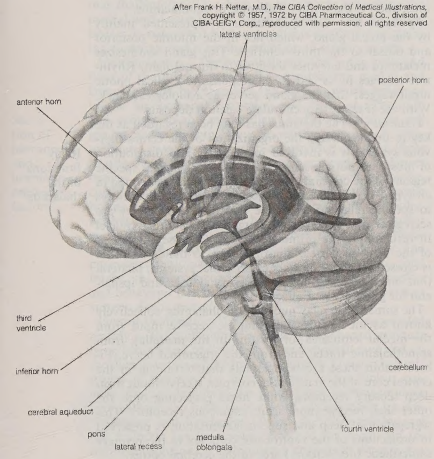


Figure 17: Lateral view of the cerebrum, cerebellum, and brain stem, highlighting features of the ventricular system.

Ventricles. Deep within the white matter are fluid-filled cavities that form the ventricular system. These cavities include a pair of C-shaped lateral ventricles with anterior, inferior, and posterior "horns" protruding into the frontal, temporal, and occipital lobes, respectively (see Figure 17). Most of the cerebrospinal fluid is produced in the ventricles. About 70 percent of the fluid produced by the central nervous system is secreted by the choroid plexus, a collection of blood vessels in the walls of the lateral ventricles. The fluid drains via interventricular foramina, or openings, into a slitlike third ventricle, which, situated along the midline of the brain, separates the symmetrical halves of the thalamus and hypothalamus (see Figure 18). From there it passes through the cerebral aqueduct in the midbrain and into the fourth ventricle in the hindbrain. Openings in the fourth ventricle permit cerebrospinal fluid to enter so-called subarachnoid spaces surrounding both brain and spinal cord.

Basal ganglia. Deep within the cerebral hemispheres, large gray masses or nerve cells, called nuclei, form components of the basal ganglia. Four nuclei can be distinguished: (1) the caudate nucleus, (2) the putamen, (3) the globus pallidus, and (4) the amygdala. Phylogenetically, the amygdala is the oldest of the basal ganglia and is therefore often referred to as the archistriatum; the globus pallidus is known as the paleostriatum, and the caudate nucleus and putamen are together known as the neostriatum, or simply striatum. The putamen and the adjacent globus pallidus are referred to descriptively as the lentiform nucleus, while the caudate nucleus, putamen, and globus pallidus form the corpus striatum.

The caudate nucleus and the putamen are continuous rostrally and ventrally (see Figure 18), and they have similar cytology (cellular makeup), cytochemical features, and functions, but they also have slightly different connections. The putamen lies deep within the cortex of the insular lobe, while the caudate nucleus has a C-shaped configuration that parallels the lateral ventricle. The head of the caudate nucleus protrudes into the anterior horn of the lateral ventricle, the body lies above and lateral to the thalamus, and the tail is in the roof of the inferior horn of the lateral ventricle. The tail of the caudate nucleus ends in relationship to the amygdaloid nuclear complex, which lies in the temporal lobe beneath the cortex of the uncus.

The caudate nucleus and putamen

There is an enormous number of neurons within the caudate nucleus and putamen; these are of two basic types, spiny and aspiny. Spiny striatal neurons are medium-size cells with radiating dendrites that are studded with spines. Axons of these cells project beyond the boundaries of the neostriatum. All afferent systems entering the neostriatum terminate upon the dendritic spines of spiny striatal neurons, and all output is via axons of the same neurons. Chemically, spiny striatal neurons are heterogeneous—that is, most contain more than one neurotransmitter. Neurotransmitters identified in spiny striatal neurons are gamma-aminobutyric acid (GABA), substance P, and enkephalin, with overwhelming dominance by GABA.

Aspiny striatal neurons have smooth dendrites and short axons confined to the caudate nucleus or putamen. Small aspiny striatal neurons secrete GABA, neuropeptide Y, somatostatin, or some combination of these. The largest aspiny neurons are evenly distributed cholinergic neurons that play a crucial role in maintaining the balance of dopamine and GABA.

Because the caudate nucleus and putamen receive varied and diverse inputs from multiple sources that utilize different neurotransmitters, they are regarded as the receptive component of the corpus striatum. The most massive input originates from virtually all regions of the cerebral cortex, with the connecting corticostriate fibres containing the excitatory neurotransmitter glutamate. In addition, afferent fibres originating from the substantia nigra in the midbrain or from intralaminar thalamic nuclei in the diencephalon project to the caudate nucleus or the putamen. The neurotransmitter secreted by thalamostriate neurons has not been identified, while neurons from the substantia nigra synthesize dopamine. All striatal afferent systems terminate in patchy arrays referred to as strisomes; areas not receiving terminals are called the matrix. Striatal efferent systems—that is, spiny neurons containing GABA, substance P, and enkephalin—project in a specific pattern onto the globus pallidus and the substantia nigra; GABA, an inhibitory neurotransmitter, is dominant in all neostriatal projections.

The globus pallidus, consisting of two cytologically similar wedge-shaped segments, the lateral and the medial, lies between the putamen and the internal capsule (see Figure 18). Fibres terminating on the pallidum arise mostly from the caudate nucleus and putamen; these so-called striatopallidal fibres converge on the globus pallidus like spokes of a wheel. Both segments of the pallidum receive GABAergic terminals, but in addition the medial segment receives substance P fibres, and the lateral segment receives enkephalinergic projections. The output of the entire corpus striatum (*i.e.*, the caudate nucleus, putamen, and globus pallidus together) arises from GABAergic cells in the medial pallidal segment and in the substantia nigra, both of which receive fibres from the striatum. GABAergic cells in the medial pallidal segment and the substantia nigra project to different nuclei in the thalamus; these in turn influence distinct regions of the cortex concerned with motor function. The lateral segment of the globus pallidus, on the other hand, projects almost exclusively to the subthalamic nucleus (in the ventral thalamus), from

The globus pallidus

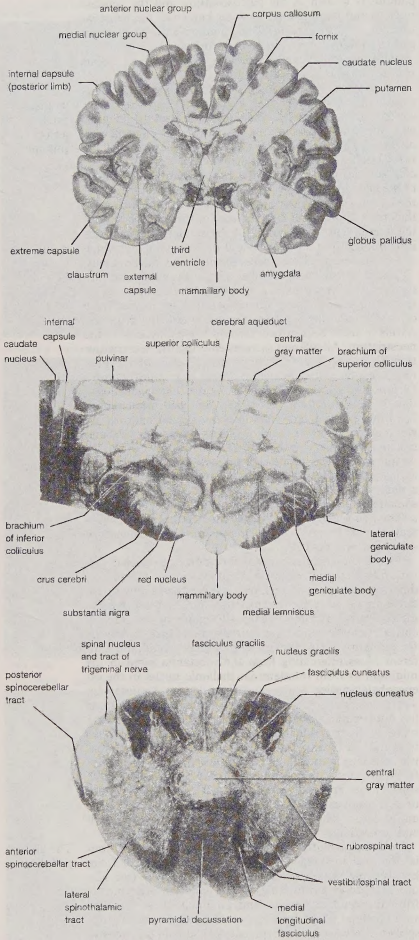


Figure 18: *Three cross sections of the brain.* (Top) Frontal section through the thalamus, internal capsule, and basal ganglia. (Centre) Myelin-stained section through the midbrain and thalamus, showing the red nucleus, substantia nigra, and crus cerebri of the midbrain and the medial and lateral geniculate bodies of the thalamus. (Bottom) Myelin-stained section through the medulla oblongata, revealing the nuclei gracilis and cuneatus and the decussation of the corticospinal tract.
From M.B. Carpenter, *Core Text of Neuroanatomy*, 4th ed. (1991); Williams & Wilkins, Baltimore

which it receives a reciprocal input. No part of the corpus striatum projects fibres to spinal levels.

Pathological processes involving the corpus striatum and related nuclei are associated with a variety of specific syndromes characterized by abnormal involuntary movements (collectively referred to as dyskinesia) and significant alterations of muscle tone (see below *Nervous system diseases and disorders: The basal ganglia*). Parkinson's disease and Huntington's disease are among the more prevalent syndromes; each appears related to deficiencies in the synthesis of particular neurotransmitters.

The amygdala, located ventral to the corpus striatum in medial parts of the temporal lobe, is an almond-shaped nucleus underlying the uncus. Although it receives olfactory inputs, it plays no role in olfactory perception. This nucleus also has reciprocal connections with the hypothalamus, the basal forebrain, and multiple regions of the cerebral cortex. It plays important roles in visceral, endocrine, and cognitive functions related to motivational behaviour.

Diencephalon. The diencephalon consists of a pair of egg-shaped nuclear masses that lie on each side of the third ventricle and medial to the posterior limb of the internal capsule (see Figure 18). Four subdivisions are recognized: (1) the epithalamus, (2) the thalamus, (3) the hypothalamus, and (4) the ventral thalamus, or subthalamus.

Epithalamus. The epithalamus is represented mainly by the pineal gland, which lies in the midline posterior and dorsal to the third ventricle. This gland synthesizes melatonin and enzymes sensitive to diurnal light. Rhythmic changes in its activity in response to cyclical photic input suggest that the gland serves as a biological clock. With age it tends to accumulate calcium deposits.

Thalamus. The thalamus has long been regarded as the key to understanding the organization of the central nervous system. It is involved in the relay and distribution of most, but not all, sensory and motor signals to specific regions of the cerebral cortex. Sensory signals generated in all types of receptors are projected by complex pathways to specific relay nuclei in the thalamus, where they are segregated and systematically organized. The relay nuclei in turn supply the primary and secondary sensory areas of the cerebral cortex. Sensory input to thalamic nuclei is crossed for the somesthetic and visual systems, bilateral (but mainly crossed) for the auditory system, and ipsilateral for gustatory and olfactory sense.

Relay functions of the thalamus

The somesthetic relay nuclei of the thalamus, collectively known as the ventrobasal complex, receive input from the medial lemniscus (originating in the medulla), from spinothalamic tracts, and from the trigeminal nerve. Fibres within these ascending tracts that terminate in the central core of the ventrobasal complex receive input from deep sensory receptors, while fibres projecting onto the outer shell receive input from cutaneous receptors. This segregation of deep and superficial sensation is preserved in projections of the ventrobasal complex to the primary somesthetic (*i.e.*, sensory) area of the cerebral cortex.

The medial and lateral geniculate bodies form what is called the metathalamus. Fibres of the optic nerve end in the lateral geniculate body, which consists of six cellular laminae, or layers, folded into a horseshoe configuration. Each lamina represents a complete map of the contralateral visual hemifield, and all laminae are in perfect registration. Cells in all layers of the lateral geniculate body project via the optic radiation to the visual areas of the cerebral cortex. The medial geniculate body receives auditory impulses from the inferior colliculus of the midbrain and relays them to the auditory areas on the temporal lobe. Only the ventral nucleus of the medial geniculate body is laminated and tonotopically organized; this part projects to the primary auditory area and is finely tuned. Other subdivisions of the medial geniculate body project to the belt of secondary auditory cortex surrounding the primary area.

Major output from the cerebellum projects to specific thalamic relay nuclei in a pattern similar to that for somesthetic input. The thalamic relay nuclei in turn provide a major input to the primary motor area of the frontal lobe. This large system appears to provide coordinating and controlling influences that result in the appropriate force, sequence, and direction of voluntary motor activities. Output from the corpus striatum, on the other hand, is relayed by thalamic nuclei that have access to the supplementary and premotor areas. The supplementary motor

area, located on the medial aspect of the hemisphere (see Figure 29), exerts modifying influences upon the primary motor area and appears to be involved in programming skilled motor sequences. The premotor area, rostral to the primary motor area, plays a role in sensorially guided movements.

Other major thalamic nuclei, besides those involved in relaying sensory impulses or controlling influences from the cerebellum and corpus striatum, include the anterior nuclear group, the mediodorsal nucleus, and the pulvinar. The anterior nuclear group receives input from the hypothalamus and projects upon parts of the limbic lobe (*i.e.,* the cingulate gyrus). The mediodorsal nucleus, part of the medial nuclear group, has reciprocal connections with large parts of the frontal lobe rostral to the motor areas. The pulvinar is a huge posterior nuclear complex that, along with the mediodorsal nucleus, has projections to association areas of the cortex.

Output ascending from the reticular formation of the brain stem is relayed to the cerebral cortex by intralaminar thalamic nuclei, which lie in laminae separating the medial and ventrolateral thalamic nuclei. This ascending system is concerned with arousal mechanisms, maintaining alertness, and directing attention to sensory events.

Hypothalamus. The hypothalamus lies in the walls and floor of the third ventricle. It is divided into medial and lateral groups by fibres of the fornix, which originate in the hippocampal formation and adjacent subiculum and project to the mammillary body. Well-defined cell groups in the hypothalamus secrete hormones (*i.e.,* oxytocin and vasopressin) that are transported by nerve fibres to the neurohypophysis; other neurosecretory neurons convey hormone-releasing factors (*e.g.,* growth hormone, corticosteroids, thyrotropic hormone, and gonadotropic hormone) via a vascular portal system to the adenohypophysis. In this way the hypothalamus controls major endocrine functions; specific regions of the hypothalamus are also concerned with control of sympathetic and parasympathetic activities, temperature regulation, food intake, the reproductive cycle, and emotional expression and behaviour (see below *Functions of the human nervous system: Emotion and behaviour*).

Secretion of hormones and hormone-releasing factors

Ventral thalamus. The ventral thalamus is represented mainly by the subthalamic nucleus, a lens-shaped structure lying behind and to the sides of the hypothalamus and on the dorsal surface of the internal capsule. The subthalamic region is traversed by fibres related to the globus pallidus. Discrete lesions in the subthalamic nucleus produce hemiballism, the most violent form of dyskinesia known.

Midbrain and hindbrain. Below the diencephalon are the midbrain (or mesencephalon) and the hindbrain (or rhombencephalon). The hindbrain consists of the pons (or metencephalon) and the medulla oblongata (or myelencephalon). These parts of the brain stem are characterized by three main features: (1) a roof plate superior to the cerebral aqueduct and fourth ventricle; (2) a central core of gray matter, known as the reticular formation; and (3) a massive basal collection of fibres descending from the cerebral cortex to the brain stem and spinal cord.

The roof plate of the midbrain is formed by two paired rounded eminences, the superior and inferior colliculi. The superior colliculus receives input from the retina and the visual cortex and participates in a variety of visual reflexes, particularly the tracking of objects in the contralateral visual field. The inferior colliculus receives both crossed and uncrossed auditory fibres and projects upon the medial geniculate body, the auditory relay nucleus of the thalamus (see above *Diencephalon*). In the hindbrain the roof plate is formed by the cerebellum and a membrane containing the choroid plexus of the fourth ventricle.

The reticular formation contains a core collection of cells of various sizes that project to the thalamus, the cerebellum, and the spinal cord. Surrounding this core are long ascending and descending tracts in which various cranial nerve nuclei are embedded.

Fibres derived from the cerebral cortex lie on or near the ventral surface of the midbrain, pons, and medulla. At the midbrain they gather into two bundles called the crura cerebri; from there they descend into the pons, where most terminate upon cell nuclei that project into the cerebellum. These constitute the corticopontine tract. The other major tract, called the corticospinal tract, forms the medullary pyramids before descending to the spinal cord.

Midbrain. The midbrain contains the nuclear complex of the oculomotor nerve as well as the trochlear nucleus; these cranial nerves innervate muscles that move the eye and control the shape of the lens and the diameter of the pupil. In addition, between the midbrain reticular formation (known here as the tegmentum) and the crus cerebri is a large, pigmented structure called the substantia nigra (see Figure 18). This nucleus consists of two parts, the pars reticulata and the pars compacta. Cells of the pars compacta contain the black pigment melanin; these synthesize dopamine and project to cells of either the caudate nucleus or the putamen but not to both. By exercising an inhibitory action on large aspiny cholinergic neurons in the neostriatum, the dopaminergic cells of the pars compacta influence the output of the neurotransmitter GABA from spiny striatal neurons. These spiny neurons in turn project to cells of the pars reticulata, which, by projecting fibres to the thalamus, are in effect part of the output system of the corpus striatum.

The substantia nigra

At the caudal midbrain, crossed fibres of the superior cerebellar peduncle (the major output system of the cerebellum) surround and partially terminate in a large, centrally located structure known as the red nucleus. Most crossed ascending fibres of this bundle project to thalamic nuclei, which have access to the primary motor cortex. A smaller number of fibres synapse on large cells in caudal regions of the red nucleus; these give rise to the crossed fibres of the rubrospinal tract (see below *The spinal cord: Descending spinal tracts*).

Pons. The pons consists of two parts: the tegmentum, a phylogenetically older part that contains the reticular formation; and the pontine nuclei, a larger part composed of masses of neurons that lie among large bundles of longitudinal and transverse fibres.

Fibres originating from neurons in all major lobes of the cerebral cortex terminate upon the pontine nuclei, which in turn project to the opposite cerebellar hemisphere. These massive crossed fibres form the middle cerebellar peduncle (see Figures 16 and 19)—in effect serving as the

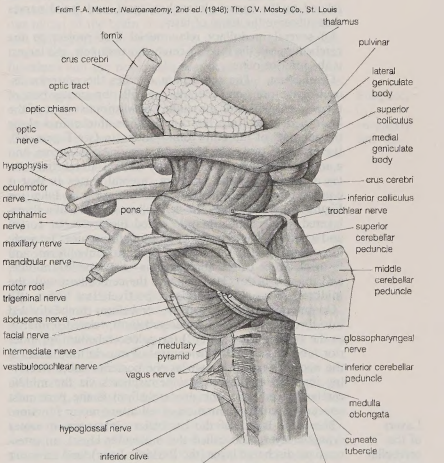


Figure 19: The lateral surface of the brain stem, showing attached cranial nerves.

bridge that connects each cerebral hemisphere with the opposite half of the cerebellum.

The reticular formation in the pontine tegmentum contains multiple cell groups that exert facilitating influences upon motor function. It also contains the nuclei of several cranial nerves. The facial nerve and the two components of the vestibulocochlear nerve, for example, emerge from and enter the brain stem at the junction of the pons, medulla, and cerebellum. Motor nuclei for the trigeminal nerve lie in the upper pons. Located on the periphery of the pons are long ascending and descending tracts that connect the brain to the spinal cord.

Medulla oblongata. The medulla, the most caudal segment of the brain stem, appears as a conical expansion of the spinal cord (see Figures 18 and 19). Both the pons and the medulla are separated from the overlying cerebellum by the fourth ventricle, and cerebrospinal fluid entering the fourth ventricle from the cerebral aqueduct passes into the cisterna magna, a subarachnoid space surrounding the medulla and the cerebellum, via foramina in the lateral recesses and in the midline of the ventricle.

Decussation of nerve fibres

At the transition from the medulla to the spinal cord, there are two major decussations, or crossings, of nerve fibres. The corticospinal decussation is the site at which 90 percent of the fibres of the medullary pyramid cross and enter the dorsolateral funiculus of the spinal cord (see Figure 21). Signals conveyed by this tract provide the basis for voluntary motor function on the opposite side of the body (see below *The spinal cord: Descending spinal tracts*). In the other decussation, sensory fibres ascending in the fasciculus gracilis and fasciculus cuneatus of the spinal cord terminate upon large nuclear masses on the dorsal surface of the medulla. Known as the nuclei gracilis and cuneatus, these masses give rise to fibres that decussate above the corticospinal tract and form a major ascending sensory pathway known as the medial lemniscus. Present at all brain-stem levels, the medial lemniscus projects upon the somesthetic relay nuclei of the thalamus.

The medulla contains nuclei associated with the hypoglossal, accessory, vagus, and glossopharyngeal cranial nerves. In addition, it contains portions of the vestibular nuclear complex, parts of the trigeminal nuclear complex concerned with pain and thermal sense, and solitary nuclei related to the vagus, glossopharyngeal, and facial nerves that subserve the sense of taste.

Of several medullary relay nuclei that project to the cerebellum via the inferior cerebellar peduncle, the largest is the inferior olive.

Cerebellum. The cerebellum overlies the posterior aspect of the pons and medulla and fills the greater part of the posterior fossa of the skull. This distinctive part of the brain is derived from the rhombic lips, thickenings along the margins of the embryonic hindbrain (see Figure 15). It consists of two paired lateral lobes, or hemispheres, and a midline portion known as the vermis. Cerebellar cortex appears very different from cerebral cortex in that it consists of small, leaflike laminae, referred to as folia (see Figure 16). Structurally the cerebellum consists of a three-layered, gray cellular mantle called the cerebellar cortex and a core of white matter containing four paired intrinsic (*i.e.,* deep) nuclei, the dentate, globose, emboliform, and fastigial. Three paired fibre bundles—the superior, middle, and inferior peduncles—connect the cerebellum with the midbrain, pons, and medulla, respectively (see Figure 19).

On an embryological basis the cerebellum can be divided into three parts: (1) the archicerebellum, related primarily to the vestibular system; (2) the paleocerebellum, or anterior lobe, concerned with control of muscle tone; and (3) the neocerebellum, known as the posterior lobe. Receiving input from the cerebral hemispheres via the middle cerebellar peduncle, the neocerebellum is the part most concerned with coordination of voluntary motor function.

Layers of the cerebellar cortex

The three layers of the cerebellar cortex are an outer synaptic layer (also called the molecular layer), an intermediate discharge layer (the Purkinje layer), and an inner receptive layer (the granular layer). Sensory input from all sorts of receptors are conveyed to specific regions of the receptive layer, which consists of enormous numbers of small nerve cells (hence the name granular) that project axons into the synaptic layer. There they excite the dendrites of the Purkinje cells, which in turn project axons to portions of the four intrinsic nuclei and upon dorsal portions of the lateral vestibular nucleus. Because most Purkinje cells are GABAergic and therefore exert strong inhibitory influences upon the cells that receive their terminals, all sensory input into the cerebellum results in inhibitory impulses being exerted upon the deep cerebellar nuclei and parts of the vestibular nucleus. Cells of all deep cerebellar nuclei, on the other hand, are excitatory (secreting the neurotransmitter glutamate) and project upon parts of the thalamus, red nucleus, vestibular nuclei, and reticular formation.

The cerebellum thus functions as a kind of computer, providing a quick and clear response to any set of sensory signals. It plays no role in sensory perception, but it exerts profound influences upon equilibrium, muscle tone, and the coordination of voluntary motor function. Lesions of the cerebellum produce a constellation of disturbances, including intention tremor, ataxia, hypotonus, easy fatigability, and disturbances of speech.

THE SPINAL CORD

The spinal cord is an elongated cylindrical structure, about 45 centimetres (18 inches) long, that extends from the medulla oblongata of the hindbrain to a level between the first and second lumbar vertebrae of the backbone. The terminal part of the spinal cord is called the conus medullaris. Associated with local regions of the spinal cord and imposing upon it an external segmentation are 31 pairs of spinal nerves, each of which receives and furnishes one dorsal and one ventral root (see Figure 25). On this basis the spinal cord is divided into the following segments: 8 cervical (C), 12 thoracic (T), 5 lumbar (L), 5 sacral (S), and 1 coccygeal (Coc). Spinal nerve roots emerge via

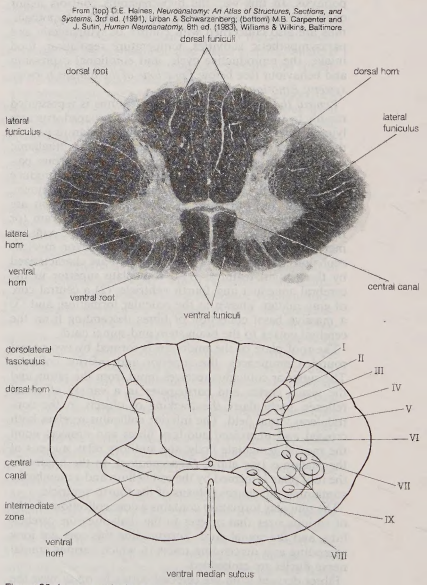


Figure 20: *Lower cervical section of the spinal cord.* (Top) Photograph of a cross section, with the white matter stained dark. (Bottom) Schematic drawing showing cytoarchitectural lamination.

intervertebral foramina; lumbar and sacral spinal roots, descending for some distance within the subarachnoid space before reaching the appropriate foramina, produce a group of nerve roots about the conus medullaris known as the cauda equina. Two enlargements of the spinal cord are evident: (1) a cervical enlargment (C_5 through T_1), which provides innervation for the upper extremity, and (2) a lumbosacral enlargement (L_1 through S_2), which innervates the lower extremity.

Appearance in cross section

A cross section of the spinal cord reveals long tracts of myelinated nerve fibres (known as white matter) arranged around the periphery of a symmetrical, butterfly-shaped cellular matrix of gray matter (see Figure 20). The gray matter forms three pairs of horns throughout most of the spinal cord: (1) the dorsal horns, composed of sensory neurons; (2) the lateral horns, well defined in thoracic segments and composed of visceral neurons; and (3) the ventral horns, especially large in the cord enlargements and composed of motor neurons. The white matter forming the ascending and descending spinal tracts falls in three paired funiculi, or sectors: the dorsal or posterior funiculi, lying between the dorsal horns; the lateral funiculi, lying on each side of the spinal cord between the dorsal-root entry zones and the emergence of the ventral roots; and the ventral funiculi, lying between the ventral median sulcus and each ventral-root zone.

Gray matter. The cellular gray matter has a "cytoarchitectural lamination" in which nine laminae are customarily indicated by Roman numerals (see Figure 20, bottom). Laminae I to V, forming the dorsal horns, receive sensory input. Lamina VII forms the intermediate zone at the base of all horns. Lamina IX is composed of clusters of large (alpha) motor neurons, whose axons innervate striated muscle, and small (gamma) motor neurons, which innervate contractile elements of the muscle spindle. Axons of both alpha and gamma motor neurons emerge via the ventral roots. Laminae VII and VIII have variable configurations, and lamina VI is present only in the cervical and lumbosacral enlargements. In addition, cells surrounding the central canal of the spinal cord form an area often referred to as lamina X.

All primary sensory neurons that enter the spinal cord originate in ganglia that are located in the intervertebral foramina. Peripheral processes of the nerve cells in these ganglia convey sensation from various receptors, and central processes of the same cells enter the spinal cord dorsolaterally as bundles of nerve filaments. Fibres conveying specific forms of sensation follow separate pathways. Impulses concerned with pain and noxious stimuli largely end upon cells in parts of laminae I and II, while impulses associated with tactile sense end in lamina IV or on processes of cells in that lamina. Signals from stretch receptors (*i.e.,* muscle spindles and tendon organs) end upon cells in parts of laminae V, VI, and VII; collaterals of these fibres involved in the stretch reflex project into lamina IX.

Virtually all parts of the spinal gray contain interneurons, which connect various cell groups. Many interneurons have short axons distributed locally, but some have axons that extend for several spinal segments. Some interneurons may modulate or change the character of signals, while others play key roles in transmission and in patterned reflexes.

Ascending spinal tracts. Sensory tracts ascending in the white matter of the spinal cord arise either from cells of spinal ganglia or from intrinsic neurons within the gray matter that receive primary sensory input.

The fasciculi gracilis and cuneatus

Dorsal column. The largest ascending tracts, the fasciculi gracilis and cuneatus, arise from spinal ganglion cells and ascend in the dorsal funiculus to the medulla. The fasciculus gracilis receives fibres from ganglia below thoracic 6, while spinal ganglia from higher segments of the spinal cord project fibres into the fasciculus cuneatus. The fasciculi terminate upon large nuclear masses (the nuclei gracilis and cuneatus) in the medulla. Cells of these nuclei give rise to fibres that cross completely and form the medial lemniscus; the medial lemniscus in turn projects to the ventrobasal nuclear complex of the thalamus. In this way, the dorsal column/medial lemniscal system conveys signals associated with tactile, pressure, and kinesthetic (or positional) sense to sensory areas of the cerebral cortex.

Spinothalamic tracts. Fibres concerned with pain, thermal sense, and light touch enter the lateral-root entry zone and then ascend or descend near the periphery of the spinal cord before entering superficial laminae of the dorsal horn—largely parts of laminae I, IV, and V. Cells in these laminae then give rise to fibres of the two spinothalamic tracts. Those crossing in the ventral white commissure (ventral to the central canal) form the lateral spinothalamic tract, which, ascending in the ventral part of the lateral funiculus, conveys signals related to pain and thermal sense. The anterior spinothalamic tract arises from fibres that cross the midline in the same fashion but ascend more anteriorly in the spinal cord; these convey impulses related to light touch. At medullary levels the two spinothalamic tracts tend to merge and cannot be distinguished as separate entities. Many of the fibres, or collaterals, of the spinothalamic tracts end upon cell groups in the reticular formation, while the principal tracts convey sensory impulses to relay nuclei in the thalamus.

Spinocerebellar tracts. Impulses from stretch receptors are carried by large-diameter fibres that synapse upon cells in deep laminae of the dorsal horn or in lamina VII. The posterior spinocerebellar tract arises from the dorsal nucleus of Clarke and ascends peripherally in the dorsal part of the lateral funiculus. The anterior spinocerebellar tract ascends on the ventral margin of the lateral funiculus. Both tracts transmit signals to portions of the anterior lobe of the cerebellum and are involved in mechanisms that automatically regulate muscle tone without reaching consciousness.

Descending spinal tracts. Tracts descending to the spinal cord are concerned with voluntary motor function, muscle tone, reflexes and equilibrium, visceral innervation, and modulation of ascending sensory signals. The largest and most important, the corticospinal tract, originates in broad regions of the cerebral cortex. Smaller descending tracts, which include the rubrospinal tract, the vestibulospinal tract, and the reticulospinal tract, originate in discrete and diffuse nuclei in the midbrain, pons, and medulla. Most of these brain-stem nuclei themselves receive input from the cerebral cortex, the cerebellar cortex, deep nuclei of the cerebellum, or some combination of these.

In addition, autonomic tracts, which descend from various nuclei in the brain stem to preganglionic sympathetic and parasympathetic neurons in the spinal cord, constitute a vital link between the centres that regulate visceral functions and the nerve cells that actually effect changes.

Function in voluntary activity

Corticospinal tract. Universally regarded as the single most important tract concerned with skilled voluntary activity, the corticospinal tract originates from pyramid-shaped cells in the premotor, primary motor, and primary sensory cortex. Containing about one million fibres, it forms a significant part of the posterior limb of the internal capsule and is a major constituent of the crus cerebri in the midbrain. As the fibres emerge from the pons, they form compact bundles on the ventral surface of the medulla, known as the medullary pyramids (see Figure 19). In the lower medulla about 90 percent of the fibres of the corticospinal tract decussate and descend in the dorsal part of the lateral funiculus of the spinal cord. Of the fibres that do not cross in the medulla, approximately 8 percent cross in cervical spinal segments (see Figure 21). As the tract descends, fibres and collaterals are given off at all segmental levels, synapsing upon interneurons in lamina VII and upon motor neurons in lamina IX. Approximately 50 percent of the corticospinal fibres terminate within cervical segments.

At birth, few of the fibres of the corticospinal tract are myelinated; myelination takes place during the first year after birth, parallel to the acquisition of motor skills. Because the tract passes through, or close to, nearly every major division of the neuraxis, it is vulnerable to vascular and other kinds of lesions. A relatively small lesion in the posterior limb of the internal capsule, for example, may result in contralateral hemiparesis, which is characterized by weakness, spasticity, greatly increased deep tendon reflexes, and certain abnormal reflexes.

Rubrospinal tract. The rubrospinal tract arises from

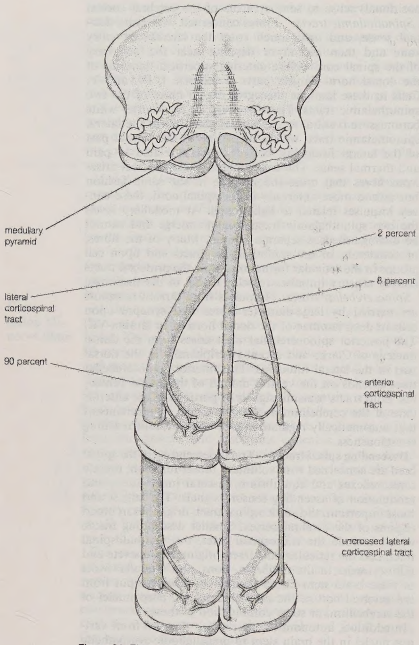


Figure 21: The decussation of the medullary pyramids and the formation of the corticospinal system in the spinal cord.
From M.B. Carpenter, *Core Text of Neuroanatomy*, 4th ed. (1991); Williams & Wilkins, Baltimore

cells in the caudal part of the red nucleus, an encapsulated cell group in the midbrain tegmentum (see Figure 18). Fibres of this tract decussate at midbrain levels, descend in the lateral funiculus of the spinal cord (overlapping ventral parts of the corticospinal tract), enter the spinal gray, and terminate on interneurons in lamina VII. Through these crossed rubrospinal projections, the red nucleus exerts a facilitating influence on flexor alpha motor neurons and a reciprocal inhibiting influence on extensor alpha motor neurons. Because cells of the red nucleus receive input from the motor cortex (via corticorubral projections) and from globose and emboliform nuclei of the cerebellum (via the superior cerebellar peduncle), the rubrospinal tract effectively brings flexor muscle tone under the control of these two regions of the brain.

Vestibulospinal tract. The vestibulospinal tract originates from cells of the lateral vestibular nucleus, which lies in the floor of the fourth ventricle. Fibres of this tract descend the length of the spinal cord in the ventral and lateral funiculi without crossing, enter laminae VIII and IX of the anterior horn, and end upon both alpha and gamma motor neurons, which innervate ordinary muscle fibres and fibres of the muscle spindle (see below *Functions of the human nervous system: Movement*). Cells of the lateral vestibular nucleus receive facilitating impulses from labyrinthine receptors in the utricle and from fastigial nuclei in the cerebellum. In addition, inhibitory influences upon these cells are conveyed by direct projections from Purkinje cells in the anterior lobe of the cerebellum. Thus, the vestibulospinal tract mediates the influences of the vestibular end organ and the cerebellum upon extensor muscle tone.

Mediation of balance and coordination functions

A smaller number of vestibular projections, originating from the medial and inferior vestibular nuclei, descend ipsilaterally in the medial longitudinal fasciculus only to cervical levels. These fibres exert excitatory and inhibitory effects upon cervical motor neurons.

Reticulospinal tract. The reticulospinal tracts arise from relatively large but restricted regions of the reticular formation of the pons and medulla—the same cells that project ascending processes to intralaminar thalamic nuclei and play an important role in maintaining alertness and the conscious state. The pontine reticulospinal tract arises from aggregations of cells in the pontine reticular formation, descends ipsilaterally as the largest component of the medial longitudinal fasciculus, and terminates among cells in laminae VII and VIII. Fibres of this tract exert facilitating influences upon voluntary movements, muscle tone, and a variety of spinal reflexes. The medullary reticulospinal tract, originating from reticular neurons on both sides of the median raphe, descends in the ventral part of the lateral funiculus and terminates at all spinal levels upon cells in laminae VII and IX. The medullary reticulospinal tract inhibits the same motor activities that are facilitated by the pontine reticulospinal tract. Both tracts receive input from regions of the motor cortex.

Autonomic pathways. Descending fibre systems concerned with visceral and autonomic activities emanate from collections of cells at various levels of the brain stem. For example, hypothalamic nuclei project to visceral nuclei in both the medulla and spinal cord; in the spinal cord these direct hypothalamospinal projections terminate upon cells of the intermediolateral cell column in thoracic, lumbar, and sacral segments. Preganglionic parasympathetic neurons originating in the oculomotor nuclear complex in the midbrain project not only to the ciliary ganglion but also directly to spinal levels. Some of these fibres reach lumbar segments of the spinal cord, most of them terminating in parts of laminae I and V. Pigmented cells in an area of the rostral pons known as the isthmus form a blackish blue collection visible in gross brain sections; known as the locus ceruleus, these cells are rich in norepinephrine and distribute this neurotransmitter widely to all regions of the brain and spinal cord. Fibres from the locus ceruleus descend to spinal levels without crossing and are distributed to terminals in the anterior horn, the intermediate zone, and the dorsal horn. Other noradrenergic cell groups in the pons, near the motor nucleus of the facial nerve, project uncrossed noradrenergic fibres that terminate in the intermediolateral cell column (that is, lamina VII of the lateral horn). Postganglionic sympathetic neurons associated with this system have direct effects upon the cardiovascular system. Cells in the nucleus of the solitary tract project crossed fibres to the phrenic nerve nucleus (in cervical segments 3 through 5), the intermediate zone, and the anterior horn at thoracic levels; these innervate respiratory muscles. (Ed.)

The peripheral nervous system

The peripheral nervous system is a channel for the relay of sensory and motor impulses between the central nervous system on the one hand and the body surface, skeletal muscles, and internal organs on the other hand. It is composed of (1) spinal nerves, (2) cranial nerves, and (3) certain parts of the autonomic nervous system. As in the central nervous system, peripheral nervous pathways are made up of neurons (that is, nerve cell bodies and their axons and dendrites) as well as the points at which one neuron communicates with the next (that is, the synapse). The structures commonly known as nerves (or by such names as roots, rami, trunks, and branches) are actually composed of orderly arrangements of the axonal and dendritic processes of many nerve cell bodies.

Ganglia

The cell bodies of peripheral neurons are often found grouped into clusters called ganglia. Based on the type of nerve cell bodies found in ganglia, they may be classified as either sensory or motor. Sensory ganglia are found as oval swellings on the dorsal roots of spinal nerves,

and they are also found on the roots of certain cranial nerves. The sensory neurons making up these ganglia are unipolar. Shaped much like a golf ball on a tee, they have round or slightly oval cell bodies with concentrically located nuclei, and they give rise to a single fibre that undergoes a T-shaped bifurcation, one branch going to the periphery and the other entering the brain or spinal cord. There are no synaptic contacts between neurons in a sensory ganglion.

Motor ganglia are associated with neurons of the autonomic nervous system. Many of these are found in the sympathetic trunks, two long chains of ganglia lying along each side of the vertebral column from the base of the skull to the coccyx; these are referred to as paravertebral. Other motor ganglia (called prevertebral) are found near internal organs innervated by their projecting fibres, while still others (called terminal ganglia) are found on the surfaces or within the walls of the target organs themselves. Motor ganglia contain multipolar cell bodies, which have irregular shapes and eccentrically located nuclei and which project several dendritic and axonal processes. Preganglionic fibres originating from the brain or spinal cord enter motor (autonomic) ganglia, where they synapse on multipolar cell bodies. These postganglionic cells, in turn, send their processes to visceral structures.

SPINAL NERVES

Sensory input from the body surface, from joint, tendon, and muscle receptors, and from internal organs passes centrally through the dorsal roots of the spinal cord. Fibres from motor cells in the spinal cord exit via the ventral roots and course to their peripheral targets (autonomic ganglia or skeletal muscle). The spinal nerve is formed by the joining of dorsal and ventral roots, and it is the basic structural and functional unit on which the peripheral nervous system is built.

Structure of the spinal nerve. In humans there are 31 pairs of spinal nerves. In descending order from the most rostral end of the spinal cord, there are 8 cervical (designated C_1–C_8), 12 thoracic (T_1–T_{12}), 5 lumbar (L_1–L_5), 5 sacral (S_1–S_5), and 1 coccygeal (Coc_1). Each spinal nerve exits the vertebral canal through an opening called the intervertebral foramen (see Figure 25). The first spinal nerve (C_1) exits between the skull and the first cervical vertebra; consequently, spinal nerves C_1–C_7 exit above the correspondingly numbered vertebrae. Spinal nerve C_8, however, exits between the 7th cervical and first thoracic vertebrae, so that, beginning with T_1, all other spinal nerves exit below their corresponding vertebrae.

Just outside the intervertebral foramen, two branches, known as the gray and white rami communicates, connect the spinal nerve with the sympathetic trunk. These rami, along with the sympathetic trunk and more distal ganglia, are concerned with the innervation of visceral structures. In addition, small meningeal branches leave the spinal nerve and gray ramus and reenter the vertebral canal, where they innervate dura and blood vessels.

Ventral and dorsal rami

More peripherally, the spinal nerve divides into ventral and dorsal rami (see Figure 22). All dorsal rami (with the exception of those from C_1, S_4, S_5, and Coc_1) have medial and lateral branches, which innervate deep back muscles and overlying skin. The medial and lateral branches of the dorsal rami of spinal nerves C_2–C_8 supply both muscles and skin of the neck. Those of T_1–T_6 are mostly cutaneous (that is, supplying only the skin), while those from T_7–T_{12} are mainly muscular. Dorsal rami from L_1–L_3 have both sensory and motor fibres, while those from L_4–L_5 are only muscular. Dorsal rami of S_1–S_3 may also be divided into medial and lateral branches, serving deep muscles of the lower back as well as cutaneous areas of the lower buttocks and perianal area. Undivided dorsal rami from S_4, S_5, and Coc_1 also send cutaneous branches to the gluteal and perianal regions.

Ventral rami of the spinal nerves carry sensory and motor fibres for the innervation of the muscles, joints, and skin of the lateral and ventral body walls and the extremities (see below *Plexuses of the ventral rami*). Both dorsal and ventral rami also contain autonomic fibres.

Functional components. Because spinal nerves contain both sensory fibres (from the dorsal roots) and motor fibres (from the ventral roots), they are known as mixed nerves. When individual fibres of a spinal nerve are identified by their specific function, they may be categorized as one of four types: (1) general somatic afferent, (2) general visceral afferent, (3) general somatic efferent, and (4) general visceral efferent. The term somatic refers to the body wall (broadly defined to include skeletal muscles as well as the surface of the skin), and visceral refers to structures composed of smooth muscle, cardiac muscle, or glandular epithelium (or a combination of these). Efferent fibres carry motor information to skeletal muscle and to autonomic ganglia (and then to visceral structures), and afferent fibres carry sensory information from them.

General somatic afferent receptors are sensitive to pain, thermal sensation, touch and pressure, and changes in the position of the body. (Pain and temperature sensation coming from the surface of the body are called exteroceptive, while sensory information arising from tendons, muscles, or joint capsules are called proprioceptive.) General visceral afferent receptors are found in organs of the thorax, abdomen, and pelvis; their fibres convey, for example, pain information from the digestive tract. Both types of afferent fibre project centrally from cell bodies in dorsal-root ganglia.

Carrying motor information

General somatic efferent fibres originate from large ventral-horn cells and distribute to skeletal muscles in the body wall and in the extremities. General visceral efferent fibres also arise from cell bodies located within the spinal cord, but they exit only at thoracic and upper lumbar levels or at sacral levels (more specifically, at levels T_1–L_2 and S_2–S_4). Fibres from T_1–L_2 enter the sympathetic trunk, where they either form synaptic contacts within a ganglion, ascend or descend within the trunk, or exit the trunk and proceed to ganglia situated closer to their target organs. Fibres from S_2–S_4, on the other hand, leave the cord as the pelvic nerve and proceed to terminal ganglia located in the target organs. Postganglionic fibres arising from ganglia in the sympathetic trunk rejoin the spinal nerves and distribute to blood vessels, sweat glands, and arrector pili muscles, while postganglionic fibres arising from prevertebral and terminal ganglia innervate viscera of the thorax, abdomen, and pelvis.

Plexuses of the ventral rami. All plexuses arising from the ventral rami of spinal nerves contain sensory, motor, and autonomic fibres. The plexuses are the cervical, brachial, lumbar, sacral, and coccygeal.

Cervical plexus. Cervical levels C_1–C_4 are the main contributors to the cervical plexus; in addition, small branches link C_1 and C_2 with the vagus nerve, C_1 and C_2 with the

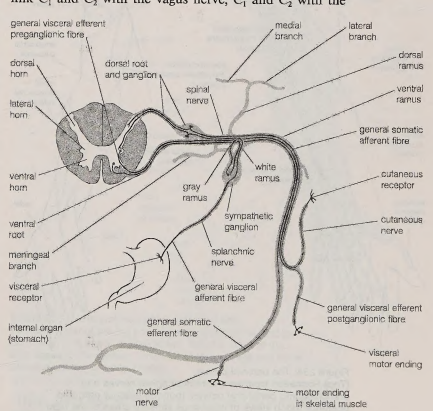


Figure 22: A typical spinal nerve.

hypoglossal nerve, and C_2–C_4 with the accessory nerve. Sensory branches of the cervical plexus are the lesser occipital nerve (to scalp behind the ear), the great auricular nerve (to the ear and to the skin over the mastoid and parotid areas), transverse cervical cutaneous nerves (to lateral and ventral neck surfaces), and supraclavicular nerves (along the clavicle, shoulder, and upper chest). Motor branches serve muscles that stabilize and flex the neck, muscles that stabilize the hyoid bone (to assist in actions like swallowing), and muscles that elevate the upper ribs.

Originating from C_4, with small contributions from C_3 and C_5, are the phrenic nerves, which carry sensory information from parts of the pleura and pericardium and motor impulses to muscles of the diaphragm. Injury to the phrenic nerves would paralyze the diaphragm and render breathing difficult or impossible.

Brachial plexus. Cervical levels C_5–C_8 and thoracic level T_1 contribute to the formation of the brachial plexus; small fascicles also arrive from C_4 and T_2 (see Figure 23A). Spinal nerves from these levels converge to form superior (C_5 and C_6), middle (C_7), and inferior (C_8 and T_1) trunks, which in turn split into anterior and posterior divisions. The divisions then form cords (posterior, lateral, and medial), which provide motor, sensory, and autonomic fibres to the shoulder and upper extremity.

Innervation of the shoulder, arm, and hand

Nerves to shoulder and pectoral muscles include the dorsal scapular (to the rhomboid muscles), suprascapular (to supraspinatus and infraspinatus), medial and lateral pectoral (to pectoralis minor and major), long thoracic (to serratus anterior), thoracodorsal (to latissimus dorsi), and subscapular (to teres major and subscapular). The axillary nerve carries motor fibres to the deltoid and teres minor muscles as well as sensory fibres to the lateral surface of the shoulder and upper arm. The biceps, brachialis, and coracobrachialis muscles, as well as the lateral surface of the forearm, are served by the musculocutaneous nerve.

The three major nerves of the arm, forearm, and hand are the radial, median, and ulnar (see Figure 23B). The radial nerve innervates the triceps, anconeus, and brachioradialis muscles, eight extensors of the wrist and digits, and one abductor of the hand; it is also sensory to part of the hand. The median nerve branches in the forearm to serve the palmaris longus, two pronator muscles, four flexor muscles, thenar muscles, and lumbrical muscles; most of these serve the wrist and hand. The ulnar nerve serves two flexor muscles and a variety of small muscles of the wrist and hand.

Cutaneous innervation of the upper extremity originates, via the brachial plexus, from spinal cord levels C_5–T_2. The shoulder is served by supraclavicular branches (C_3, C_4) of the cervical plexus, while the anterior and lateral aspects of the arm and forearm have sensory innervation via the axillary (C_5, C_6), nerve as well as the dorsal (C_5, C_6), lateral (C_5, C_6), and medial (C_8, T_1) antebrachial cutaneous nerves. These same nerves have branches that wrap around to serve portions of the posterior and medial surfaces of the extremity. The palm of the hand is served by the median (C_6–C_8) and ulnar (C_8, T_1) nerves. The ulnar nerve also wraps around to serve medial areas of the dorsum, or back, of the hand. A line drawn down the midline of the ring finger represents the junction of the ulnar-radial distribution on the back of the hand and the ulnar-median distribution on the palm (see Figure 23A). A small part of the thumb and the distal thirds of the index, middle, and lateral surface of the ring finger are served by the median nerve. The inner aspect of the arm and adjacent armpit is served by intercostobrachial and posterior and medial brachial cutaneous nerves (T_1–T_2).

Lumbar plexus. Spinal nerves from lumbar levels L_1–L_4 contribute to the formation of the lumbar plexus, which, along with the sacral plexus, provides motor, sensory, and autonomic fibres to gluteal and inguinal regions and to the lower extremity. Lumbar roots are organized into dorsal and ventral divisions.

Minor cutaneous and muscular branches of the lumbar plexus include the iliohypogastric, genitofemoral, and ilioinguinal (projecting to the lower abdomen and to inguinal and genital regions) and the lateral femoral cutaneous nerve (to skin on the lateral thigh). Two major branches are the obturator and femoral nerves. The obturator enters the thigh through the obturator foramen; motor branches proceed to the obturator internus and gracilis muscles as well as the adductor muscles, while sensory branches supply the articular capsule of the knee joint. An accessory obturator nerve supplies the pectineus muscle of the thigh and is sensory to the hip joint.

The sartorius muscle and medial and anterior surfaces of the thigh are served by branches of the anterior division of the femoral nerve. The posterior division of the femoral nerve provides sensory fibres to the inner surface of the leg (saphenous nerve), to the quadriceps muscles (muscu-

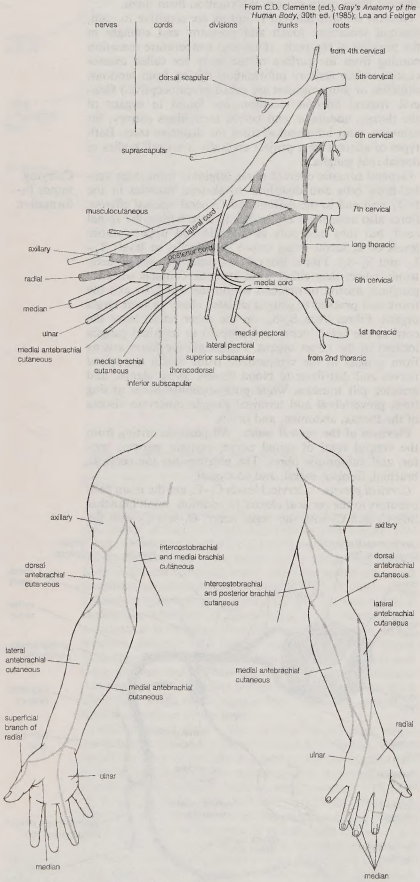


Figure 23A: *The brachial plexus.*
(Top) Formation from ventral rami of spinal nerves and branching into peripheral nerves; (bottom) anterior (left) and posterior (right) views of cutaneous sensory areas of the right arm supplied by the brachial plexus.

lar branches), the hip and knee joints, and the articularis genu muscle.

Sacral plexus. The ventral rami of L_4 and S_1–S_3 form the sacral plexus, with contributions from L_5 and S_4. Branches from this plexus innervate gluteal muscles, muscles forming the internal surface of the pelvic basin (including those forming the levator ani), and muscles that run between the femur and pelvis to stabilize the hip joint (such as the obturator, piriformis, and quadratus femoris muscles). These muscles lend their names to the nerves that innervate them. Cutaneous branches from the plexus serve the buttocks, perineum, and posterior surface of the thigh.

Innervation of the leg and foot

The major nerve of the sacral plexus, and the largest in the body, is the sciatic (see Figure 23B). Formed by the joining of ventral and dorsal divisions of the plexus, it passes through the greater sciatic foramen and descends in back of the thigh. There, sciatic branches innervate the biceps femoris, semitendinosus and semimembranosus muscles, and part of the adductor magnus muscle. In the popliteal fossa (just above the knee) the sciatic nerve divides into the tibial nerve and the common fibular (or peroneal) nerve. The tibial nerve (from the dorsal division) continues distally in the calf and innervates the gastrocnemius muscle, deep leg muscles such as the popliteus, soleus, and tibialis posterior, and the flexor muscles, lumbrical muscles, and other muscles of the ankle and plantar aspects of the foot. The peroneal nerve, from the ventral division, passes to the anterior surface of the leg and innervates the tibialis anterior, the fibularis muscles, and extensor muscles that elevate the foot and fan the toes. Cutaneous branches from the tibial and common fibular nerves serve the outer sides of the leg and the top and bottom of the foot and toes.

Coccygeal plexus. The ventral rami of S_4, S_5, and Coc_1 form the coccygeal plexus, from which small anococcygeal nerves arise to innervate the skin over the coccyx (tailbone) and around the anus.

CRANIAL NERVES

Cranial nerves can be thought of as modified spinal nerves, since the "general" functional fibre types found in spinal nerves also are found in cranial nerves but are supplemented by "special" afferent or efferent fibres. Fibres conveying olfaction (in cranial nerve I) and taste (in cranial nerves VII, IX, and X) are classified as special visceral afferent, while the designation of special somatic afferent is applied to fibres conveying vision (cranial nerve II) and equilibrium and hearing (cranial nerve VIII). Skeletal muscles that arise from the branchial (pharyngeal) arches are innervated by fibres of cranial nerves V, VII, IX, and X; these are classified as special visceral efferent fibres.

The 12 pairs of cranial nerves are commonly identified either by name or by Roman or Arabic numeral.

Olfactory nerve (CN I or 1). Bipolar cells in the nasal mucosa give rise to axons that enter the cranial cavity through foramina in the cribriform plate of the ethmoid bone. These cells and their axons, totaling about 20–24 in number, make up the olfactory nerve. Once in the cranial cavity, the fibres terminate in a small oval structure resting on the cribriform plate called the olfactory bulb (see Figure 24). As stated above, the functional component of olfactory fibres is special visceral afferent. Injury or disease of the olfactory nerve may result in anosmia, an inability to detect odours; this may also dull the sense of taste.

Optic nerve (CN II or 2). Rods and cones in the retina of the eye receive information from the visual fields and, through intermediary cells, convey this input to retinal ganglion cells. Ganglion cell axons converge at the optic disc, pass through the sclera, and form the optic nerve. The optic nerve from each eye enters the skull via the optic foramen and joins its opposite to form the optic chiasm. At the chiasm, fibres from the nasal halves of each retina cross, while those from the temporal halves remain uncrossed. In this way the optic tracts, which extend from the chiasm to the thalamus, contain fibres conveying information from both eyes. Injury to one optic nerve therefore results in total blindness in that eye, while damage to the optic tract on one side results in partial blindness in both eyes.

Crossing of optic nerve fibres

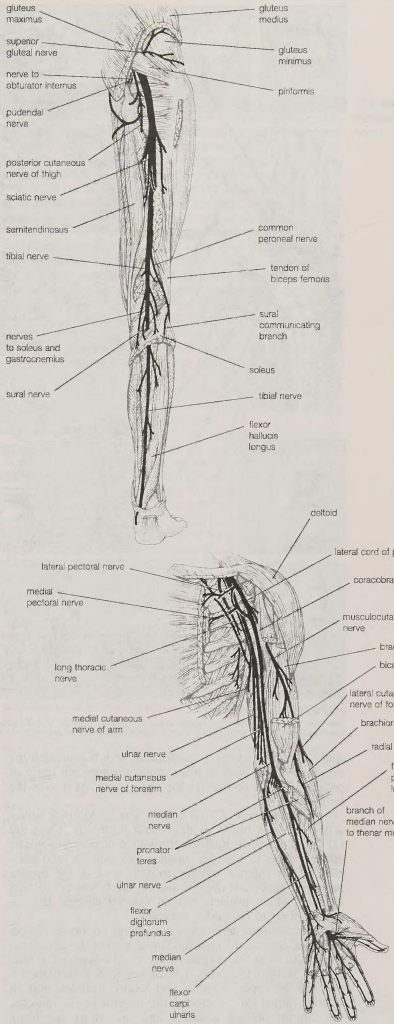


Figure 23B: *Nerves of the right leg and left arm.* Posterior view of the leg showing the sciatic nerve and its branches, part of the sacral plexus. Anterior view of the arm showing the median, ulnar, and radial nerves and other branches of the brachial plexus.

From P.L. Williams *et al.*, *Gray's Anatomy*, 37th ed. (1989): Churchill Livingstone, Edinburgh

Optic fibres also participate in accommodation of the lens and in the pupillary light reflex. Since the subarachnoid

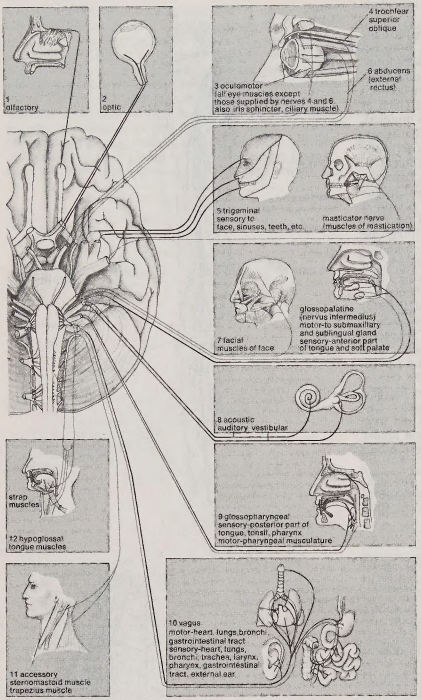


Figure 24: Cranial nerves.

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space around the brain is continuous with that around the optic nerve, increases in intracranial pressure can result in papilledema, or damage to the optic nerve, as it exits the bulb of the eye.

Oculomotor nerve (CN III or 3). The oculomotor nerves arise from two nuclei in the rostral midbrain. These are (1) the oculomotor nucleus, the source of general somatic efferent fibres to superior, medial, and inferior recti muscles, to the inferior oblique muscle, and to the levator palpebrae superious muscle; and (2) the Edinger-Westphal nucleus, which projects general visceral efferent preganglionic fibres to the ciliary ganglion.

The oculomotor nerve exits the ventral midbrain, pierces the dura, courses through the lateral wall of the cavernous sinus, and exits the cranial cavity via the superior orbital fissure. Within the orbit it branches into a superior ramus (to the superior rectus and levator muscles) and an inferior ramus (to the medial and inferior rectus muscles, the inferior oblique muscles, and the ciliary ganglion). Postganglionic fibres from the ciliary ganglion innervate the sphincter pupillae muscle of the iris as well as the ciliary muscle.

With the exception of the levator palpebrae superioris muscle, which is innervated bilaterally, oculomotor neurons project primarily to orbital muscles on the same side of the head. A lesion of the oculomotor nerve will result in paralysis of the three rectus muscles and the inferior oblique muscle (causing the eye to rotate downward and slightly outward), paralysis of the levator palpebrae superious muscle (drooping of the eyelids), and paralysis of the sphincter pupillae and ciliary muscles (so that the iris will remain dilated and the lens will not accommodate).

Trochlear nerve (CN IV or 4). The fourth cranial nerve is unique for three reasons. First, it is the only cranial nerve to exit the dorsal side of the brain stem. Second, fibres from the trochlear nucleus cross in the midbrain before they exit, so that trochlear neurons innervate the contralateral (opposite side) superior oblique muscle of the eye. Third, trochlear fibres have a long intracranial course before piercing the dura.

The trochlear nucleus is located in the caudal midbrain; the functional component of these cells is general somatic efferent. After exiting at the dorsal side of the midbrain, the trochlear nerve loops around the midbrain, pierces the dura, and passes through the lateral wall of the cavernous sinus. It then enters the orbit through the superior orbital fissure and innervates only the superior oblique muscle, which rotates the eye downward and slightly outward. Damage to the trochlear nerve will result in a loss of this eye movement and may produce double vision (diplopia).

Trigeminal nerve (CN V or 5). The trigeminal nerve is the largest of the cranial nerves. It has both motor and sensory components, the sensory fibres being general somatic afferent and the motor fibres being special visceral

efferent. Most of the cell bodies of sensory fibres are located in the trigeminal ganglion, which is attached to the pons by the trigeminal root (see Figure 19). These convey pain and thermal sensations from the face, oral and nasal cavities, and parts of the dura and nasal sinuses, sensations of deep pressure, and information from sensory endings in muscles. Trigeminal motor fibres, projecting from nuclei in the pons, serve the muscles of mastication.

Lesions of the trigeminal nerve result in sensory losses over the face or in the oral cavity. Damage to motor fibres results in paralysis of the masticatory muscles; as a result, the jaw may hang open or deviate toward the uninjured side when opened. Trigeminal neuralgia, or tic douloureux, is an intense idiopathic pain originating mainly from areas supplied by sensory fibres of the maxillary and mandibular branches of this nerve.

Threefold division of the trigeminal nerve

The trigeminal ganglion gives rise to three large nerves, the ophthalmic, maxillary, and mandibular.

Ophthalmic nerve. The ophthalmic nerve passes through the wall of the cavernous sinus and enters the orbit via the superior orbital fissure. Branches in the orbit are (1) the lacrimal nerve, serving the lacrimal gland, part of the upper eyelid, and the conjunctiva; (2) the nasociliary nerve, serving the mucosal lining of part of the nasal cavity, the tentorium cerebelli and some of the dura of the anterior cranial fossa, and skin on the dorsum and tip of the nose; and (3) the frontal nerve, serving the skin on the upper eyelid and the forehead and scalp above the eyes up to the vertex of the head.

Maxillary nerve. The maxillary nerve courses through the cavernous sinus below the ophthalmic nerve and passes through the foramen rotundum into the orbital cavity. Branches of the maxillary nerve are (1) the meningeal branches, which serve the dura of the middle cranial fossa; (2) the alveolar nerves, serving the upper teeth and gingiva and the lining of the maxillary sinus; (3) the nasal and palatine nerves, which serve portions of the nasal cavity and the mucosa of the hard and soft palate; and (4) the infraorbital, zygomaticotemporal, and zygomaticofacial nerves, serving the upper lip, the lateral surfaces of the nose, the lower eyelid and conjunctiva, and skin on the cheek and the side of the head behind the eye.

Mandibular nerve. The mandibular nerve exits the cranial cavity via the foramen ovale and serves (1) the meninges of middle and parts of the anterior cranial fossae (meningeal branches); (2) the temporomandibular joint, skin over part of the ear, and skin over the sides of the head above the ears (auriculotemporal nerve); (3) oral mucosa, the anterior two-thirds of the tongue, gingiva adjacent to the tongue, and the floor of the mouth (lingual nerve); and (4) the mandibular teeth (inferior alveolar nerve). Skin over the lateral and anterior surfaces of the mandible and the lower lip is served by cutaneous branches of the mandibular nerve.

Trigeminal motor fibres exit the cranial cavity via the foramen ovale along with the mandibular nerve. They serve the muscles of mastication (temporalis, masseter, medial and lateral pterygoid), three muscles involved in aspects of swallowing (anterior portions of the digastric muscle, the mylohyoid muscle, and the tensor veli palatini), and a muscle that has a damping effect on loud noises by stabilizing the tympanic membrane (tensor tympani).

Abducens nerve (CN VI or 6). From its nucleus in the caudal pons, the abducens nerve exits the brain stem at the pons-medulla junction, pierces the dura, passes through the cavernous sinus close to the internal carotid artery, and exits the cranial vault via the superior orbital fissure. In the orbit the abducens nerve innervates the lateral rectus muscle, which turns the eye outward. Damage to the abducens nerve results in a tendency for the eye to deviate medially, or "cross." Double vision may result on attempted lateral gaze.

Facial nerve (CN VII or 7). The facial nerve is composed of a large root that innervates facial muscles and a small root (known as the intermediate nerve) that contains sensory and autonomic fibres.

From the facial nucleus in the pons, facial motor fibres enter the internal auditory meatus, pass through the temporal bone, exit the skull via the stylomastoid foramen, and fan out over each side of the face forward of the ear. Fibres of the facial nerve are special visceral efferent; they innervate small muscles of the external ear, the platysma, the stapedius, the occipitofrontalis, the stylohyoid posterior belly of the digastric, the buccinator, and the muscles of facial expression.

The intermediate nerve

The intermediate nerve contains autonomic (parasympathetic) as well as general and special sensory fibres. Preganglionic autonomic fibres, classified as general visceral efferent, project from the superior salivatory nucleus in the pons. Exiting with the facial nerve, they pass to the pterygopalatine ganglion via the greater petrosal nerve (a branch of the facial nerve) and to the submandibular ganglion by way of the chorda tympani nerve (another branch of the facial nerve, which joins the lingual branch of the mandibular nerve). Postganglionic fibres from the pterygopalatine ganglion innervate nasal and palatine glands and the lacrimal gland, while those from the submandibular ganglion serve submandibular and sublingual salivary glands. Among the sensory components of the intermediate nerve, general somatic afferent fibres relay sensation from the caudal surface of the ear, while special visceral afferent fibres originate from taste buds in the anterior two-thirds of the tongue, course in the lingual branch of the mandibular nerve, and then join the facial nerve via the chorda tympani branch. Both somatic and visceral afferent fibres have cell bodies in the geniculate ganglion, which is located on the facial nerve as it passes through the facial canal in the temporal bone.

Injury to the facial nerve at the brain stem produces a paralysis of facial muscles known as Bell's palsy as well as a loss of taste sensation from the anterior two-thirds of the tongue. If damage occurs at the stylomastoid foramen, facial muscles will be paralyzed but taste will be intact.

Vestibulocochlear nerve (CN VIII or 8). This cranial nerve has a vestibular part, which functions in balance, equilibrium, and orientation in three-dimensional space, and a cochlear part, which functions in hearing. The functional component of these fibres is special somatic afferent; they originate from receptors located in the temporal bone.

Vestibular receptors are located in the semicircular canals, which provide input on rotatory movements (angular acceleration), and in the utricle and saccule, which generate information on linear acceleration and the influence of gravitational pull. This information is relayed by the vestibular fibres, whose bipolar cell bodies are located in the vestibular (Scarpa's) ganglion. The central processes of these neurons exit the temporal bone via the internal acoustic meatus and enter the brain stem alongside the facial nerve.

Auditory receptors of the cochlear division are in the organ of Corti and follow the spiral shape (about 2.5 turns) of the cochlea. Air movement against the eardrum produces mechanical actions by the ossicles of the ear, which, in turn, cause movement of fluid in the spiral cochlea. This fluid movement is transduced by the organ of Corti into nerve impulses interpreted as auditory information. The bipolar cells of the spiral (Corti's) ganglion give rise to central processes that course with the vestibular nerve. At the brain stem, cochlear fibres separate from vestibular fibres to end in the dorsal and ventral cochlear nuclei.

Lesions of the vestibular root result in eye movement disorders (nystagmus), unsteady gait with a tendency to fall toward the side of the lesion, nausea, and vertigo. Damage to the cochlea or cochlear nerve results in complete deafness, ringing in the ear (tinnitus), or both.

Glossopharyngeal nerve (CN IX or 9). The ninth cranial nerve, which exits the skull through the jugular foramen, has both motor and sensory components. Cell bodies of motor neurons, located in the nucleus ambiguus in the medulla, project as special visceral efferent fibres to the stylopharyngeal muscle. The action of the stylopharyngeus is to elevate the pharynx, as in gagging or swallowing. In addition, the inferior salivatory nucleus of the medulla sends general visceral efferent fibres to the otic ganglion via the lesser petrosal branch of the ninth nerve; postganglionic otic fibres distribute to the parotid salivary gland.

Innervation of the pharynx and tongue

Among the sensory components, special visceral afferent fibres convey taste sensation from the back third of the

tongue via lingual branches of the nerve. General visceral afferent fibres from the pharynx, the back of the tongue, parts of the soft palate and eustachian tube, and the carotid body and carotid sinus have their cell bodies in the superior and inferior ganglia, which are situated, respectively, within the jugular foramen and just outside the cranium. Sensory fibres in the carotid branch detect increased blood pressure in the carotid sinus and send impulses into the medulla that ultimately produce a reduction in heart rate and arterial pressure; this is known as the carotid sinus reflex.

Vagus nerve (CN X or 10). The vagus nerve has the most extensive distribution in the body of all the cranial nerves, innervating structures as diverse as the external surface of the eardrum and internal organs of the abdomen. The root of the nerve exits the cranial cavity via the jugular foramen. Within the foramen is the superior ganglion, containing cell bodies of general somatic afferent fibres, and just external to the foramen is the inferior ganglion, containing visceral afferent cells.

Pain and temperature sensations from the eardrum and external auditory canal, and pain fibres from the dura of the posterior cranial fossa, are conveyed on general somatic afferent fibres in the auricular and meningeal branches of the nerve. Taste buds on the root of the tongue and on the epiglottis contribute special visceral afferent fibres to the superior laryngeal branch. General visceral afferent fibres conveying sensation from the lower pharynx, larynx, trachea, esophagus, and organs of the thorax and abdomen to the left (splenic) flexure of the colon converge to form the posterior (or right) and anterior (or left) vagal nerves. Right and left vagal nerves are joined in the thorax by cardiac, pulmonary, and esophageal branches. In addition, general visceral afferent fibres from the larynx below the vocal folds join the vagus via the recurrent laryngeal nerves, while comparable input from the upper larynx and pharynx is relayed by the superior laryngeal nerves and by pharyngeal branches of the vagus. A vagal branch to the carotid body usually arises from the inferior ganglion.

Motor functions of the vagus nerve

Motor fibres of the vagus nerve include special visceral efferent fibres arising from the nucleus ambiguus of the medulla and innervating pharyngeal constrictor muscles and palatine muscles via pharyngeal branches of the vagus as well as the superior laryngeal nerve. All laryngeal musculature (excluding the cricothyroid but including the muscles of the vocal folds) are innervated by fibres arising in the nucleus ambiguus. Cells of the dorsal motor nucleus in the medulla distribute general visceral efferent fibres to plexuses or ganglia serving the pharynx, larynx, esophagus, and lungs. In addition, cardiac branches arise from plexuses in the lower neck and upper thorax, and, once in the abdomen, the vagus gives rise to gastric, coeliac, hepatic, renal, intestinal, and splenic branches or plexuses.

Damage to one vagus nerve results in hoarseness and difficulty in swallowing and speaking. Injury to both nerves results in increased heart rate, paralysis of pharyngeal and laryngeal musculature, atonia of the esophagus and intestinal musculature, vomiting, and loss of visceral reflexes. Such a lesion is usually life-threatening, as paralysis of laryngeal muscles can result in asphyxiation.

Accessory nerve (CN XI or 11). The accessory nerve is formed by fibres from the medulla (known as the cranial root) and by fibres from cervical levels C_1–C_4 (known as the spinal root). The cranial root originates from the nucleus ambiguus and exits the medulla below the vagus. Its fibres join the vagus and distribute to some muscles of the pharynx and larynx via pharyngeal and recurrent laryngeal branches of that nerve. For this reason, the cranial part of the accessory nerve is, for all practical purposes, part of the vagus nerve.

Fibres that arise from spinal levels exit the cord, coalesce and ascend as the spinal root of the accessory nerve, enter the cranial cavity through the foramen magnum, and then immediately leave through the jugular foramen. The accessory nerve then branches into the sternocleidomastoid muscle, which tilts the head toward one shoulder with an upward rotation of the face to the opposite side, and the trapezius muscle, which stabilizes and elevates (or shrugs) the shoulder.

Hypoglossal nerve (CN XII or 12). The hypoglossal nerve innervates certain muscles that control movement of the tongue. From the hypoglossal nucleus in the medulla, general somatic efferent fibres exit the cranial cavity through the hypoglossal canal and enter the neck in close proximity to the accessory and vagus nerves and the internal carotid artery. The nerve then loops down and forward into the floor of the mouth and branches into the tongue musculature from underneath. Hypoglossal fibres end in intrinsic tongue muscles, which modify the shape of the tongue (as in rolling the edges), as well as in extrinsic muscles that are responsible for changing its position in the mouth.

A lesion of the hypoglossal nerve on one side of the head would result in paralysis of intrinsic and extrinsic musculature on the same side. The tongue would atrophy and, on attempted protrusion, would deviate toward the side of the lesion. (D.E.H.)

The autonomic nervous system

Maintenance of bodily functions

The autonomic nervous system is a part of the peripheral nervous system that functions to regulate the basic visceral processes needed for the maintenance of normal bodily functions. It operates independently of voluntary control, although certain events, such as emotional stress, fear, sexual excitement, and alterations in the sleep-wakefulness cycle, change the level of autonomic activity.

The autonomic system is usually defined as a motor system that innervates three major types of tissue: cardiac muscle, smooth muscle, and glands. However, this definition needs to be expanded to encompass the fact that it also relays visceral sensory information into the central nervous system and processes it in such a way as to make alterations in the activity of specific autonomic motor outflows, such as those that control the heart, blood vessels, and other visceral organs. It also causes the release of certain hormones involved in energy metabolism (*e.g.*, insulin, glucagon, epinephrine) or cardiovascular functions (*e.g.*, renin, vasopressin). These integrated responses maintain the normal internal environment of the body in an equilibrium state called homeostasis.

The autonomic system consists of two major divisions: the sympathetic nervous system and the parasympathetic nervous system. These often function in antagonistic ways. The motor outflow of both systems is formed by two serially connected sets of neurons. The first set, called preganglionic neurons, originates in the brain stem or the spinal cord, and the second set, called ganglion cells or postganglionic neurons, lies outside the central nervous system in collections of nerve cells called autonomic ganglia. Parasympathetic ganglia tend to lie close to or within the organs or tissues that their neurons innervate, whereas sympathetic ganglia lie at a more distant site from their target organs. Both systems have associated sensory fibres that send feedback information into the central nervous system regarding the functional condition of target tissues.

A third division of the autonomic system, termed the enteric nervous system, consists of a collection of neurons embedded within the wall of the entire gastrointestinal tract and its derivatives. This system controls gastrointestinal motility and secretions.

SYMPATHETIC NERVOUS SYSTEM

Sympathetic preganglionic neurons originate in the lateral horns of the 12 thoracic and the first 2 or 3 lumbar segments of the spinal cord. (For this reason the sympathetic system is sometimes referred to as the thoracolumbar outflow.) The axons of these neurons exit the spinal cord in the ventral roots and then synapse on either sympathetic ganglion cells or specialized cells in the adrenal gland called chromaffin cells.

Sympathetic ganglia. Sympathetic ganglia can be divided into two major groups, paravertebral and prevertebral (or preaortic), on the basis of their location within the body. Paravertebral ganglia generally lie on each side of the vertebrae and are connected to form the sympathetic chain or trunk (see Figure 25). There are usually 21 or 22 pairs of these ganglia: 3 in the cervical region,

The sympathetic trunk

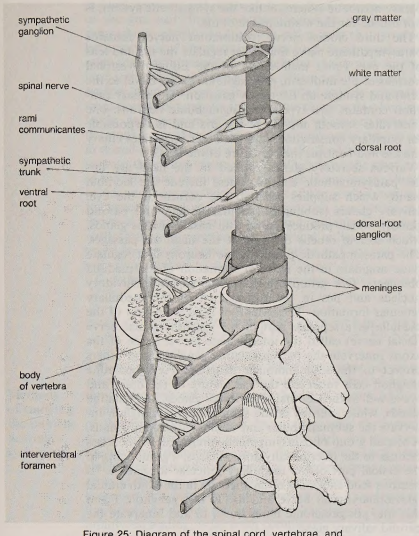


Figure 25: Diagram of the spinal cord, vertebrae, and sympathetic trunk (shown on one side only). Dorsal rami of the spinal nerves are not shown.
From E. Gardner, *Fundamentals of Neurology*, 5th ed. (1968); W.B. Saunders Co.

10 to 11 in the thoracic region, 4 in the lumbar region, 4 in the sacral region, and a single, unpaired ganglion lying in front of the coccyx called the ganglion impar. The three cervical sympathetic ganglia are the superior cervical ganglion, the middle cervical ganglion, and the cervicothoracic ganglion (also called the stellate ganglion). The superior ganglion innervates viscera of the head; the middle and stellate ganglia innervate viscera of the neck, thorax (*i.e.*, the bronchi and heart), and upper limb. The thoracic sympathetic ganglia innervate the trunk region, and the lumbar and sacral sympathetic ganglia innervate the pelvic floor and lower limb. All the paravertebral ganglia provide sympathetic innervation to blood vessels in muscle and skin, arrector pili muscles attached to hairs, and sweat glands (see Figure 26).

The three preaortic ganglia are the celiac, superior mesenteric, and inferior mesenteric. Lying on the anterior surface of the aorta, they provide axons that are distributed with the three major gastrointestinal arteries arising from the aorta. The three ganglia retain a pattern of innervation that originates in the embryo. Thus, the celiac ganglion innervates structures derived from the embryonic foregut, including the stomach, liver, pancreas, duodenum, and the first part of the small intestine; the superior mesenteric ganglion innervates the small intestine, which is derived from the embryonic midgut; and the inferior mesenteric ganglion innervates embryonic hindgut derivatives, which include the descending colon, sigmoid colon, rectum, urinary bladder, and sexual organs.

Neurotransmitters and receptors. Upon reaching their target organs by traveling with the blood vessels that supply them, sympathetic fibres terminate as a series of varicosities close to the end organ. Because of this anatomical arrangement, autonomic transmission takes place across a junction rather than a synapse. "Presynaptic" sites can be identified because they contain aggregations of synaptic vesicles and membrane thickenings; postjunctional membranes, on the other hand, rarely possess morphological specializations, but they do contain specific receptors for various neurotransmitters. The distance between pre- and postsynaptic elements can be quite large as compared to typical synapses. For instance, the gap between cell membranes of a typical chemical synapse is 30–50 nanometres, while in blood vessels the distance is often greater than 100 nanometres and, in some cases, 1–2 micrometres (1,000–2,000 nanometres). Owing to these relatively large gaps between autonomic nerve terminals and their effector cells, transmitters tend to act slowly; they become inactivated rather slowly as well. To compensate for this apparent inefficiency, many effector cells, such as those in smooth and cardiac muscle, are connected by low-resistance pathways that allow for electrotonic coupling of the cells. In this way, if only one cell is activated, multiple cells will respond and work as a group.

Acetylcholine, norepinephrine, and other transmitters

At a first approximation, chemical transmission in the sympathetic system appears simple: preganglionic neurons use acetylcholine as a neurotransmitter, whereas most postganglionic neurons utilize norepinephrine (noradrenaline)—with the major exception that postganglionic neurons innervating sweat glands use acetylcholine (see Figure 26). On closer inspection, however, neurotransmission is seen to be more complex, because multiple chemicals are released, and each functions as a specific chemical code affecting different receptors on the target cell. In addition, these chemical codes are self-regulatory, in that they act on presynaptic receptors located on their own axon terminals.

The chemical codes are specific to certain tissues. For example, most sympathetic neurons that innervate blood vessels secrete both norepinephrine and neuropeptide Y, sympathetic neurons that innervate the submucosal neural plexus of the gut contain both norepinephrine and somatostatin, and sympathetic neurons that innervate sweat glands contain calcitonin gene-related peptide, vasoactive intestinal polypeptide, and acetylcholine. In addition, other chemicals besides the neuropeptides mentioned

From E. Gardner, *Fundamentals of Neurology*, 5th ed. (1968); W.B. Saunders Company

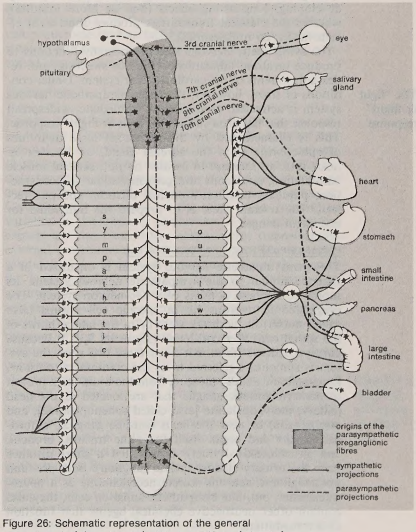


Figure 26: Schematic representation of the general arrangement of the autonomic nervous system. Autonomic fibres to the organs of the head and trunk are shown on the right side; the autonomic fibres on the left side represent the sympathetic outflow to blood vessels, sweat glands, and smooth muscle of hair follicles.

above are released from autonomic neurons along with the so-called classical neurotransmitters, norepinephrine and acetylcholine. For instance, some neurons synthesize a gas, nitric oxide, that functions as a novel type of neuronal messenger molecule. Thus, neural transmission in the autonomic nervous systems involves the release of combinations of different neuroactive agents that affect both pre- and postsynaptic receptors.

Neurotransmitters released from nerve terminals bind to specific receptors, which are specialized macromolecules embedded in the cell membrane. The binding action initiates a series of specific biochemical reactions in the target cell that produce a physiological response. These effects can be modified by various drugs that act as agonists or antagonists. In the sympathetic nervous system, for example, there are five types of adrenergic receptors (receptors binding epinephrine): α_1, α_2, β_1, β_2, and β_3. These are found in different combinations in various cells throughout the body. Activation of α_1 receptors in arterioles causes blood-vessel constriction, whereas stimulation of α_2 autoreceptors (receptors located in sympathetic presynaptic nerve endings) function to inhibit the release of norepinephrine. Other types of tissue have unique adrenergic receptors. Heart rate and myocardial contractility, for example, is controlled by β_1 receptors, bronchial smooth muscle relaxation is mediated by β_2 receptors, and lipolysis is controlled by β_3 receptors.

Cholinergic receptors (receptors binding acetylcholine) also are found in the sympathetic system (as well as the parasympathetic system). Nicotinic cholinergic receptors cause sympathetic postganglionic neurons, adrenal chromaffin cells, and parasympathetic postganglionic neurons to fire and release their chemicals. Muscarinic receptors are associated mainly with parasympathetic functions and are located in peripheral tissues (*e.g.,* glands, smooth muscle). Peptidergic receptors exist in target cells as well.

The length of time that each type of chemical acts on its target cell is variable. As a rule, peptides cause slowly developing, long-lasting effects (one or more minutes), whereas the classical transmitters produce short-term effects (about 25 milliseconds).

The sympathetic nervous system normally functions to produce localized adjustments (such as sweating) and reflex adjustments of the cardiovascular system. Under conditions of stress, however, the entire sympathetic nervous system is activated, producing an immediate, widespread response that has been called the "fight or flight" response. This is characterized by the release of large quantities of epinephrine from the adrenal gland, an increase in heart rate, an increase in cardiac output, skeletal muscle vasodilation, cutaneous and gastrointestinal vasoconstriction, pupillary dilation, bronchial dilation, and piloerection. The overall effect is to prepare the individual for imminent danger.

The "fight or flight" response

PARASYMPATHETIC NERVOUS SYSTEM

The parasympathetic nervous system is organized in a manner similar to the sympathetic nervous system. Its motor component consists of a two-neuron system. The preganglionic neurons lie in specific cell groups (also called nuclei) in the brain stem or in the lateral horns of the spinal cord at sacral levels (segments S_2–S_4). Because parasympathetic fibres exit from these two sites, the system is sometimes referred to as the craniosacral outflow. Preganglionic axons emerging from the brain stem project to parasympathetic ganglia that are located in the head (ciliary, pterygopalatine [also called sphenopalatine], and otic ganglia) or near the heart (cardiac ganglia), embedded in the end organ itself (*e.g.,* the trachea, bronchi, and gastrointestinal tract), or situated a short distance from the urinary bladder (pelvic ganglion). Both pre- and postganglionic neurons secrete acetylcholine as a neurotransmitter, but, like sympathetic ganglion cells, they also contain other neuroactive chemical agents that function as cotransmitters.

The parasympathetic nervous system modulates mainly visceral organs such as glands. These are never activated en masse as in the "fight or flight" sympathetic response. While providing important control of many tissues, the parasympathetic system, unlike the sympathetic system, is not crucial for the maintenance of life.

The third cranial nerve (oculomotor nerve) contains parasympathetic nerve fibres that regulate the iris and lens of the eye. From their origin in the Edinger-Westphal nucleus of the midbrain, preganglionic axons travel to the orbit and synapse on the ciliary ganglion. The ciliary ganglion contains two types of postganglionic neurons: one innervates smooth muscle of the iris and is responsible for pupillary constriction, and the other innervates ciliary muscle and controls the curvature of the lens.

Various secretory glands located in the head are under parasympathetic control. These include the lacrimal gland, which supplies tears to the cornea of the eye; salivary glands (sublingual, submandibular, and parotid glands), which produce saliva; and nasal mucous glands, which secrete mucus throughout the nasal air passages. The parasympathetic preganglionic neurons that regulate these originate in the reticular formation of the medulla oblongata. One group belongs to the superior salivatory nucleus and lies in the rostral part of the medullary reticular formation. These neurons send axons out of the medulla in a separate part of the seventh cranial nerve (facial nerve) called the intermediate nerve. Some of the axons innervate the pterygopalatine ganglion, and others project to the submandibular ganglion. Pterygopalatine ganglion cells innervate the vasculature of the brain and eye as well as the lacrimal gland, nasal glands, and palatine glands, while neurons of the submandibular ganglion innervate the submandibular and sublingual salivary glands. A second group of parasympathetic preganglionic neurons belongs to the inferior salivatory nucleus, a group lying in the caudal part of the medullary reticular formation. Its neurons send axons out of the medulla in the ninth cranial (glossopharyngeal) nerve and to the otic ganglion. From this site, postganglionic fibres travel to and innervate the parotid salivary gland.

Preganglionic parasympathetic fibres of the tenth cranial nerve (vagus) arise from two different sites in the medulla. Neurons that slow heart rate arise from a part of the ventral medulla called the nucleus ambiguus, while those that control the gastrointestinal tract arise from the dorsal vagal nucleus. After exiting the medulla in the vagus nerve and traveling to their respective organs, the fibres synapse on ganglion cells embedded in the organs themselves. The vagus nerve also contains visceral afferent fibres that carry sensory information from organs of the neck (larynx, pharynx, and trachea), chest (heart and lungs), and gastrointestinal tract into a visceral sensory nucleus located in the medulla and called the solitary tract nucleus.

Parasympathetic components of the vagus nerve

ENTERIC NERVOUS SYSTEM

The enteric nervous system is made up of two plexuses, or networks of neurons, embedded in the wall of the gastrointestinal tract. The outermost collection, lying between the inner circular and outer longitudinal smooth-muscle layers of the gut, is called the myenteric (or Auerbach's) plexus. Neurons of this plexus regulate the peristaltic waves, consisting of polarized muscular activity, that move digestive products from oral to anal openings. In addition, myenteric neurons control local muscular contractions that are responsible for stationary mixing and churning. The innermost group of neurons is called the submucosal (or Meissner's) plexus. This group regulates the configuration of the luminal surface, controls glandular secretions, alters electrolyte and water transport, and regulates local blood flow.

Three functional classes of intrinsic enteric neurons are recognized: sensory neurons, interneurons, and motor neurons. Sensory neurons, activated by either mechanical or chemical stimulation of the innermost surface of the gut, transmit information to interneurons located within the myenteric and submucosal plexi, and the interneurons relay the information to motor neurons. Motor neurons in turn modulate the activity of a variety of target cells, including mucous glands, smooth muscle cells, endocrine cells, epithelial cells, and blood vessels.

Extrinsic neural pathways also are involved in the control of gastrointestinal functions. Three types exist: intesti-

nofugal, sensory, and motor. Intestinofugal neurons reside in the gut wall; they send their axons to the preaortic sympathetic ganglia and control reflex arcs that involve large portions of the gastrointestinal tract. Sensory neurons relay information regarding distention (pain) and acidity into the central nervous system. There are two types of sensory neurons: sympathetic neurons, which originate from dorsal-root ganglia found at the thoracic and lumbar levels; and parasympathetic neurons, which originate in the nodose ganglion of the tenth cranial nerve (vagus) or in dorsal-root ganglia at sacral levels S_2–S_4. The former innervate the entire gastrointestinal tract from the pharynx to the left colic flexure, and the latter innervate the distal colon and rectum. Each portion of the gastrointestinal tract receives a dual sensory innervation: pain sensations travel via sympathetic afferents, and sensations that signal information regarding the chemical milieu of the gut travel by way of parasympathetic fibres and are not consciously perceived.

The third extrinsic pathway, exercising motor control over the gut, arises from parasympathetic preganglionic neurons found in the dorsal vagal nucleus of the medulla and from sympathetic preganglionic neurons in the lateral horns of the spinal cord. These outflows provide modulatory commands to the intrinsic enteric motor system and are nonessential in that basic functions can be maintained in their absence.

Motor innervation of the gut

Through the pathways described above, the parasympathetic system activates digestive processes while the sympathetic system inhibits them. The sympathetic system inhibits digestive processes by two mechanisms: (1) contraction of circular smooth muscle sphincters located in the distal portion of the stomach (pyloric sphincter), small intestine (ileo-cecal sphincter), and rectum (internal anal sphincter), which act as valves to prevent the oral-to-anal passage (as well as reverse passage) of digestive products; and (2) inhibition of motor neurons throughout the length of the gut. In contrast, the parasympathetic system provides messages only to myenteric motor neurons.

(A.D.L.)

FUNCTIONS OF THE HUMAN NERVOUS SYSTEM

The human nervous system differs from that of other mammals chiefly in the great enlargement and elaboration of the cerebral hemispheres. Much of what is known of the function of the brain is derived from observations of the effects of disease or by analogy with the results of experimentation on animals, particularly the monkey. Such sources of information are clearly inadequate for the elucidation of the nervous activity underlying many properties of the human brain—particularly speech and mental processes. It is not surprising, therefore, that knowledge of the functions of this uniquely complex system, although rapidly expanding, is far from complete.

Methods of studying the human nervous system

In the following account of the functions of the human nervous system, there are numerous references to tracts and to less well-defined connections between different regions of the brain and spinal cord. The identification of these pathways is not always a simple matter; indeed, in humans, many are incompletely known or are simply conjectural.

A great deal of information has been obtained by observing the spreading effects of axonal destruction. If a nerve fibre is severed, the length of axon farthest from the cell body, or soma, will be deprived of the axonal flow of metabolites and will begin to break up. The myelin sheath will also degenerate, so that, for some months after the injury, breakdown products of myelin will be seen under the microscope with special stains. This method is obviously of limited application in humans, as it requires precise lesions and subsequent examination before the myelin has been completely removed. The staining of degenerated axons and of the terminals that form synapses with other neurons is also possible using silver impregnation, but the techniques are laborious and results sometimes difficult to interpret.

That a damaged neuron should show degenerative changes, however difficult to detect, is not unexpected, but the interdependence of neurons is sometimes shown by transneuronal degeneration. Neurons deprived of major input from axons that have been destroyed may themselves atrophy. This phenomenon is called anterograde degeneration. In retrograde degeneration, similar changes may occur in neurons that have lost the main recipient of their outflow.

These anatomical methods are occasionally applicable to human disease. They can also be used postmortem when lesions in the central nervous system have been deliberately made—for example, in the surgical treatment of intractable pain. Some more recently developed techniques can be used only in experiments on animals, but these are not always relevant to humans. For example, normal biochemical constituents labeled with a radioactive isotope can be injected into neurons and then transported the length of the axon, where they can be detected by picking up the radioactivity on an X-ray plate.

An observation technique dependent on retrograde axonal flow has been used extensively to demonstrate the origin of fibre tracts. In this technique, the enzyme peroxidase is taken up by axon terminals and is transported up the axon to the soma, where it can be shown by appropriate staining.

The staining of neurotransmitter substances is possible in postmortem human material as well as in animals and is an important method. Success, however, is dependent on examining relatively fresh or frozen material, and results may be greatly affected by previous treatment with neurologically active drugs.

Electrical stimulation of a region of the nervous system gives rise to the generation of nerve impulses in centres receiving input from the site of stimulation. This method, using microelectrodes, has been widely used in animal studies. The precise path followed by the artificially generated impulse may be difficult to establish.

Receptors

Receptors are biological transducers, converting the various kinds of energy they receive from the external and internal environments into electrical impulses. They are of many kinds and are classified in many ways. Steady-state receptors, for example, generate impulses as long as a particular state such as temperature remains constant. Changing-state receptors, on the other hand, respond to variation in the intensity or position of the stimulus. Receptors are also classified as exteroceptive (reporting the external environment), interoceptive (sampling the environment of the body itself), and proprioceptive (sensing the posture and movements of the body). Exteroceptors are used for looking, listening, smelling, tasting, touching, and feeling. Interoceptors report the state of the bladder, the alimentary canal, the blood pressure, and the osmotic pressure of the blood plasma. Proprioceptors report the position and movements of parts of the body and the position of the body in space.

Classifying receptors according to stimulus

Receptors are also classified according to the kinds of stimulus to which they are sensitive. Chemical receptors, or chemoreceptors, are sensitive to substances taken into the mouth (taste or gustatory receptors), inhaled through the nose (smell or olfactory receptors), or found in the body itself (detectors of glucose or of acid–base balance in the blood). Receptors of the skin are classified as thermoreceptors, mechanoreceptors, and nociceptors—the last being sensitive to stimulation that is noxious, or likely to damage the tissues of the body.

Thermoreceptors of the skin are of two kinds, warmth and cold. Warmth fibres are excited by rising temperature and inhibited by falling temperature, and cold fibres respond in the opposite manner.

Mechanoreceptors in the skin are also of several different

types. Sensory nerve terminals around the base of hairs are activated by very slight movement of the hair, but they rapidly adapt to continued stimulation and stop firing. In hairless skin there are both rapidly and slowly adapting receptors. These can provide information about the force of mechanical stimulation. The Pacinian corpuscles, elaborate structures found in the skin of the fingers but also in other organs, are layers of fluid-filled membranes forming structures just visible to the naked eye at the terminals of axons. The precise function of the corpuscles is not fully known, but they are probably activated by rapidly changing or alternating stimuli such as vibration.

In some places receptors are massed together to form a sense organ, such as the eye or ear. At other places they are scattered, as are those of the skin and viscera. Receptors are connected to the central nervous system by afferent nerve fibres. The region or area in the periphery from which a neuron within the central nervous system receives input is called its receptive field. Receptive fields are changing and not fixed entities.

All receptors report two features of stimulation, its intensity and its site. Intensity is signaled by the frequency of nerve impulse discharge in a neuron and also by the number of afferent nerves reporting the stimulation. As the strength of a stimulus increases, the change in electrical potential of the receptor increases, and the frequency of nerve impulse generation likewise increases. (The relationship between the magnitude of the receptor potential and the frequency of nerve impulse generation is discussed above; see *Form and function of nervous systems.*)

Locating stimuli with multiple receptors

The location of a stimulus, whether in the environment or in the body, is readily resolved by the nervous system. Localization of stimuli in the environment depends to a great extent on having pairs of receptors, one on each side of the body. For example, people in early childhood learn that a loud sound is probably coming from a nearer source than a weak sound. They localize the sound by noticing the difference in intensity and the minimal difference in time of arrival at the ears, increasing these differences by turning the head.

Localization of a stimulus on the skin depends upon the arrangement of nerve fibres in the skin and in the deep tissues beneath the skin, as well as upon the overlap of receptive fields. Most mechanical stimuli indent the skin, stimulating nerve fibres in the connective tissue below the skin. Any point on the skin is supplied by at least three, and sometimes up to 40, nerve fibres, and no two points are supplied by precisely the same pattern of fibres (Figure 27).

Finer localization is achieved by what is called surround inhibition. In the retina, for example, there is an inhibitory area around the excited area. This mechanism accentuates the excited area, making it stand out. There can also be a mechanism called surround excitation, in which a central area is inhibited and the surrounding area excited. In both cases contrast is brought out and discrimination sharpened.

From P.W. Nathan, *Nervous System*, 2nd ed. (1982); Oxford University Press

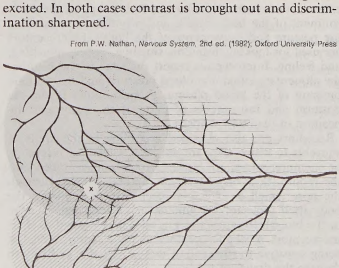


Figure 27: Diagram illustrating how a single point (x) on the skin is supplied by at least three nerve fibres.

In seeking information about the environment, the nervous system presents the most sensitive receptors to a stimulating object. At its simplest, this action is reflex. In the retina is a small region about the size of a pinhead, called the fovea, which is particularly sensitive to colour. When a part of the periphery of the visual field is excited, a reflex movement of the head and eyes focuses the light rays upon that part on the fovea. A similar reflex turns the head and eyes in the direction of a noise. As the English physiologist Charles Sherrington said in 1900, "In the limbs and mobile parts, when a spot of less discriminative sensitivity is touched, instinct moves the member, so that it brings to the object the part where its own sensitivity is delicate. . . ."

Reflex actions

Of the many kinds of neural activity, there is one simple kind in which a stimulus leads to an immediate action. This is reflex activity. The word reflex was introduced into biology by a 19th-century neurologist, Marshall Hall, who fashioned the word from Latin *reflexus* ("reflection") because he thought of the muscles as reflecting a stimulus much as a wall reflects a ball thrown against it. By reflex, Hall meant the automatic response of a muscle or several muscles to a stimulus that excites an afferent nerve. The word is now used to mean a certain kind of inborn central nervous activity, not involving consciousness, in which a particular stimulus, by exciting an afferent nerve, produces a stereotyped, immediate response of muscle or gland. If the same activity involves consciousness, it is not categorized as a reflex.

Reflex as unconscious activity

The anatomical pathway used in a reflex is called the reflex arc. It consists of an afferent (or sensory) nerve, usually one or more interneurons within the central nervous system, and an efferent (motor, secretory, or secretomotor) nerve. (For detailed description of the structures making up the reflex arc, see above *Anatomy of the human nervous system: The central nervous system.*)

Most reflexes have several synapses in the reflex arc. The stretch reflex is exceptional in that, with no interneuron in the arc, it has only one synapse between the afferent nerve fibre and the motor neuron (see below *Movement: The regulation of muscular contraction*). The flexor reflex, which removes a limb from a noxious stimulus, has a minimum of two interneurons and three synapses.

Probably the best-known reflex is the pupillary light reflex. If a light is flashed near one eye, the pupils of both eyes contract. Light is the stimulus, impulses reach the brain via the optic nerve, and the response is conveyed to the pupillary musculature by autonomic nerves that supply the eye.

Another ocular reflex is the lacrimal reflex. When something irritates the conjunctiva or cornea of the eye, nerve impulses pass along the trigeminal nerve and reach the midbrain. The efferent limb of this reflex arc is autonomic and mainly parasympathetic. These nerve fibres stimulate the lacrimal glands of the orbit, causing the outpouring of tears. Other reflexes of the midbrain and medulla oblongata are the cough and sneeze reflexes. The cough reflex is set off by an irritant in the trachea and the sneeze reflex by one in the nose. In both, the reflex response involves many muscles; this includes a temporary diversion of respiration from its usual biochemically ordered function in order to expel the irritant.

The first reflexes develop in the womb. By seven and a half weeks after conception, the first reflex can be observed: stimulation around the mouth of the fetus causes the lips to be turned toward the stimulus. By birth, sucking and swallowing reflexes are ready for use. Touching the baby's lips induces sucking, and touching the back of its throat induces swallowing.

Sensitization and habituation

Although the word stereotyped is used in the above definition, this does not mean that the reflex response is invariable and unchangeable. When a stimulus is repeated regularly, two changes occur in the reflex response—sensitization and habituation. Sensitization is an increase in response; in general it occurs during the first 10 to 20 responses. Habituation is a decrease in response; it contin-

ues until, eventually, the response is extinguished. When the stimulus is irregularly repeated, habituation does not occur or is minimal.

There are also long-term changes in reflexes, which may be seen in experimental spinal cord transections performed on kittens. Repeated stimulation of the skin below the level of the lesion, such as rubbing the same area for 20 minutes every day, causes a change in latency (the interval between the stimulus and the onset of response) of certain reflexes, with diminution and finally extinction of the response. Although this procedure takes several weeks, it shows that, with daily stimulation, one reflex response can be changed into another. Repeated activation of synapses increases their efficiency, causing some kind of lasting change. When this repeated stimulation is stopped, the reflex responses return to their original form, for there is a regression of synaptic function with disuse.

Although a reflex response is said to be rapid and immediate, some reflexes, called recruiting reflexes, can hardly be evoked by a single stimulus. Instead, they require increasing stimulation to induce the response. The reflex contraction of the bladder, for example, requires an increasing amount of urine to stretch the muscle and to obtain muscular contraction.

Reflexes can be changed by impulses from higher levels of the central nervous system. For example, the cough reflex can be suppressed easily, and even the gag reflex (the movements of incipient vomiting resulting from mechanical stimulation of the wall of the pharynx) can be suppressed with training.

The so-called conditioned reflexes are not reflexes at all but complicated acts of learned behaviour. Salivation is one such conditioned reflex. It occurs only when the person is conscious of the presence of food or when he imagines food.

Movement

Every movement of the body has to be correct for force, speed, and position. These aspects of movement are continuously reported to the central nervous system by receptors sensitive to the position, posture, equilibrium, and internal conditions of the body. These receptors are called proprioceptors, and those proprioceptors that keep a continuous report on the position of the limbs are the muscle spindles and tendon organs. (Proprioceptors reporting acceleration and direction of movement are located in the vestibular apparatus of the inner ear. For detailed discussion, see below *The vestibular system.*)

Forty-five percent of the weight of an adult male consists of muscle. The muscles of the trunk and limbs are known as skeletal muscles; they are attached to bones and produce movement at the joints. Skeletal muscles are innervated by efferent motor nerves and sometimes by efferent sympathetic and parasympathetic nerves. Muscles of the viscera (alimentary canal and bladder, for example) are called smooth muscle; they are innervated by efferent sympathetic and parasympathetic nerves.

The movements of the body are brought about by the harmonious contraction and relaxation of selected muscles. Contraction occurs when nerve impulses are transmitted across the neuromuscular junctions to the membrane covering each muscle fibre. Most of the muscles of the body are not continually contracting but are kept in a state ready to contract. The slightest movement or even the intention to move results in widespread activity of the muscles of the trunk and limbs.

Movements may be intrinsic to the body itself and carried out by muscles of the trunk and body cavity. Examples are those involved in breathing, swallowing, laughing, sneezing, urinating, and defecating. Other movements relate the body to the environment, either for moving or for signaling to other individuals. These are carried out by skeletal muscle.

Controlling movement at several levels of the nervous system

Movements can be organized at several levels of the nervous system. At the lowest level are movements of the viscera, some of which do not involve the central nervous system, being controlled by neurons of the autonomic nervous system within the viscera themselves.

At the next level is the spinal cord. If the spinal cord is cut across so that no nerve impulses reach it from the brain, certain movements of the trunk and limbs below the level of the injury can still occur. This state is called paraplegia; if the damage to the cord is above the upper limbs, it is called quadriplegia. Immediately after the cord has been divided, there is a state called spinal shock, when no movements of the skeletal muscles can be induced. Weeks or months later the period of shock passes and movements return. They are not commanded by the brain, however, and they are greatly augmented—that is, uncontrolled reflex movements may continue for minutes or hours, one reflex following another.

At a higher level, respiratory movements are controlled by the lower brain stem. The upper brain stem controls muscles of the eye, the bladder, and basic movements of walking and running. At the next level is the hypothalamus. It commands certain totalities of movement, such as those of vomiting, urinating and defecating, and curling up and going to sleep.

At the highest level is gray matter of the cerebral hemispheres, both the cortex and the subcortical basal ganglia. This is the level of conscious control of movements.

The natural phenomena included in movement cannot be neatly classified. The categories given above do not include some essential contributions, such as the influence of the cerebellum, occurring at every level. (P.W.N.)

THE REGULATION OF MUSCULAR CONTRACTION

Only a minority of the nerve fibres supplying a muscle are the ordinary motor fibres that actually make it contract. The rest are either afferent sensory fibres telling the central nervous system what the muscle is doing, or they are specialized motor fibres regulating the behaviour of the sensory nerve endings. If the constant feedback of proprioceptive information from the muscles, tendons, and joints is cut off, movements can still occur, but they cannot be adjusted in the face of external disturbances or readily modified to suit changing conditions; nor can new motor skills be developed. As stated above, the sensory receptors chiefly concerned with body movement are the muscle spindles and the tendon organs. The muscle spindle is vastly more complicated than the tendon organ, so that although it has been much more intensively studied, it is less well understood.

The simple knee-jerk reflex

The muscle spindle. The familiar knee jerk, tested routinely by physicians, is a spinal reflex in which a brief, rapid stretch excites muscle spindle afferent neurons, which then excite the motor neurons of the stretched muscle via a single synapse in the spinal cord. In this simplest of reflexes, which is not transmitted through interneurons of the spinal cord, virtually all the delay (approximately 0.02 second) occurs in the conduction of impulses to and from the spinal cord.

Information provided by muscle spindles is also put to elaborate use by the cerebellum and the cerebral cortex in ways that continue to elude detailed analysis. One example is kinesthesia, or the subjective sensory awareness of the position of limbs in space. It might be supposed (as it long was) that sensory receptors in joints, not the muscles, provide kinesthetic signals, since people are very aware of joint angle and not at all of the length of the various muscles involved. In fact, kinesthesia depends largely upon the integration within the cerebral cortex of signals from the muscle spindles.

Figures 28A and 28B are drawings of the tendon organ and muscle spindle made at the beginning of the 20th century with the aid of a light microscope. The tendon organ consists simply of an afferent nerve fibre that terminates in a number of branches upon slips of tendon where the tendons join onto muscle fibres. By lying in series with muscle, the tendon organ is well placed to signal muscular tension. In fact, the afferent fibre of the tendon organ has proved to be sufficiently sensitive to give a useful signal on the contraction of a single muscle fibre. In this way tendon organs provide a continuous flow of information on the level of muscular contraction.

The muscle spindle is much larger and more complicated; moreover, new features of its structure and function

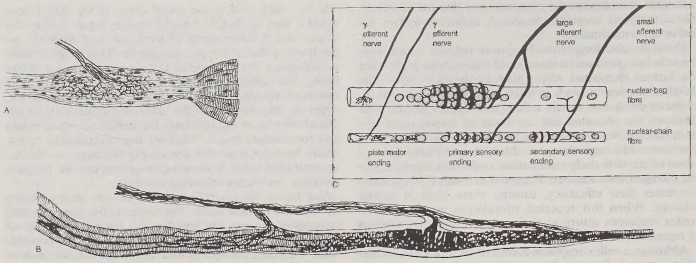


Figure 28: (A) The tendon organ as drawn in 1909 by the Spanish biologist Santiago Ramón y Cajal. The nerve fibre terminates on a tendon, with muscle fibres lying to the right. (B) The muscle spindle as drawn in 1898 by the Italian anatomist Angelo Ruffini, illustrating three types of nerve terminal—primary sensory endings, secondary sensory endings, and motor plates. (C) Simplified modern diagram of the central region (about one millimetre) of the muscle spindle. Two types of intrafusal fibre, the nuclear-bag and nuclear-chain, are shown, each having a distinct motor supply and different relationship to the two kinds of sensory ending. A given muscle spindle contains two to three bag fibres and four to six chain fibres.

From (A) S.R. Cajal, *Histologie du système nerveux de l'homme et des vertébrés* (1909), vol. 1, Maloine, Paris; (B) A. Ruffini, *Journal of Physiology* (1898), Physiological Society of Great Britain; (C) P.B.C. Matthews, *Physiological Review* (1964), The American Physiological Society

continue to be discovered. Within it are several specialized muscle fibres, known as intrafusal muscle fibres (from Latin *fusus*, "spindle"). The spindle is several millimetres long, and the approximately five intrafusal muscle fibres run throughout its length. They are considerably thinner and shorter than the ordinary skeletal muscle fibres, though they show similar contractions and have the same histological appearance. The characteristic central swelling of the spindle (giving it a shape reminiscent of the spindle of a spinning wheel) is produced by fluid contained in a capsule surrounding the central millimetre of the intrafusal fibres. Figure 28C illustrates this central region.

Sensory receptors of the muscle spindle

Classically, the nerve terminals are considered to be of three kinds, namely primary sensory endings, secondary sensory endings, and plate motor endings. There are approximately equal numbers of primary and secondary sensory endings, so that they may be considered equally important. However, the primary, or annulo-spiral, ending has traditionally attracted the most attention, largely through its prominent appearance and the simplicity of its chief reflex action, the tendon jerk. It consists of a large axon, which branches to wind spirals around the equatorial region of every intrafusal fibre. The secondary ending is supplied by a smaller axon. It has less dramatic "flower spray" terminals lying mostly upon the smaller intrafusal fibres to one side of the primary ending. The reflex actions of the secondary ending remain incompletely understood. The plate motor endings lie toward the ends of the intrafusal fibres. They are fairly similar to the ordinary motor end plates of the skeletal, or extrafusal, muscle fibres.

Two separate types of intrafusal muscle fibre are distinguished, both histologically and on their contractile properties, as nuclear-bag and nuclear-chain intrafusal fibres. These have since been further subdivided and the complexities multiply, but there is general agreement that just as the spindle has a dual afferent innervation, it also has a dual motor supply.

The working of this elaborate piece of biologic machinery is not yet fully understood. The muscle spindle lies "in parallel" with the main muscle fibres and so sends a signal whenever the muscle changes its length. Both types of sensory endings increase their discharge of impulses when the muscle is stretched and reduce their firing when the muscle is slackened. The primary ending differs from the secondary ending in two important respects: first, it is much more sensitive to changing length of the muscle; second, it is much more sensitive to small stimuli than large ones. Together, these properties explain the exquisite sensitivity of the primary sensory ending to the stimulus of a tendon tap, which has little effect on the secondary ending or on the tendon organ. The essential principle is that the ability of the muscle spindle to signal a wide range of movement is increased by its having two separate output channels of different sensitivity.

Motor endings of the muscle spindle

The motor supply of the muscle spindle is more complex. Most of the intrafusal fibres receive specialized fusimotor nerve fibres. These are much smaller than the motor axons innervating extrafusal muscle fibres and are given the name gamma (γ) efferents. As their sole function is to regulate the behaviour of the muscle spindles, their stimulation produces no significant contraction of the muscle as a whole. The γ efferents are of two functionally distinct kinds with different effects on the afferent fibres—especially on the primary ending. One type, the dynamic fusimotor axon, increases the normal sensitivity of the primary ending to movement; the other type, the static fusimotor axon, decreases its sensitivity, making it behave much more like a secondary ending. Thus, the two types of efferent fibre provide a means whereby the sensitivity of the muscle spindle to external stimuli may be regulated over a very wide range. Stimulation of both types also increases the rate of firing of the afferent fibres when the length of the muscle is constant; this is called a biasing action. It is believed that they produce these different effects by supplying different types of intrafusal fibre.

In addition to receiving specialized fusimotor fibres, the muscle spindle may also receive, though on a less regular basis, branches of the ordinary extrafusal motor axons. Called alpha (α) efferents, these fibres have either a static or dynamic effect. The physiologically important point is that most of the motor supply to the muscle spindles is largely independent of that of the ordinary muscle fibres, and only a small part is obligatorily coupled with them. The specific mechanisms by which the sensitivity of the spindle is regulated remain obscure; they may differ from muscle to muscle and for movements of different kinds.

Stretch reflexes including antagonistic muscles

Stretch reflexes. The primary afferents are responsible for the stretch reflex, in which pulling the tendon of a muscle causes the muscle to contract. As noted above, the basis for this simple spinal reflex is a monosynaptic excitation of the motor neurons of the stretched muscle. At the same time, however, motor neurons of the antagonist muscle (the muscle that moves the limb in the opposite direction) are inhibited. This action is mediated by an inhibitory interneuron interposed between the afferent neuron and the motor neuron. These reflexes have a transitory, or phasic, action, even though the afferent impulses continue unabated; this is probably because they become submerged in more complex delayed reflex responses elicited by the same and other afferent inputs.

Traditionally, it was thought that the stretch reflex provided uniquely for the automatic reflex control of stand-

ing, so that if the body swayed, then the stretched muscle would automatically take up the load and the antagonist would be switched off. This is now recognized to be only part of the process, since more powerful, slightly delayed reflex responses occur not only in the stretched muscle but also in others that help restore balance but have not themselves been stretched. Some of these late responses seem to be spinal reflexes, but in humans, with their huge brains, there is evidence that certain others are transcortical reflexes, in which the afferent impulse is transmitted at high speed up to the motor areas of the cerebral cortex to influence the level of ongoing voluntary motor impulses.

(P.B.C.M.)

THE BASIC ORGANIZATION OF MOVEMENT

Reciprocal innervation. Any cold, hot, or noxious stimulus striking the skin of the foot contracts the flexor muscle of that limb, relaxes the extensor muscles of the same limb, and extends the opposite limb. The purpose of these movements is to remove one limb from harm while shifting weight to the opposite limb. That is the first and immediate response, but a slower and longer-lasting reflex response is also possible. For example, noxious stimulation of the deep tissues of the limb can cause a prolonged discharge of impulses conducted by nonmyelinated afferent fibres to the spinal cord. The result is prolonged flexion of the damaged limb or at least a pattern of posture and movement favouring flexion. These effects last far longer than the original discharges from the afferent neurons of the damaged region—often continuing not for minutes but for weeks or months.

The flexor and extensor reflexes are only two examples of the sequential ordering of muscular contraction and relaxation. Underlying this basic organization is the principle of reciprocal innervation—the contraction of one muscle or group of muscles with the relaxation of muscles that have the opposite function. In reciprocal innervation, afferent nerve fibres from the contracting muscle excite inhibitory interneurons in the spinal cord; the interneurons, by inhibiting certain motor neurons, cause an antagonist muscle to relax.

Reciprocal innervation can be seen in eye movements. On looking to the right, the right lateral rectus and left medial rectus muscles contract, while the antagonist left lateral rectus and right medial rectus muscles relax. One eye cannot be turned without turning the other eye in the same direction (except in the movement of convergence, when both eyes turn medially toward the nose in looking at a near object).

Reciprocal innervation does not underlie all movement. For example, in order to fix the knee joint, antagonist muscles must contract simultaneously. Indeed, in the movement of walking, there are both reciprocal innervation and simultaneous contraction of different sets of muscle. Because this basic organization of movement takes place at lower levels of the nervous system, the training of skilled movements such as walking requires the suppression of some lower-level reflexes as well as a proper arrangement of the reciprocal inhibition and simultaneous contraction of antagonist muscles.

Posture. Posture is defined as the position and carriage of the limbs and the body as a whole. Except when lying down, the first postural requirement is to counteract the pull of gravity. This is done by the stretch reflexes. Gravity pulls the body—every part of the body—toward the ground. This force induces stretch reflexes to keep the lower limbs extended and the back upright. The muscles are not kept contracting all the time, however. As the posture alters and the centre of gravity changes, different muscles are stretched and contracted. Another important reflex is the extensor thrust reflex of the lower limb. Pressure on the foot stretches the ligaments of the sole, which causes reflex contraction of both flexor and extensor muscles, making the leg into a rigid pillar. As soon as the sole of the foot leaves the ground, the reflex response ceases, and the limb is free to move again.

The body is balanced when the centre of gravity is above the base formed by the feet. When the centre of gravity moves outside this base, the body starts to fall and has to bring the centre back to the base. Striding forward in walking depends on leaning forward so that the centre of gravity moves in front of the feet. When a baby is learning to walk, he must either take a step forward or fall down. Both happen; eventually the former happens more frequently than the latter.

Unconscious adjustment of posture

In addition to continuous postural adjustment for the changing centre of gravity, all movements require that certain parts of the body be fixed so that other parts can be supported as they move. For instance, when manipulating objects with the fingers, the forearm and arm are fixed. This does not mean that they do not move; they move so as to support the fine movements of the fingers. This changing postural fixation is carried out automatically and unconsciously. Before any movement is carried out, the essential posture is arranged and continues to be adjusted throughout the movement.

LOWER-LEVEL MECHANISMS OF MOVEMENT

The success of Charles Sherrington in opening up the physiology and pathology of movement by the study of reflexes caused a lack of interest in any other concept of movement, particularly in English-speaking lands. It was the German physiologist Erich Walter von Holst who, around the mid-20th century, first showed that many series of movements of invertebrates and vertebrates are organized not reflexly but endogenously. His general hypothesis was that within the gray matter there are networks of local neurons that generate alternating or cyclical patterns of movement. Von Holst proposed that these are the mechanisms of such rhythmically repeated movements as the movements of locomotion, breathing, scratching, feeding, and chewing.

In fish, von Holst demonstrated that the movements of the fins in swimming that need careful and correct timing and coordination continued even after the sensory dorsal roots of the spinal cord had been cut, so that there could be no sensory input to trigger reflexes. In these animals, command neurons in the lower medulla oblongata switch on the rhythmical movement built into the spinal cord, so that even when the brain has been cut out, the motor impulses and rhythmic movements continue.

Von Holst's theory differs from previous concepts in that it attributes little or no importance to the role of feedback from the parts of the body being moved. Instead, it proposes, as the essential mechanism of repetitive movements, certain central pacemakers or oscillators. The role of feedback, according to this theory, is merely to modulate the central oscillator. This is seen in the above example of swimming movements of fish and even in purring rhythms in cats, which continue after dorsal roots have been cut.

In certain kinds of movement the input of the dorsal roots is essential, but the movement needs to be defined in every case. For example, stepping movements of certain vertebrates, of which the mechanisms are within the spinal cord, can occur only with intact dorsal roots.

Higher levels of the brain can set spinal centres in motion, can stop them, and can change the amplitude and frequency of repetitive movements. In the case of humans, when the spinal cord is cut off from the brain by disease or trauma, the movements that occur are uncontrolled. The movements of locomotion, seen in lower vertebrates, do not occur. This is because the cerebral hemispheres in humans have taken over the organization of movements that in lower species are organized at lower levels of the central nervous system, such as the reticular formation of the brain stem and the spinal cord.

Within the centre of the brain stem the reticular formation consists of vast numbers of neurons and their interconnections. The majority of them have motor functions, and many of their fibres branch. This branching means that a single fibre can affect several different levels of the spinal cord. For example, one nerve fibre may excite motor neurons of the neck and of various regions of the back. This is one way in which commands from the higher neural level are sent to several segments of the spinal cord.

The movements of breathing are instigated and regu-

Regulation of rhythmic movement

lated by chemoreceptors in blood vessel walls, which sense carbon dioxide tension in the blood plasma. The essential drive or central rhythm generator consists of pacemaker neurons in the reticular formation of the pons and throughout the medulla oblongata. These neurons show rhythmic changes in electrical potential, which are relayed by reticulospinal tracts to the spinal neurons concerned with respiration. When this pathway is severed, breathing ceases.

Other movements intrinsic to the body are those needed for urination and defecation. Cats and dogs from which the cerebral cortex has been removed urinate and defecate in a normal manner. This is because nuclei in the midbrain near those that organize the movements of locomotion control these movements, so that urination and defecation occur whenever there are enough waste products to be expelled. This is also the condition of the healthy baby animal. But as the infant grows up, it learns to fit these events into the social circumstances of living, and this requires higher-level control by the cerebral hemispheres.

HIGHER-LEVEL MECHANISMS OF MOVEMENT

Because of the many differences in the movements used in standing, coughing, or laughing, or playing a scale on the piano, it is convenient to think of movements as lower and more automatic or as higher and less automatic. According to this concept, movements are not placed in totally different categories but are regarded as different in degree.

Cerebral hemispheres. Basic organizations of movement, such as reciprocal innervation, are organized at levels of the central nervous system lower than the cerebral hemispheres—both at the spinal and brain-stem level. Examples of brain-stem reflexes are turning of the eyes and head toward a light or sound. The same movements, of course, can also be organized consciously when one decides to turn the head and eyes to look. The cerebral hemispheres themselves can organize certain series of movements that are often referred to as programmed movements. These are movements that need to be performed so rapidly that there is no time for correction of error by local feedback. For this reason the program is arranged before the movements begin. Examples of such movements are those of a pianist performing a trill or of an athlete hitting a ball.

Most of the movements organized by the cerebral cortex are carried out automatically. But when a new series of movements is being learned, or when a movement is difficult, the attributes usually associated with the higher levels of the brain—such as planning, internal speech, remembering, and learning—are used. (For the role of the cerebral hemispheres in these higher mental activities, see below *Higher cerebral functions.*)

Motor areas of the brain

In the 19th century the first motor area of the cerebral cortex was discovered by electrical stimulation. Successive areas responding to electrical stimulation were numbered in the order of their discovery. Therefore, although motor and sensory areas are named numerically, no hierarchical organization is implied.

The first motor area to be discovered was the motor strip of the precentral gyrus; it became known as the primary motor area (Figure 29). Immediately behind it is the postcentral gyrus, found on electrical stimulation to be sensory; it was named the primary sensory area. Each of these areas displays a maplike correspondence with various body parts, the legs represented near the top of the hemispheres and the arms and face lower on the cortical surface. Each of these areas is to some extent both motor and sensory. The motor region, for example, receives inputs from the skin, joints, and muscles via the postcentral gyrus behind and the thalamus below.

Experiments in monkeys have shown that the motor strip is able to arrange activity of muscles to produce the correct force for the loading conditions of the limbs. To do this, it continually receives information from the primary sensory area both before and during the movement. Cutaneous areas having the greatest tactile acuity have the largest representative in the primary sensory area; these areas are connected to equally large areas in the primary motor area.

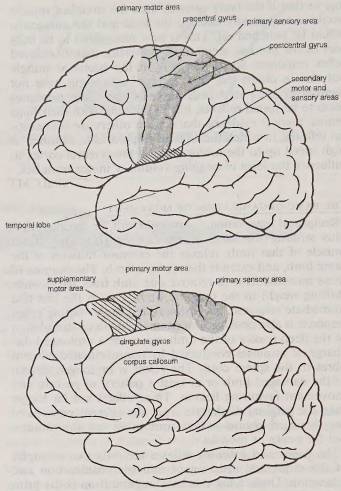


Figure 29: (Top) Lateral and (bottom) medial views of the cerebral hemispheres, showing motor and sensory areas.

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In front of the motor strip is an area known as the premotor cortex or area. When this area is stimulated in a monkey, the animal turns its head and eyes as though it is looking in a particular direction. This cortical area, then, organizes the guiding of movements by vision and hearing.

An area labeled the secondary motor area is at the lower end of the precentral gyrus. It is secondary not only because it was discovered after the primary motor area but also because it does not function in a discrete manner like the primary area. Stimulation of this small area produces movements of large parts of the body. It is also a sensory area, as sensations in the parts of the body being moved are felt during stimulation.

The supplementary motor area

On the medial surface of the hemisphere, in front of the motor strip, is the supplementary motor area. Stimulation there can produce vocalization or can interrupt speech. There also may be large movements of both sides of the body—often symmetrical movements of the two limbs. Stimulation also produces movements of the opposite side, such as raising the upper limb and turning the head and eyes as if looking at something opposite. In experiments on monkeys, when the animal chooses to respond to one kind of sensation rather than to another, it is the supplementary area that is active rather than the precentral area. In this animal—it is unknown for humans—the fibres descending from the supplementary motor area run to the spinal cord and terminate throughout its whole length. Fibres are also sent to the precentral gyri of both hemispheres, the reticular formation of the pons, the hypothalamus, the midbrain, and many other masses of cerebral gray matter such as the caudate nucleus and the globus pallidus. The supplementary motor area is upstream from the primary motor area; it initiates movements, whereas the motor strip of the precentral gyrus is part of the apparatus for carrying them out.

Other regions of the cerebral hemisphere from which movements are produced on electrical stimulation are the insula and the surface of the temporal lobe. Stimulation of the anterior end of one temporal lobe causes movements of the head and body toward the other side. The insula

is a region below the frontal and temporal lobes hidden from the surface; stimulation there causes movements of the face, larynx, and neck.

Fibres from the anterior part of the cingulate gyrus are involved in the control of urination and defecation. The organization of these functions also depends on regions anterior to the cingulate gyrus in the medial wall of the frontal lobe. These regions form a part of the limbic lobe, which is responsible for some emotional states with their autonomic components.

Movements closely guided by vision have their own pathways. Occipital visual areas send fibres to the pons and from there to the cerebellum. Also just in front of the visual cortex in the parietal lobe are neurons organizing certain types of eye movement. In the monkey, these neurons are at rest during steady gaze, becoming active when the animal turns its eyes to look at something. That the movements constitute a high level of motor behaviour is shown by the activation of these neurons only when the animal is attempting to satisfy an appetite by using its upper limbs and hands; using the limbs for other purposes does not activate them. The neurons are also active when the animal is carrying out the movements of grooming, which also satisfies an innate drive.

One of the main pathways for cortically directed movement of the limbs is the corticospinal tract. This tract developed among animals that used their forelimbs for exploring and affecting the environment as well as for locomotion. It is largest in man. Fibres of the tract go to various regions of the brain stem and the spinal cord that organize movement. Excitation via the corticospinal tract is then brought to many muscles, all of them presumably working together in a coordinated manner. This is achieved by the anatomical arrangement of the motor neurons and by the termination of the corticospinal tract on interneurons, which convey a coordinated pattern of stimulation to the motor neurons.

The corticospinal tract is not merely a straight pathway to medullary and spinal motor neurons. Activity in this tract can suppress the input from cutaneous areas while facilitating proprioceptive input. This is probably a mechanism important in the organization of movement. The corticospinal neurons themselves receive constant input needed for internal feedback. This input comes from the cerebellum, much of it having originated in the muscles, joints, and skin of the body parts being moved.

The control of complex movement through sensory feedback

Cerebellum. Although a cycle of simple repetitive movements can be organized without sensory feedback, more sophisticated movements require feedback as well as what is called feed-forward control. This is provided by the cerebellum. Many parts of the brain have to be kept informed of movements being carried out in order to detect error and continually correct the movement. The cerebellum continuously receives inputs from the trunk, limbs, eyes, ears, and vestibular apparatus, maintaining in turn a continuous transfer of information to the motor parts of the thalamus and to the cerebral cortex.

As a movement is being prepared, a replica of the instructions is sent to the cerebellum; the cerebellum sends back its own information to the cortex. The cortex, meanwhile, sends information about the movement to various afferent neurons that are about to receive information from receptors in the body parts where the movement is about to begin. This comparison between instructions sent and movement performed is a fundamental requirement of all complicated movement. The discharge of impulses from motor to sensory regions is called the corollary discharge. The mechanisms involving the cerebellum do not come to consciousness. There are no sensory consequences of damage to the cerebellum, for the cerebellum is a motor structure.

As series of movements are learned and improved with practice, a replica of the movement is probably retained in the cerebral hemispheres. (The mechanisms of this postulated "replica" are as yet unknown.) Whenever the learned movements are repeated, they are formed and guided by the replica. This hypothesis of controlling movement by previously practiced patterns was developed by von Holst. He gave the name efference to the totality of motor impulses necessary for a movement, and he proposed that whenever the efference is produced it leaves an image of itself somewhere in the central nervous system. This image he called the efference copy. According to von Holst's theory, as the movement is repeated, afferent impulses return to the brain from receptors activated by muscular activity. These impulses are called the re-afference. There is then a comparison between the efference copy and the re-afference. When they are identical, the movement is "correct" in relation to its previous performance. When the re-afference differs from the efference copy, corrections have to be made so as to bring the present pattern of movement back to the original image left in the brain.

If the cerebellum is damaged or degenerates, any error between the movement being performed and the efference copy will no longer be corrected, and the postural adjustments sent from the cerebral hemispheres will no longer be implemented. The force and extent of movements also will be abnormal, the movement going too far or not far enough. The various muscles may not come into play at the right time, and there will be a disturbance in the relationship of antagonist muscles, so that the accurate arrival on target will be replaced by oscillation.

Basal ganglia. Most of what is known about the contribution of the basal ganglia has been obtained from studying abnormal conditions that occur when these nuclei are affected by disease. In Parkinson's disease there is a loss of the pigmented neurons of the substantia nigra, which release the neurotransmitter dopamine at synapses in the basal ganglia. Patients with this disease have a certain type of muscle stiffness called rigidity, a typical tremor, flexed posture, and difficulty in maintaining equilibrium. They have difficulty in starting movements, including walking, and they cannot put adequate force into fast movements. They have particular difficulty in changing from one movement to its opposite, in carrying out two movements simultaneously, and in stopping one movement while starting another.

The organization of posture, which is based on vestibular, proprioceptive, and visual input to the globus pallidus, is severely damaged when this region of the basal ganglia degenerates. As a changing posture of the various parts of the body is a prerequisite of every movement, this factor alone upsets all movement. Visual reflexes contributing to motion also act through the globus pallidus. When this structure is degenerate, what the patient sees may affect his ability to move. One patient may be unable to go forward if he has to pass through a narrow door, another may not be able to do so if he has to go into a wide expanse like a field. (P.W.N.)

The vestibular system

Animals have evolved sophisticated sensory receptors to detect features of the environment in which they live. In addition to the special senses such as hearing and sight, there are unobtrusive sensory systems such as the vestibular system, which is sensitive to acceleration.

Linear and angular acceleration

Acceleration can be considered as occurring in two forms—linear and angular. One familiar type of linear acceleration is gravity. Because this environmental feature, unlike any other encountered by an organism, is always present, highly sophisticated systems have developed to detect gravity and enable an animal to maintain its position relative to the earth. A common form of angular acceleration is that induced by rotation, such as a turning of the head. Through the vestibular apparatus these forces are detected and appropriate motor activities are organized to counter the postural perturbations that they induce.

RECEPTORS

The vestibular sensory organ is a paired structure located symmetrically on either side of the head within the inner ear. Inside each end organ are the hair cells, the detection units for both linear and angular acceleration. Extending from one surface of each hair cell are fine, hairlike cilia, displacement of which alters the electrical potential of the cell. Bending the cilia in one direction causes the cell membrane to depolarize while hyperpolarization is

induced by movement in the opposite direction. Changes in membrane potential induce alteration in the firing of nerve impulses by the afferent neurons supplying each hair cell. (For a discussion of the neurobiology of depolarization and hyperpolarization of cell membranes, see above *Form and function of nervous systems: Transmission of information in the nervous system.*)

The two types of acceleration are detected by two types of vestibular end organ. Linear acceleration is sensed by a pair of organs—the saccule and utricle—while there are three receptor organs—called semicircular canals—in each vestibular apparatus for the detection of angular acceleration.

Saccule and utricle. Each saccule and utricle has a single cluster, or macula, of hair cells located in the vertical and horizontal planes, respectively. Resting upon the hair cells is a gelatinous membrane in which are embedded calcareous granules known as otoliths. Changes in linear acceleration alter the pressure of the otoliths, causing changes in the distortion of the cilia and providing an adequate stimulus for membrane depolarization. Within each macula the hair cells are arranged in two groups oriented in opposite directions, so that the receptor functions in a push-pull fashion within each organ. Since many of the nerve fibres passing from the hair cells to the brain are constantly active, this push-pull arrangement makes the receptors a highly sensitive detection system for linear acceleration in the vertical and horizontal planes.

Semicircular canals. The angular acceleration detectors within the semicircular canals function in a different way. The three canals—which in fact are considerably more than a semicircle in circumference—are oriented at approximately right angles to one another. Two are vertically placed, and one is at about 30 degrees to the horizontal. In this arrangement the anterior canal of one side of the head is in the plane of the posterior canal of the other side. A ridge, or crista, covered by sensory hair cells is located at the end of each canal within an expanded chamber called the ampulla. The canals are filled with an endolymphatic fluid. Rotation of the canals about an axis passing through the centre of each semicircle causes the fluid to flow toward or away from the crista, generating a force that bends the cilia by displacement of a gelatinous plate resting upon the hairs. The cells of the vertical canals are oriented in such a way that centrifugal movement away from the cristae depolarizes the hair cell membranes, while the converse applies to the horizontal canal.

NERVE SUPPLY

As in the case of the utricle and saccule, some of the nerve fibres conveying information from the cells are constantly active. The hair cells receive nerve impulses from the brain (via efferent fibres) and send them to the central nervous system (via afferent fibres). Excitatory efferent fibres increase the sensitivity of the hair cells, while inhibitory fibres decrease sensitivity. This system gives the semicircular canals a plasticity that is essential to maintaining optimal activity under different environmental conditions—including such extraordinary states as the microgravity encountered in space travel.

The vestibular apparatus is supplied by neurons that make up the vestibular portion of the vestibulocochlear, or eighth cranial, nerve. The somata, or cell bodies, of the afferent fibres lie in the vestibular ganglion near the end organ. Most of the nerve fibres pass from there to vestibular nuclei in the pons, while others pass directly to the cerebellum. The efferent fibres of the vestibular nerve arise from nuclei in the pons.

VESTIBULAR FUNCTIONS

For vision to be effective, the retinal image must be stationary. This can be achieved only by maintaining the position of the eyes relative to the earth and using this stable platform for pursuing a moving target. The vestibular system plays a critical part in this, mainly through complex and incompletely understood connections between the vestibular apparatus and the musculature. Rotation of the head in any direction is detected by the semicircular canals, and a velocity signal is then passed via the vestibular nuclei to the somatic and extraocular muscles. In the case of the eye muscles, the velocity signal reaching the brain stem is in some way integrated with impulses signaling the eyes' position, thus ensuring that the eyes maintain their position relative to space and the object of regard. This integration partly occurs in the vestibular nuclei, the source of secondary neurons destined for the extraocular muscle nuclei of both sides.

Vestibulo-ocular reflex. When the head is oscillated, the eyes maintain their position in space but move in relation to the head. This so-called vestibulo-ocular reflex operates in both horizontal and vertical planes, owing to the arrangement of the three semicircular canals, and it maintains such stability that the object of vision does not oscillate until quite high velocities are attained. The other component of the vestibular system, the saccule and utricle, also contributes to the vestibulo-ocular reflex. Under normal circumstances the otolith receptors cause torsional movement of the eyes. For example, tilting the head toward one shoulder results in counter-rolling of the eyes, thereby stabilizing the image upon the retina. The two components of the vestibulo-ocular reflex also interact, enabling appropriate eye movements to be generated when both linear and angular accelerations are changing.

Importance of vestibular system to posture

While the vestibulo-ocular reflex is the best understood of the vestibulo-motor connections, information from the vestibular receptors is also known to be passed via vestibular and other brain-stem nuclei to the somatic musculature of the trunk and limbs. Through these pathways body posture is adjusted to counter acceleration forces applied to the vestibule. These reflexes are so important in maintaining vertical posture that devastating short-term consequences on posture are seen if the vestibulocochlear nerve is cut.

Conscious sensation. Besides maintaining input for the generation of motor reflexes, vestibular impulses reach consciousness and create a powerful sensation. A person being rotated knows when he is accelerating even in the absence of an object upon which he can fix his eyes. This occurs because acceleration is the adequate stimulus for the semicircular canals. Similarly, information detected by the otoliths is readily brought to consciousness—as occurs, for example, when a darkened elevator accelerates up or down. The pathways to the cerebral cortex, which mediate conscious sensation, are not fully known, but there is considerable evidence that areas of the parietal and temporal lobes receive connections via the thalamus.

One important aspect of vestibular physiology is the interaction of vestibular impulses, which signal changes of position, and impulses from other sensory receptors that signal changes in bodily movement. For example, when the head turns to one side about a vertical axis, not only is the horizontal canal of that side stimulated and that of the other side inhibited, but receptors in the neck joints and muscles are also stimulated, and the retina indicates movement if fixation is not maintained perfectly. This information is fed to the brain via sensory pathways in the spinal cord and various visual sensory systems. Therefore, within the vestibular nuclei of the pons, neurons that respond to acceleration signals from the semicircular canals receive impulses from other sources as well. Other information from visual and spinal sensory systems pass to the cerebellum, which also receives direct impulses from the vestibular apparatus that bypass the vestibular nuclei. In this way the cerebellum has the opportunity to compare signals and assess the degree of mismatch between them. (Such mismatch is an unpleasant experience and is important in the phenomenon of motion sickness. Motion sickness is often generated by a mismatch between the various inputs signaling orientation within space. People will frequently be seasick if they are below decks in rough weather and the visual system signals no movement while the vestibular system indicates motion.) In another example, the vestibulo-ocular reflex may be underactive, so that for a given head movement the eyes do not deviate sufficiently within the orbit and the object of regard does not remain stationary upon the retina. Thus, the image slips and cannot be seen clearly during movement. The cerebellum has the opportunity to detect this mismatch

Motion sickness

between the required position of the eyes with respect to the environment and the movement actually achieved. Through inhibitory connections to the vestibular nuclei, the cerebellum can then adjust the vestibulo-ocular reflex so that a more appropriate movement of the eyes is achieved with the next acceleration signal. In other words, there is a continual updating of the vestibulo-ocular reflex via the cerebellum or structures associated with it.

A similar situation also obtains for somatosensory input from the spinal cord. A dramatic demonstration of short-term adaptation via the visual system occurs when someone dons prisms that reverse the perception of the environment in the horizontal plane, making everything look upside down. The person is at first unable to move about because any rotation of the head results in apparent movement of the environment in the wrong direction. However, over a few days normal mobility gradually returns. Incredibly, during this time the vestibulo-ocular reflex is at first diminished in amplitude and then is reversed. Removal of the prisms results in a rapid return to the normal state. These experiments are a powerful demonstration of the plasticity of the vestibulo-ocular reflex, which can continue functioning throughout life in spite of the various insults that befall it. (P.Ru.)

The autonomic system

The autonomic nervous system is regulated by cell groups in the brain that process visceral information arriving in specific neural networks, integrate that information, and then issue specific regulatory instructions through the appropriate autonomic outflows. Each end organ is processed in a unique way by functionally specific sets of neurons in which there is often coordination of both the sympathetic and parasympathetic nervous systems.

THE EYE

Innervating smooth muscle of the eye

In order for the eye to function properly, specific autonomic functions must maintain adjustment of four types of smooth muscle: (1) smooth muscle of the iris, which controls the amount of light that passes through the pupil to the retina; (2) ciliary muscle on the inner aspect of the eye, which controls the ability to focus vision on nearby objects; (3) smooth muscle of arteries providing oxygen to the eye; and (4) the smooth muscle of veins that drain blood from the eye and affect intraocular pressure. In addition, the cornea must be kept moist by adequate secretion from the lacrimal gland.

Light reflex. When bright light is shined into an eye, the pupils of both eyes constrict. This response, termed the light reflex, is regulated by three structures: the retina, pretectum, and midbrain. In the retina is a three-neuron circuit consisting of light-sensitive photoreceptors (rods), bipolar cells, and retinal ganglion cells. The latter transmit luminosity information to the pretectum, where particular types of neurons relay the information to parasympathetic preganglionic neurons located in the Edinger-Westphal nucleus of the midbrain. These neurons send axons out of the ventral surface of the midbrain to synapse in the ciliary ganglion. From there, parasympathetic postganglionic neurons innervate the pupillary sphincter muscle, causing constriction.

Accommodation. In order to bring a nearby object into focus, several changes must occur in both the external and internal muscles of the eyes. The initial stimulus for accommodation is a blurred visual image that first reaches the visual cortex. From there, through a series of cortical connections, it reaches two specialized motor centres. One of these, located in the frontal cortex, sends motor commands to neurons in the oculomotor nucleus controlling the medial rectus muscles; this causes the eyes to converge. The other motor centre, located in the temporal lobe, functions as the accommodation area. Via multineuronal pathways, it activates specific parasympathetic pathways arising from the ciliary ganglion. This pathway causes the ciliary muscle to contract, thereby reducing tension on the lens and allowing it to become more rounded so the visual image of the near object can be focused on the central part of the retina. Concomitant with this change is a constriction of the iris, also under control of the oculomotor parasympathetic system, that acts to enhance the resolution of the lens.

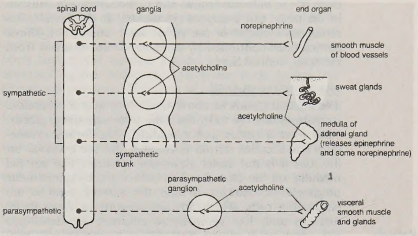


Figure 30: Chemical transmission in the autonomic nervous system.

Adapted from R.H. Johnson and J.M.K. Spalding, *Disorders of the Autonomic Nervous System* (1974): Blackwell's Scientific Publications, Oxford

THE URINARY SYSTEM

The kidney is involved in maintenance of water and electrolyte balance. It also produces vasoactive hormones such as renin, a proteolytic enzyme that initiates the formation of angiotensin II (a potent hormone involved in the regulation of blood pressure), and erythropoietin, a glycoprotein hormone important in formation of red blood cells. While the autonomic nervous system is not crucial to these functions, the fine-tuning of some of these processes is regulated by sympathetic fibres. There is no known parasympathetic innervation of the kidney.

Innervation of the bladder

In contrast to renal functions, the normal physiology of the urinary bladder depends entirely on the autonomic nervous system. For example, retention of urine is made possible by activation of sympathetic pathways originating from lateral horns in spinal segments T_{11}–L_2; these cause contraction of smooth muscle that forms the internal urinary sphincter. Working in concert with this sphincter is the external urinary sphincter, which is made up of skeletal muscle controlled by motor fibres of the pudendal nerve. These fibres, arising from ventral horns of segments S_2–S_4, provide tonic excitation of the external sphincter. Because they are under voluntary control, micturition is initiated by higher brain centres. The first command causes voluntary inhibition of the sacral motor outflow, resulting in relaxation of the external urinary sphincter. Simultaneously, an increase in abdominal pressure, caused by contraction of muscles of the abdominal wall, starts an initial flow of urine. This is followed by a reflex inhibition of sympathetic outflow, resulting in relaxation of the internal urinary sphincter, and by activation of parasympathetic outflow to smooth muscle that causes the bladder to contract and expel the urine.

SEXUAL FUNCTIONS

The sexual response in both males and females can be defined by three physiological events. The first stage begins with psychogenic events in higher neural centres, which travel through multineuronal pathways and cause excitation of sacral parasympathetic outflow innervating vascular tissues of the penis and clitoris. This results in dilation of these arteries and erection of the penis and clitoris. The second stage involves secretion of glandular fluids; this is mediated by sympathetic neurons arising in the T_{12}–L_2 levels of the lateral horns. In the male, it involves contraction of the epididymis, vas deferens, seminal vesicles, and prostate gland, with the overall effect of moving fluids into the urethra; at the same time, sympathetic activation causes a closure of the internal urinary sphincter to prevent retrograde ejaculation of semen into the bladder. In the female, the response involves mucous secretions of the greater vestibular glands, resulting in lubrication of the vaginal orifice.

The third phase is a muscular response. Somatic efferent fibres in the pudendal nerve produce rhythmic contrac-

tions of the bulbocavernous and ischiocavernosus muscles in the male; this produces ejaculation. In the female, homologous muscles of the pelvic floor undergo rhythmic contractions controlled by somatic efferent neurons from the S_2–S_4 ventral horns.

THE ADRENAL GLANDS

The adrenal glands lie above the kidney and are therefore sometimes referred to by the older term suprarenal glands. They have a cortex and a medulla. The former synthesizes and secretes steroid hormones that are essential for life, but it is not under autonomic control. The adrenal medulla, on the other hand, is innervated by sympathetic preganglionic neurons. Within the adrenal medulla are chromaffin cells, which are homologous to sympathetic neurons and, like sympathetic neurons, are developed from embryonic neural crest cells. Chromaffin cells produce epinephrine (adrenalin) and, to a much lesser extent, norepinephrine as well as other chemicals such as chromogranins, enkephalins, and neuropeptide Y—all of which are released into the bloodstream and act as hormones. Epinephrine, in particular, affects many different types of tissues throughout the body and has a particularly potent effect on cells that possess β-adrenergic receptors.

Release of epinephrine and other chemicals

The release of epinephrine prevents hypoglycemia (low blood sugar), through the following mechanism. By binding to α_2-adrenergic receptors embedded in the hormone-releasing cells of the pancreas, epinephrine inhibits the release of insulin. Since insulin promotes the absorption of glucose from the bloodstream into liver, skeletal muscle, and fat cells, inhibition of its release results in a greater amount of glucose that is available for entry into the brain. In addition, by binding to certain β-adrenergic receptors, epinephrine stimulates the release of glucagon, a pancreatic peptide hormone that acts in the liver to convert glycogen to glucose. Under emergency conditions, epinephrine causes even more widespread effects on glucose metabolism. Glycogen in the liver and skeletal muscle is broken down to glucose, fat held in adipose cells is converted to fatty acids and glycerol, and production of glucose and ketone bodies (β-hydroxybutyric acid, acetoacetic acid) is increased in the liver. All these substances can be used as energy sources for the body.

THE CARDIOVASCULAR SYSTEM

The function of the cardiovascular system is to maintain an adequate supply of oxygen to all tissues of the body. In order to maintain this function, the autonomic system must process visceral information and coordinate neural elements that innervate the heart, blood vessels, and respiration. In addition, certain hormones such as angiotensin II and vasopressin are released and act in concert with the autonomic nervous system.

Reflex pathways. The cardiovascular system is regulated by sets of neurons that form two major types of reflex circuit. One type is triggered by mechanoreceptors found in the major arteries near the heart and in the heart itself. Lying in the wall of the aortic arch and the carotid sinuses are receptors sensitive to high pressure. These are innervated by the aortic branch of the vagus nerve and by a branch of the glossopharyngeal nerve. Both branches send information regarding increases in arterial blood pressure into the medulla oblongata and synapse in the nucleus of the solitary tract. Another group of mechanoreceptors provides information about venous pressure and volume; these are low-pressure receptors located in the walls of the major veins as they enter the heart and within the walls of the atria. Low-pressure afferents also relay sensory information to the solitary tract.

Lowering blood pressure

The mechanoreceptors described above trigger what is called the baroreceptor reflex, which causes a decrease in the discharge of sympathetic vasomotor and cardiac outflows whenever an increase in blood pressure occurs. In addition, the baroreceptor reflex causes stimulation of vagal cardioinhibitory neurons, which produces a decrease in heart rate, a decrease in cardiac contractility, and dilation of peripheral blood vessels. Overall, the net effect is to lower blood pressure.

The second major class of afferents that trigger reflex responses are chemoreceptors found in the major arteries near the heart in loci close to the high-pressure mechanoreceptors. Functioning as oxygen sensors, these receptors are innervated by separate sets of fibres that travel parallel with the baroreceptor nerves, and they also project to the nucleus of the solitary tract. Overall, the chemoreceptor reflex regulates respiration, cardiac output, and regional blood flow, ensuring that proper amounts of oxygen are delivered to the brain and heart.

Vasopressin and cardiovascular regulation. Vasopressin is a peptide hormone that is synthesized in magnocellular neurons of the supraoptic and paraventricular nuclei of the hypothalamus. These neurons send their axons into the posterior lobe of the pituitary gland, from which vasopressin is released into nearby capillaries and distributed throughout the body.

Vasopressin has two main functions: volume regulation and vasomotor tone. It acts to increase water retention by increasing the permeability of kidney tubules to water as the kidney filters blood plasma. As more water is reabsorbed, extracellular fluid volume is increased, and this in turn increases venous volume and, ultimately, blood pressure. Under emergency conditions, vasopressin also selectively constricts certain vascular beds that are nonessential for life (*e.g.*, gastrointestinal, muscle); this shunts blood to critical tissues such as the heart or brain.

Two major stimuli trigger the release of this hormone: increases in extracellular fluid osmolality and decreases in blood volume (as in hemorrhage). Osmotic stimuli cause vasopressin to be released by acting on specialized brain centres called circumventricular organs. Surrounding the third and fourth ventricles of the brain and containing neurons with central projections that alter autonomic and neuroendocrine functions, these "osmosensitive" areas possess a unique vascular system that permits diffusion of large molecules such as peptides and ions to cross readily from the plasma to the brain. Normally, such chemical agents do not have free passage because the capillaries form a blood-brain barrier, but at these special sites they have direct access to central neurons. One of the areas, called the organum vasculosum of the lamina terminalis, lies in the third ventricle and is involved in osmo- and sodium regulation. Another circumventricular organ, called the subfornical organ, lies in the dorsal part of the third ventricle; it is particularly sensitive to hormones such as angiotensin II and signals changes needed for the regulation of salt and water balance. Both regions project directly to vasopressin-producing hypothalamic neurons. The area postrema, which lies on the floor of the fourth ventricle in the medulla, is the third site involved as a special chemical sensor of the plasma.

When blood is lost through hemorrhage, atrial receptors and baroreceptors relay volume and pressure information, via the vagus nerve, into the nucleus of the solitary tract. Neurons in this nucleus send commands to other relay neurons that project directly to the magnocellular hypothalamic neurons and cause the release of vasopressin.

(A.D.L.)

Pain

THEORIES OF PAIN

There have always been two theories of the sensation of pain, a quantitative or intensity theory and a stimulus-specific theory. According to the former, pain results from excessive stimulation of every kind: *e.g.*, excessive heat or cold, excessive damage to the tissues. This theory in its simplest form entails the belief that the same afferent nerve fibres are activated by all of these various stimuli; pain is felt merely when they are conducting far more impulses than usual. But knowledge acquired in the 20th century has shown that the quantitative theory—at least in its classic form—is wrong. Peripheral nerve fibres have been found to be stimulus-specific, each one excited by certain forms of energy. The stimulus-specific theory proposes that pain results from interactions between various impulses arriving at the spinal cord and brain, that these impulses are brought to the spinal cord in certain non-myelinated and small myelinated fibres, and that the spe-

cific stimuli that excite these nerve fibres are noxious, or harmful.

Special receptors for reporting pain

In the somatic tissues there are certain kinds of nerve fibre that do not give rise to pain, no matter how many there are or how frequently they are stimulated. Included in this category are mechanoreceptors that report only deformation of the skin and the larger afferent nerve fibres from muscles and tendons that form part of the organization of posture and movement. No matter how they are excited, these receptors never give rise to pain. But the smaller fibres from these tissues do cause pain when they are excited mechanically or chemically.

Warmth and cold fibres are specific. Warmth fibres are excited by rising temperature and quieted by falling temperature, and cold fibres respond similarly with cold stimuli. Although pain arises from very hot and very cold stimulation and with intense forms of mechanical stimulation, this occurs only with the activation of afferent nerve fibres that specifically report noxious events. When no noxious events are occurring, these nerve fibres are silent.

In contrast, the quantitative theory seems to apply to the viscera, where afferent nerve fibres used in reflex organization also report events giving rise to pain. In the heart, for example, the same nerve fibres are excited by mechanical stimulation as are excited by chemical substances formed in the body that cause pain. Also, in the bladder, rectum, and colon, nerve fibres activated by substances that cause pain are the same as those activated by distension and contraction of the viscera. This means that the same nerve fibres are reporting the state that underlies the desire to urinate or defecate and the sensation underlying the pain felt when these organs are strongly contracting in an attempt to evacuate their contents. In the heart, rectum, and bladder, therefore, pain appears to be due to a summation of impulses in sensory nerve fibres and is not mediated by a special group of fibres reserved for reporting noxious events. It must be pointed out, however, that not all researchers accept the argument.

LOWER-LEVEL PAIN PATHWAYS

Tissues. *Normal conditions.* Not all the tissues making up the body give rise to pain; furthermore, each tissue must be stimulated in an appropriate way to invoke its particular sensation of pain. Skin, being the outer covering of the body, easily raises the warning of pain, but other tissues that do not come in direct contact with the outer environment are just the opposite. The brain, for example, can be pierced, cut, and burned in neurosurgery, while the patient would require only local anesthesia of the pain-sensitive scalp. The lung, liver, and spleen also do not give rise to pain, no matter how they are stimulated. Pain arises from hollow viscera when the passage of their contents is obstructed and the musculature must undergo strong contraction and stretching. Pain cannot be induced by cutting or burning the wall of the intestine, but pulling on the mesenteric tissue that fixes the intestines to the posterior wall of the abdomen causes pain. The reason for these differences is clear. Tissues are sensitive to the kinds of damage they are likely to meet during life and not to those that they probably will never meet.

Although the warning function of pain is obvious, it is not equivalent to nociception, the perception of forces likely to damage the tissues of the body. First, nociception can occur without pain and pain without nociception; also, the sensation of pain is only a part of the total act of nociception. There are reflex effects as well, such as a local reflex withdrawal from a sudden noxious stimulation of the skin. There are autonomic effects, such as a rise in blood pressure, quickening of the heart rate and respiration, and other excitatory sympathetic nervous effects. There may even be shrieking or howling, warning other animals that something dangerous and painful is occurring.

Acute and chronic pain

Pathological conditions. Acute and chronic pain differ in many ways. Acute pain occurs with sudden damage, such as stepping on a nail or biting the tongue. Chronic pain is the pain of pathological conditions—the pain that accompanies gout, arthritis, inflammation, or cancer. Each type of pain has effects on the nervous system.

The effect of acute inflammation of the joints on nerves reporting the state of the joint and on the central nervous system has been studied by inducing arthritis in animals. In this condition, locally formed chemical substances excite the small myelinated and nonmyelinated afferent fibres that report noxious events. Most of these nerves, sensitized by the inflammatory exudate, begin to fire impulses continuously. This flow of impulses to the dorsal-horn neurons of the spinal cord increases their excitability so that many of them also begin to fire continuously. Neurons that are normally excited only by noxious stimulation now respond to light touch as well. Meanwhile, motor neurons in related areas also fire spontaneously, and stimuli that would not normally cause withdrawal reflexes now cause a prolonged reflex response. There is no change in the motor neurons themselves; the change is in the firing threshold of peripheral neurons coming from the inflamed area and in the interneurons between the afferent nerve fibres and the motor neurons. These interneurons are ultimately connected to the brain, so that the state of increased sensitivity is passed on to related cerebral neurons. Eventually, neurons in the cerebral hemispheres continuously and spontaneously generate impulses. Other neurons of the brain start responding to movements of the affected joints that normally would not do so.

In some people with chronic painful conditions, the constant pain impulses change the character of neurons of the thalamus and cortex. For example, one patient who had had a toothache 10 days before he had an operation on the thalamus for parkinsonism suddenly got the pain of toothache again when the thalamus was stimulated electrically. Normally, no pain can be induced by stimulating that part of the thalamus.

Peripheral nerves. Most of the afferent nerves making up the dorsal roots are nonmyelinated fibres. These fibres are activated by warmth within a physiological range (and by higher temperatures likely to damage the body), by chemical substances (including those made in the body), and by strong mechanical stimulation such as pricking and crushing. The smaller myelinated fibres report mechanical stimulation of the skin, noxious stimulation, and cold.

As stated above, pain is not the inevitable result of the firing of nonmyelinated fibres reporting noxious events. These fibres may fire at a slow rate without causing pain; they may even continue to fire for an hour or so without pain. Furthermore, the pain threshold does not correspond with the onset of activity in the nonmyelinated fibres, for pain can increase while the discharge of nerve impulses decreases.

Spinal cord. The stimulus-specific organization of the peripheral nerve fibres is not continued within the spinal cord, as the various afferent nerve fibres do not transmit their impulses exclusively to neurons of only one kind of sensibility. In the dorsal horns (the spinal region that receives afferent impulses) a few neurons are purely nociceptive, but most neurons reporting noxious events receive both noxious and mechanoreceptive input. These latter are called convergent neurons. The size of the peripheral field (the area of the body from which it receives stimuli) of a dorsal-horn neuron continually varies, depending on the state of excitability of the neuron. Furthermore, events in the peripheral field affect future responses. For example, repeated input along a group of afferent nerve fibres produces a gradually decreasing response in the central nervous system. This is called habituation. Also, the region of decreased response spreads from local neurons that received the input to neighbouring neurons.

Changes in sensitivity to pain

The state of excitability of a dorsal-horn neuron depends on many variables. If it is very excitable, it will respond to impulses from many afferent peripheral nerve fibres; if it is relatively inexcitable, it will be affected only by those peripheral fibres that are habitually connected to it and located near it. A neuron excited by many afferent fibres receives input from a larger area than a neuron receiving only from the fibres most nearly related to it. For this reason the area of skin or deep tissue connected to neurons of the dorsal horn varies and changes. In experiments using damaged skin, it has been found that a barrage of nerve impulses from the damaged region increases the excitability of the dorsal-horn neurons. Once this hyper-

excitable state has been set up, it continues for a time without further input from peripheral nerves. In this state of local excitability, some dorsal-horn neurons receive an input from the area of damaged skin that they would not receive were the skin in a normal state.

The convergent neurons mentioned above can have their activity inhibited by tactile stimulation of a region near their peripheral fields or of a homologous region on the opposite side of the body. Also, their responsiveness to stimuli can be increased by damage to the skin in their peripheral fields.

From these convergent neurons and from other neurons of the dorsal horns, there arise tracts of long fibres that cross the midline and lead to the thalamus and other nuclei of the brain. These constitute the spinothalamic tracts. The other main pathway of pain impulses ends in the reticular formation of the medulla oblongata and pons and is known as the spinoreticular tract. It is believed that spinoreticular input to the brain serves the autonomic responses and emotional components associated with pain, whereas the spinothalamic serves conscious sensation, with its exact temporal and spatial aspects. Neurons around the central spinal canal that receive input from the bladder and colon and their overlying somatic tissues may be connected to an ascending tract that stays within the gray matter in the neighbourhood of the central canal.

HIGHER-LEVEL PAIN PATHWAYS

Inhibition of pain transmission

Brain. Many regions of the brain can influence the input arriving at the lower levels of the nervous system. This so-called descending inhibition can be selective, with different regions of the brain inhibiting certain inputs to the spinal cord. Some regions reduce mechanoreceptive input, and others reduce noxious and warmth inputs. Descending inhibition can also reduce input from the skin while increasing that related to movement.

Prominent regions of influence are those that themselves receive noxious input. For instance, the lateral reticular nuclei of the medulla oblongata cause a constant inhibition of input brought to the spinal cord by the nonmyelinated fibres. In the rat (in which the discovery was first made), descending inhibition can be so effective that a noxious input does not enter the spinal cord. In other words, normally painful stimuli cause no reaction or concern, and there is no change in blood pressure, respiration, and other reflex activities. In these circumstances it seems that pain simply is not felt.

Electrical stimulation of the nucleus ceruleus, a small nucleus with widely ranging axons, and the nucleus raphe magnus, a nucleus in the central reticular formation of the medulla, inhibits input from noxious stimulation of the skin, and it also inhibits activities of dorsal-horn neurons receiving mechanoreceptive input. Since it was discovered that pain could be obliterated in this manner, attempts have been made to stop the chronic pain of cancer and other conditions by implanting electrodes in the brain. These can be placed in relevant parts of the brain so that constant stimulation can inhibit the input coming from the region of the pain.

This built-in system for obliterating or reducing pain can normally be brought into play by stress. Furthermore, it has always been known that one pain can mask another. A volley of nerve impulses reaching the brain via the spinothalamic and spinoreticular tracts and causing a moderate degree of pain is stopped when the cells of origin of this tract are inhibited. Experiments have shown that this suppression can be brought about by a more severe pain or by a pain in a larger area of the body, which causes descending inhibition of neurons of the spinal tract. This descending inhibition is the main mechanism of acupuncture analgesia.

The reticular formation consists of a vast number of small interconnected neurons occupying the central area of the brain stem. Parts of the reticular formation, hypothalamus, and thalamus excite the cerebral hemispheres and keep the cerebral cortex active and alert—partly in response to noxious input. In fact, it may be said that pain reaches consciousness in the thalamus. The thalamus receives noxious input from the spinal cord in two regions, a lateral part called the ventrobasal complex and a medial part consisting of several nuclei. The ventrobasal complex is concerned with the accurate temporal and spatial localization of conscious sensation, while the medial nuclei are concerned with the emotional, affective, and autonomic components of pain and other sensations. The ventrobasal nuclei relay impulses to the sensory areas of the postcentral gyrus. Noxious stimuli also cause responses in many areas of the cortex and the deeper islands of gray matter. This is to be expected, for, of all sensations, pain is the least pure sensation: it startles, it excites, and it has unpleasant qualities. All these aspects of pain are added by different parts of the brain.

Central pain. Pain arising within the central nervous system when there is no damage to the body is known as central pain. The most common central pain is due to lesions in or near the thalamus and is called the thalamic syndrome. This condition is characterized by diminution in sensibility as well as severe pain when any stimulus exceeds a certain threshold.

With central pain there is both spontaneous pain and excessive pain on stimulation of all kinds. The pain may occur in the entire half of the body, affecting even visual and auditory inputs, or it may occur in a restricted region, such as the upper limb and side of the face or the lower limb.

Referred pain. The term referred pain is used to describe pain felt in a region where it does not originate but to which it is "referred." It is usually used to mean pain arising in hollow viscera and felt in somatic tissues, such as the body wall. Referred pain is always referred in one direction—from deep to superficial tissues. It is pain referred from an unknown or unfamiliar part of the body to a known or familiar part.

Mingling of visceral and somatic pain pathways

Certain regions of the dorsal horns of the spinal cord receive both nerve fibres from the viscera and nerve fibres reporting noxious events in the skin and musculature. For example, afferent nerve fibres from the heart come to the same regions as those from the muscles and skin of the chest wall and upper limbs. From these two body tissues, visceral and somatic, there is an intermingling of inputs, and there is similar convergence in the thalamus. This anatomical arrangement is likely to form the basis of referred pain, although the mere convergence of impulses from viscera and soma onto the same neurons does not alone account for the false localization of visceral pain. It is probable that in sensory areas of the brain, the skin is served by a large number of neurons, the muscles with fewer, and the viscera with least, the visceral representation in the cortex being very small compared to that of the somatic tissues. It is supposed that, as the input to these sensory regions of the cortex usually comes from the skin and body wall, localization of the visceral input will be to these tissues and not to the viscera, the cortical region of which is small and relatively unused.

Changes in the cerebral cortex. Normally, electrical stimulation of the sensory region of the postcentral gyrus does not cause pain. But in many patients who have a painful state on the opposite side of the body, such as a painful amputation stump or damage to the median nerve of the hand, stimulation of this region reproduces the pain. Pain also arises from stimulation of the white matter deep in this area.

In these cases the character of the sensory region of the cortex changes in such a manner that neurons that normally never cause pain when stimulated now invariably produce the pain from which the patient is suffering. Also, the cortical area subserving the limb enlarges. For instance, the sensory area receiving impulses from the opposite lower limb is normally at the upper end of the postcentral gyrus. If there is a painful amputation of the limb, then the area of cortex in which electrical stimulation induces the pain spreads downward from the normal area to include the trunk area and sometimes the upper limb area.

Perception

To the biologist, the life of animals (including that of humans) consists of seeking stimulation and responding

appropriately. A reflex occurs before an individual knows what struck him, what made him lift a foot or drop an object. It is biologically correct to be alarmed before one knows the reason. It is only after the immediate and automatic response that the cerebral cortex is involved and conscious perception begins.

Perception comes between simple sensation and complex cognitional behaviour. By the time people are able to talk about it, perception has become so automatic that they hardly realize that seeing what they see, hearing what they hear, is an interpretation. Each act of perception is a hypothesis based on prior experience: the world is made up of things people expect to see, hear, or smell, and any new sensory event is perceived in relation to what they already know. People perceive trees, not brown, upright masses and blotches of green against a background of blue, gray, and white. Once one has learned to understand speech, it is all but impossible to hear words as sibilants and diphthongs, sounds of lower and higher frequencies. In other words, recognizing a thing entails knowing its total shape or pattern. This is usually called by its German name, gestalt.

As well as perception of the external environment, there is perception of oneself. Information about one's position in space, for example, comes from vision, from vestibular receptors, and from somatic receptors in the skin and deep tissues. This information is collected in the vestibular nuclei and passed on to the thalamus. From there it is relayed to the central gyri and the parietal region of the cortex, where it becomes conscious perception. (For detailed discussion of the perception of movement, see above *The vestibular system.*)

Central function of the thalamus

GENERAL ORGANIZATION OF PERCEPTION

Perception relies on what are called the special senses—the visual, auditory, gustatory, and olfactory. Each begins with receptors grouped together in sensory end organs, where the sensory input is organized before it is sent on to the brain. At every synapse on a sensory pathway there is an important reorganization of impulses, so that by the time an input arrives at the thalamus, it is far from being the original input that stimulated the receptors.

The afferent parts of the thalamus fall into two divisions: a medial part, which is afferent but not sensory, and a ventral and lateral part, which is sensory. Nerve impulses reaching the medial part are derived from the reticular formation. This pathway is for emotional and other rapid reactions such as surprise, alarm, vigilance, and the readiness to react. The lateral part of the thalamus is a station on the way to areas of the cortex that are specific for each kind of sensation.

There are three somatosensory areas of the cortex (Figure 29). The primary sensory area occupies the postcentral gyrus immediately behind the motor strip. The secondary area is above the Sylvian fissure, behind the secondary motor area. The supplementary area is in the upper part of the parietal lobe on the medial surface of the hemisphere, just behind the primary area.

The primary area receives its input from the ventrolateral thalamus. The secondary area receives somatosensory input from the lateral part of the thalamus and also auditory and visual input from the medial and lateral geniculate nuclei. The primary and secondary areas are reciprocally connected.

The cerebral cortex (and the thalamus as well) is divided between nonspecific and specific sensory areas. Most neurons of the specific regions have small receptive fields in the periphery, respond to only one kind of stimulus, and follow the features of stimulation exactly. Most neurons of the nonspecific regions have large receptive fields and respond to many kinds of stimuli; many do not exactly reproduce the features of the stimulus.

Changes in the sensory areas of the brain

Although different regions of the body are normally represented by specific parts of the somatosensory regions of the cortex, the parts where afferent impulses arrive are not fixed. For example, the leg area is at the top of the postcentral gyrus, but when there is a painful state in the periphery—sciatica, for example—the leg area of the cortex can enlarge and occupy some of the arm area. Furthermore, injury to the peripheral nerves or brain may alter the sensory "map" of the cortex. These changes in the cortex and similar changes in anatomical function are referred to as plasticity.

From the somatosensory area, nerve fibres run to other regions of the cortex, traditionally called association areas. It is thought that these areas integrate sensory and motor information and that this integration allows objects to be recognized and located in space. With these regions acting upon all their inputs, the brain is carrying out those aspects of neural activity that are commonly labeled mental. It must be remembered, though, that researchers have not precisely answered the question of how and where the brain collects messages from all the sensory receptors and then sifts and arranges them so as to give a complete representation of the world and of the individual's place in the world.

ORGANIZATION OF THE SPECIAL SENSES

Of the special senses, the cerebral organization of the visual and auditory senses are better understood than that behind the olfactory and gustatory. For this reason, only the former two are discussed below.

Vision. Most investigations of the visual pathways in the brain have been carried out in the cat.

The area of the human brain concerned with vision comprises the entire occipital lobe and the posterior parts of the temporal and parietal lobes. The primary visual area, also called the striate cortex, is on the medial side of the occipital lobe and is surrounded by the secondary visual area (Figure 31). The visual cortex is sensitive to the position and orientation of edges, the direction and speed of movement of objects in the visual field, stereoscopic depth, brightness, and colour. These parallel functions combine to produce visual perception.

The ganglion neurons of the retina belong to three functional types, called Y-, X-, and W-cells. X-cells are neurons needed for high-resolution vision. Y-cells respond to fast movement, whereas X- and W-cells respond poorly to fast movement. Y-cells are larger than the others and have large peripheral fields; X-cells have small fields. In the retina, 50 to 55 percent of ganglion cells are W-type, 40 percent are X-type, and 5 to 10 percent are Y-type.

As constituent fibres of the optic nerves and optic tracts, X- and Y-cells connect to the lateral geniculate nucleus of the thalamus, while W-cells connect mainly to the superior colliculus of the midbrain. From these regions input from the X-cells goes mainly to the primary visual area, that from the Y-cells goes to the secondary visual area, and that from the W-cells goes to the area surrounding the secondary area. The collicular pathway serves movement detection and direction of gaze. The tract from the lateral geniculate nucleus is the pathway for visual acuity.

The primary area sends fibres back to the lateral geniculate nucleus, the superior colliculus, and the pupillary reflex centre for feedback control of input to the visual areas. It also sends fibres to the secondary area and to the visual area of the temporal lobe. The secondary area sends fibres to the temporal and parietal lobes. Also, fibres cross from visual areas of one cerebral hemisphere to the other in the corpus callosum. This link allows neurons of the two hemispheres with similar visual fields to make direct contact with each other.

Specialized visual neurons of the brain

Neurons of the striate cortex may form the first step in appreciation of orientation of objects in the visual field. It is thought, however, that excitation of cortical neurons is insufficient to account for orientation and that inhibition of other neurons in the visual cortex is also necessary. Whatever the mechanism, it has been found in experiments on cats and monkeys that individual neurons are activated by lines at different angles—for example, at 90 degrees to the horizontal or at an angle of 45 degrees.

Most neurons of the deeper layers are movement analyzers. Some are direction analyzers, activated by a line or an edge moving in one direction and silenced when it changes direction (the changed direction then activating other neurons). One neuron may be excited by a dark line on a bright background and another by a light line on a dark background. In other regions of the striate cortex

there are form analyzers; for example, some are activated by rectangles and others by stars. There are also position neurons, which show a strong response to a spot located in a certain position and a weak response to stimulation of a larger area; others respond only to simultaneous binocular stimulation. The striate cortex provides a fused, binocular picture of the world. There are also colour-specific neurons sensitive to red, green, or blue. Each of these neurons is excited by one colour and inhibited by another.

In the secondary visual area many neurons respond particularly to the direction of moving objects. Neurons activated by colour are not activated by white light. In the part of this area where there are many neurons responding to colour, the periphery of the visual field is not mapped; this is because there are no cones in the periphery of the retina (cones being the colour receptors). The peripheral field is mapped in an area with neurons responding to movement—notably in the region of the superior temporal gyrus.

It seems that one function of the pathway from the superior colliculus to the temporal and parietal cortices is as a tracking system, enabling the eyes and head to follow moving objects and keep them in the visual field. The pathway from the geniculate nucleus to the primary visual area may be said to perceive what the object is and also how and in what direction it moves.

Some neurons in the parietal cortex become active when a visual stimulus comes in from the edge of the visual field toward the centre, while others are excited by particular movements of the eyes. Other neurons react with remarkable specificity—for example, only when the visual stimulus approaches from the same direction as a stimulus moving on the skin of the animal, or during the act of reaching for an object and tracking it with the hand. These parietal neurons greatly depend on the state of vigilance. In monkeys that are apparently merely waiting for something to happen or that have nothing to which to turn their attention, the neurons are inactive or minimally active. But when the animal is looking at a visual target whose change it has to detect in order to obtain a reward, the parietal neurons become active.

A great number of neurons of the middle temporal area are sensitive to the direction of movement of a visual stimulus and to the size of an object. In the inferior temporal area are neurons concerned with shape and colour. The neurons of the superior temporal polysensory area respond best to moving stimuli—in particular to movements away from the centre of the visual field. Both these areas are concerned with the conjunction of visual stimuli and movement.

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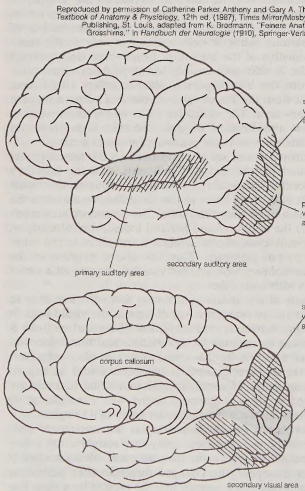


Figure 31: (Top) Lateral and (bottom) medial views of the cerebral hemispheres, showing visual and auditory areas.

Hearing. Much of the knowledge of the neurological organization of hearing has been acquired from studies on the bat, an animal that relies on acoustic information for its livelihood.

Specialized auditory neurons

In the cochlea (the specialized auditory end organ of the inner ear) the frequency of a pure tone is reported by the location of the reacting neurons in the basilar membrane, and the loudness of the sound is reported by the rate of discharge of nerve impulses. From the cochlea the auditory input is sent to many auditory nuclei. From there, it is sent on to the medial geniculate nucleus and the inferior colliculus, as with the relay stations of the retina. The auditory input finally goes to the primary and secondary auditory areas of the temporal lobes.

The auditory cortex provides the temporal and spatial frames of reference for the auditory data that it receives. In other words, it is sensitive to aspects of sound more complex than frequency. For instance, there are neurons that react only when a sound starts or stops. Other neurons are sensitive only to particular durations of sound. When a sound is repeated many times, some neurons respond, while others stop responding. There are neurons that are sensitive to differences of the intensity and timing of sounds reaching the two ears. Certain neurons that never respond to a note of constant frequency respond when the frequency falls or rises. There are others that respond to the rate of change of frequency, providing information on whether distance from the source of a sound is increasing or decreasing. Some neurons respond to the ipsilateral ear, others to the contralateral, and yet others to both ears.

Emotion and behaviour

PATHWAYS IN THE BRAIN

Importance of the hypothalamus

In order to carry out the correct behaviour—that is to say, correct in relation to the survival of the individual and the group—humans and other higher animals developed innate drives, desires, and emotions, and the ability to remember and learn. These fundamental features of living depend on the entire brain, yet there is one part of the brain that organizes metabolism, growth, sexual differentiation, and the desires and drives necessary to achieve these aspects of life. This is the hypothalamus and a region in front of it comprising the septal and preoptic areas. That such basic aspects of life might depend on a small region of the brain was conceived in the 1920s by the Swiss physiologist Walter Rudolf Hess and later amplified by Erich von Holst. Hess implanted electrodes in the hypothalamus and in septal and preoptic nuclei of cats, stimulated them, and observed the animals' behaviour. Finally, he made minute lesions by means of these electrodes and again observed the effects on behaviour. With this technique he showed that certain kinds of behaviour were organized essentially by just a few neurons in these regions of the brain. Later, von Holst stimulated electrodes by remote control after placing the animals in various biologically meaningful conditions.

When such acts result from the artificial stimulation of the neurons, the accompanying emotion also occurs, as do the movements expressing that emotion.

The hypothalamus, in company with the pituitary gland, controls the emission of hormones. It is in control of body temperature, maintains the blood pressure and the rate and force of the heartbeat, and controls the body's need for water and electrolytes. The maintenance of these and other changing events within normal limits is called homeostasis; this includes behaviour aimed at keeping the body in a correct and thus a comfortable environment.

The hypothalamus is also the centre for organizing the activity of the two parts of the autonomic system, the parasympathetic and the sympathetic (see above *The au-*

tonomic system). Above the hypothalamus, regions of the cerebral hemispheres most closely connected to the parasympathetic regions are the orbital surface of the frontal lobes, the insula, and the anterior part of the temporal lobe. The regions most closely connected to the sympathetic regions are the anterior nucleus of the thalamus, the hippocampus, and the nuclei connected to these structures.

In general, the regions of the cerebral hemispheres that are closely related to the hypothalamus are those parts that together constitute the limbic lobe, first considered as a unit and given its name in 1878 by the French anatomist Paul Broca. Together with related nuclei it is usually called the limbic system, consisting of the cingulate and parahippocampal gyri, the hippocampus, the amygdala, the septal and pre-optic nuclei, and their various connections.

The autonomic system also involves the hypothalamus in movement. The expression of emotion and signaling to others depend greatly on the sympathetic nervous system. Emotional expression is also carried out by regions of the cerebral hemispheres above the hypothalamus and by the midbrain below it.

HYPOTHALAMIC FUNCTIONS

Emotion. A great deal of behaviour in social animals, such as humans, involves social interaction. Although the whole brain contributes to social activities, certain parts of the cerebral hemispheres are particularly concerned. The operation of leucotomy, cutting through the white matter that connects parts of the frontal lobes with the thalamus, upsets this aspect of behaviour. This operation used to be performed for severe depression or obsessional neuroses. After the operation, patients lacked the usual inhibitions that were socially demanded, appearing to obey the first impulse that occurred to them. They told people what they thought of them without regard for the necessary conventions of civilization.

Which parts of the cerebral hemispheres produce emotion has been learned from patients with epilepsy and from operations under local anesthesia in which the electrical stimulation of the brain is carried out. The limbic lobe, including the hippocampus, is particularly important.

Inducing changes in emotion

Stimulating certain regions of the temporal lobes produces an intense feeling of fear or dread; stimulating nearby regions produces a feeling of isolation and loneliness, other regions a feeling of disgust, and yet others intense sorrow, depression, anxiety, and, occasionally, guilt. An ecstatic feeling can also occur in which it appears to patients that all problems have been or are just about to be solved.

In addition to these regions of the cerebral cortex and the hypothalamus, regions of the thalamus also contribute to the genesis of emotion. The hypothalamus itself does not initiate behaviour; that is done by the cerebral hemispheres—insofar as one may abstract any single part from the whole.

The defense reaction: fighting and fleeing. When certain neurons of the hypothalamus are excited, an animal either becomes aggressive and eventually attacks, or it flees. These two opposite ways of behaving are together called the defense reaction; both are in the repertoire of all vertebrates. The defense reaction is accompanied by strong sympathetic activity. Aggression is also influenced by the production of androgen hormones.

Mating. The total act of copulation is organized in the anterior part of the hypothalamus and the neighbouring septal region. In the male, erection of the penis and ejaculation are organized in this area, which is adjacent to the area for urination. Under normal circumstances the neurons that organize mating behaviour do so only when they receive relevant hormones in their blood supply. But when the septal region is electrically stimulated in conscious patients, sexual emotions and thoughts are produced.

There are visible differences between the male and female sexes in nuclei of the central nervous system related to reproduction. These differences are a form of sexual dimorphism.

Urination and defecation. Electrical stimulation in cats of regions in, and related to, the anterior part of the hypothalamus can induce the behaviour of expelling or retaining urine and feces. When electrodes planted in these regions are stimulated by radio waves, the cat stops whatever it is doing and behaves as though it were going to urinate or defecate. It goes through its usual behaviour of digging a hole, squatting, and assuming the correct posture, and then it passes urine or feces. At the end, it even goes through its customary ritual of hiding its excreta.

Eating and drinking. The eating and drinking centres are in the lateral and ventromedial regions of the hypothalamus, although such basic aspects of living concern most of the brain. If the lateral region is experimentally destroyed, the animal takes less food or stops eating altogether; if the ventromedial region is destroyed, it eats enormously. When neurons of the lateral region are electrically stimulated, the animal eats, and when those of the ventromedial area are stimulated, it stops eating. There is an increase in the activity of these neurons when a monkey looks at food, but only when it is hungry. In the lateral region are receptors that monitor blood glucose. They are stimulated into activity only when the blood glucose is low; satiety stops their response.

Hunger does not depend only on these glucose receptors. Severe hunger is associated with contractions of the stomach, which are felt almost as a sensation of pain. Yet neither is this an essential mechanism for feeling hungry, as patients who have had total removal of the stomach still feel hunger. In experiments in rats, it is found that stress may make the animal either increase or reduce the amount it eats. This is probably the same in humans.

When certain neurons in the same regions of the hypothalamus are experimentally destroyed, animals lose the urge to drink, although they continue to eat normally. Stimulation of these neurons make them drink excessively. The control of drinking depends on osmoreceptors throughout the hypothalamus. When the receptors detect a minimal increase in the concentration of dissolved substances in the extracellular fluid, which indicates cellular dehydration, the animal feels thirsty. A less important contributor is a reduction in blood volume. Dryness of the mouth can also be a component of thirst, noted by receptors in the mucous membrane. The feeling of having drunk enough depends not only on the hypothalamic neurons but also on receptors in the wall of the stomach, which report when the stomach is full.

Both glucose receptors and osmoreceptors are sensitive to the temperature of the passing blood. When the temperature starts to rise, one feels thirsty but not hungry; cooling the blood makes one feel hungry.

Temperature regulation. To maintain homeostasis, heat production and heat loss have to be balanced. This is achieved by both the somatomotor and sympathetic systems. The obvious behavioral way of keeping warm or cool is by moving into a correct environment. The posture of the body is also used, as is clearly seen in the behaviour of the cat. When lying in front of a fire, it is fully stretched out—in physiological terms, extended—thus presenting a large surface to the ambient air and losing heat. When it is cold, it curls itself up into a small volume—in physiological terms, fully flexed—thus presenting the smallest area to the ambient temperature. Humans also use these somatomotor methods.

The most important part of the nervous system for controlling body temperature is the sympathetic system. On a long-term basis, when the climate is cold, the sympathetic system produces heat by its control of certain fat cells called brown adipose tissue. From these cells, fatty acids are released, heat being produced by their chemical breakdown.

Body temperature fluctuates regularly within 24 hours; this is a type of circadian rhythm (see below). It also fluctuates in rhythm according to the menstrual cycle. During fever, the body temperature is set at a higher point than normally.

Reward and punishment. In a fundamental discovery made in 1954, James Olds and Peter Milner found that stimulation of certain regions of the brain of the rat acted as a reward in teaching the animals to run mazes and solve problems. The conclusion from such experiments is that stimulation gives the animals pleasure. The discovery

Reward centres of the brain

has also been confirmed in humans. These regions are called pleasure or reward centres. One important centre is in the septal region, and there are reward centres in the hypothalamus and in the temporal lobes of the cerebral hemispheres as well. When the septal region is stimulated in conscious patients undergoing neurosurgery, there are feelings of pleasure, optimism, euphoria, and happiness.

Regions of the brain also clearly cause rats distress when electrically stimulated; these are called aversive centres. However, the existence of an aversive centre is less certain than that of a reward centre. Electrodes stimulating neurons or neural pathways may cause an animal to have pain, anxiety, fear, or any unpleasant feeling or emotion. These pathways are not necessarily centres having the function of providing punishment in the sense that a reward centre provides pleasure. Therefore, it is not definitely known that connections to aversive centres punish the animal for biologically wrong behaviour, but it is thought that correct behaviour is rewarded by pleasure provided by neurons of the brain.

Circadian rhythms. Living organisms have inevitably become adapted to the orderly rhythms of the universe. These biologic cycles are called circadian rhythms, from the Latin *circa* ("about") and *dies* ("day"). They are essentially endogenous, built into the central nervous system. The rhythmical activities usually covered by the word circadian are sleeping and waking, rest and activity, taking in of fluid, formation of urine, body temperature, cardiac output, oxygen consumption, cell division, and the secreting activity of endocrine glands. The rhythms are upset by shift work and by rapid travel into different time zones. After long journeys it takes several days for the endogenous rhythm generator to become synchronized to the local time.

The alternation of night and day has been important in inducing rhythms affecting many physiological functions. Even in isolation, from clues giving information about light and dark, rhythms related to the time of day are maintained. Curiously, the endogenous sleep–wake rhythm deviates slightly from the Earth's 24-hour cycle; a bird's endogenous cycle is 23 hours, and the human cycle is 25 hours. In both cases the cycle is corrected by features of the environment. Such synchronizing agents are called zeitgebers ("time givers"). One zeitgeber is the Earth's magnetic field, which changes on a 24-hour cycle as the Earth turns on its axis. More obvious and important a zeitgeber is the alternation of dark and light.

One hypothalamic nucleus that is essential for the rhythms of sleeping, waking, rest, and activity is the suprachiasmatic nucleus. It is not surprising that this nucleus is adjacent to the incoming fibres from the eye, for the light–dark cycle appears to be the most important zeitgeber for circadian rhythms. The suprachiasmatic nucleus is most active in light. In experiments on the hamster, when the nucleus is destroyed, the rhythms of general activity, drinking, sleeping, waking, body temperature, and some endocrine secretion are disrupted. (P.W.N.)

Higher cerebral functions

The neurons of the cerebral cortex constitute the highest level of control in the hierarchy of the nervous system. Consequently, the terms higher cerebral functions and higher cortical functions are used by neurologists and neuroscientists to refer to all conscious mental activity of the kind normally described as thinking, remembering, and reasoning and to complex volitional behaviour such as speaking and carrying out purposive movement. They also refer to the processing of information in the cerebral cortex, most of which takes place unconsciously.

ANALYTICAL APPROACHES

Neuroscientists investigate the structure and functions of the cerebral cortex, but the processes involved in thinking are also studied by cognitive psychologists, who group the mental activities known to the neuroscientist as higher cortical functions under the headings cognitive function or human information processing. From this perspective, complex information processing is the hallmark of cognitive function. Cognitive science attempts to identify and define the processes involved in thinking without regard to their physiological basis. The resulting models of cognitive function resemble flowcharts for a computer program more than neural networks—and, indeed, they frequently make use of computer terminology and analogies.

Neuropsychology

The discipline of neuropsychology, by studying the relationship between behaviour and brain function, bridges the gap between neural and cognitive science. Examples of this bridging role include studies in which cognitive models are used as conceptual frameworks to help explain the behaviour of patients who have suffered damage to different parts of the brain. Thus, damage to the frontal lobes can be conceptualized as a failure of the "central executive" component of working memory, and a failure of the "generate" function in another model of mental imagery would fit with some of the consequences of left parietal lobe damage.

The analysis of changes in behaviour and ability following damage to the brain is by far the oldest and probably the most informative method adopted for studying higher cortical functions. Usually these changes take the form of what is known as a deficit—that is, an impairment of the ability to act or think in some way. With certain provisos, one can assume that the damaged part of the brain is involved in the function that has been lost. However, people vary considerably in their abilities, and most brain lesions occur in subjects whose behaviour has not been formally studied before they become ill. Lesions are rarely precisely congruent with the brain area responsible for a given function, and their exact location and extent can be difficult to determine even with modern imaging techniques. Abnormal behaviour after brain injury, therefore, is often difficult to attribute to precisely defined damage or dysfunction.

It would also be naive to suppose that a function is represented in a particular brain area just because it is disrupted after damage to that area. For example, a tennis champion does not play well with a broken ankle, but this would not lead one to conclude that the ankle is the centre in which athletic skill resides. Reasonably certain conclusions about brain–behaviour relationships, therefore, can be drawn only if similar well-defined changes occur reliably in a substantial number of patients suffering from similar lesions or disease states.

Pioneering studies of the brain

The most prominent series of observations clearly belonging to modern neuropsychology were made by Paul Broca in the years following 1861. He reported the cases of several patients whose speech had been affected following damage to the left frontal lobe and provided autopsy evidence of the location of the lesion. In making his famous statement, "We speak with the left hemisphere," he explicitly recognized the left hemisphere's control of language, one of the fundamental phenomena of higher cortical function.

In 1874, the German neurologist Carl Wernicke described a case in which a lesion in a different part of the left hemisphere, the posterior temporal region, affected language in a different way. In contrast to Broca's cases, language comprehension was more affected than language output. This meant that two different aspects of higher cortical function had been found to be localized in different parts of the brain. In the next few decades there was a rapid expansion in the number of cognitive processes studied and tentatively localized.

Wernicke was one of the first to recognize the importance of the interaction between connected brain areas and to think of higher cortical function as the buildup of complex mental processes through the coordinated activities of local regions dealing with relatively simple, predominantly sensory-motor functions. In doing so, he opposed the view of the brain as an equipotential organ acting en masse. Since his time, scientific fashion has swung between the localization and mass-action theories. Major changes in the 20th century have been both quantitative, with vast increases in knowledge, and methodological, with the discovery of new ways of studying the brain's anatomy and physiology and the introduction of better quantitative methods in the study of behaviour.

HEMISPHERIC ASYMMETRY, HANDEDNESS, AND CEREBRAL DOMINANCE

Broca's declaration that the left hemisphere is predominantly responsible for language-related behaviour is only the clearest and most dramatic example of an asymmetry of function in the human brain. This functional asymmetry is related to hand preference and probably to anatomical differences, although neither relationship is simple.

Dominance of the left hemisphere for language

Evidence from a number of converging sources, notably the high incidence of the language disturbance known as aphasia after left- but not right-hemisphere damage, indicates that the left hemisphere is dominant for the comprehension and expression of language in close to 99 percent of right-handed people. At least 60 percent of left-handed and ambidextrous people also have left-hemisphere language, but up to 30 percent have predominantly right-hemisphere language. The remainder have language represented to some degree in both hemispheres.

The posterior temporal region of the brain, which in the dominant hemisphere is one of the regions responsible for language, is physically asymmetrical; specifically, the area known as the planum temporale is larger in the left hemisphere in most people. This asymmetry is more common in right-handers, while left-handed individuals are likely to have more nearly symmetrical brains. Reduced anatomical asymmetry has also been found in people with right-hemisphere dominance for speech and in some developmental dyslexics (people with reading disorders). These results point to some relationship between handedness, cerebral dominance for language, anatomical asymmetry in the temporal lobe, and some aspects of language competence. Certainly, there is a tendency for right-handedness, left-hemisphere dominance for language, and a larger left planum temporale to go together. However, there are exceptions; for example, a few right-handers are right-hemisphere dominant for speech, and some right-handers who have left-hemisphere speech do not have a larger left planum temporale. In subjects who are atypical in one of these respects—for example, by being left-handed—the relationship between handedness, cerebral dominance, and anatomical asymmetry is much less consistent. It follows, therefore, that language is not invariably located in the hemisphere opposite the dominant hand or in the hemisphere with the larger planum temporale.

Studies of patients in whom the corpus callosum (the bundle of nerve fibres connecting the two halves of the brain) has been severed, allowing the two hemispheres to function largely independently, have revealed that the right hemisphere has more language competence than was hitherto supposed. These patients show evidence of comprehension of words presented to the isolated right hemisphere, although that hemisphere is not able to initiate speech. The speech of patients with a lesion of the right hemisphere may lack normal melodic quality, and they may have difficulty expressing and understanding such things as emotional overtones. They may also have difficulty appreciating some of the more subtle, connotative aspects of language, such as puns, figures of speech, and jokes. Nevertheless, the dominance of the left hemisphere for language, particularly the syntactic aspects of language and language output, is the clearest example yet discovered of the lateralization of higher cortical function.

The left hemisphere also appears to be more involved than the right in the programming of complex sequences of movement and in some aspects of awareness of one's own body. Thus, the disorders known as ideomotor and ideational apraxia are more common after left-hemisphere damage. In these disorders, the patient has difficulty carrying out actions involving several movements or the manipulation of objects in an appropriate and skillful way. The difficulty appears to be in programming the motor system to run off the sequence of movements required to perform a complex action in the appropriate order and with the appropriate timing.

A third category of deficits associated with left-hemisphere damage, disorder of the body image, is much more difficult to define. It includes a disorder called finger agnosia, in which the individual does not appear to "know" which finger is which, being unable to indicate which one the examiner touches without the aid of vision. Confusion of right and left is also found after left-hemisphere damage, making it appear that the left hemisphere is largely responsible for collating somatosensory information into a special awareness of the body called the body image. The phenomenon of the phantom limb, whereby patients "feel" sensations in amputated limbs, indicates that the brain's internal representation of the body may persist intact for some time after the loss of a body part. This internal representation appears to be maintained chiefly by the left hemisphere.

The special functions of the right hemisphere were recognized later than those of the left hemisphere, although a case of "imperception" reported by the English neurologist John Hughlings Jackson in 1876 foreshadowed later findings. Jackson's patient, who had a lesion in the posterior part of the right hemisphere, lost her way in familiar surroundings, failed to recognize familiar places and people, and had difficulty in dressing herself—all of which became well-recognized consequences of right-hemisphere damage. The right hemisphere, then, appears to be specialized for some aspects of higher-level visual perception, spatial orientation, and route finding (sense of direction), and it probably plays a dominant role in the recognition of objects and faces. The specialization of the right hemisphere, however, is less absolute than that of the left hemisphere in that these skills are less lateralized than language.

Specialized functions of the right hemisphere

There has been considerable speculation as to why the human brain should be functionally asymmetrical. Initially, both functional and anatomical asymmetry were thought, like language, to be a uniquely human trait, but less pronounced asymmetries have now been found in lower animals. One suggestion is that it is necessary to have language represented in a single hemisphere to avoid competition between the hemispheres for control of the muscles involved in speech. Another suggestion is that it is efficient to have the language system represented in a restricted area on one side of the brain because information needs to be transferred over short distances and fewer connections. A third suggestion is that the dominance of the left hemisphere over the right hand and skilled movement preceded its dominance over language. According to this view, language subsequently developed in the same hemisphere because language implies speech, which requires precise programming of sequences of movement in the articulatory musculature. All these views have something to recommend them, but none has been conclusively proved correct or has been generally accepted. Also, there remain some facts that are difficult to explain by any theory. For example, all the above theories would predict that bilateral and, in some cases, right-hemisphere language representation would be disadvantageous, but this does not seem to be generally true.

LANGUAGE

The language area of the brain surrounds the Sylvian fissure in the dominant hemisphere (Figure 32). This area

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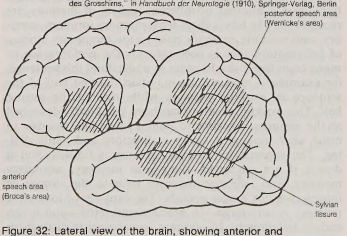


Figure 32: Lateral view of the brain, showing anterior and posterior speech areas (Broca's area and Wernicke's area).

Broca's and Wernicke's language areas

is divided into two major components named after the pioneers Paul Broca and Carl Wernicke. Broca's area lies in the third frontal convolution, just anterior to the face area of the motor cortex and just above the Sylvian fissure. This is often described as the motor, or expressive, speech area; damage to it results in Broca's aphasia, a language disorder characterized by deliberate, telegraphic speech with very simple grammatical structure though the speaker may be quite clear as to what he wishes to say and may communicate successfully. Wernicke's area is in the superior part of the posterior temporal lobe; it is close to the auditory cortex and is classically considered to be the receptive language, or language comprehension, centre. A patient with Wernicke's aphasia has difficulty understanding language; his own speech is typically fluent but is empty of content and characterized by circumlocutions, a high incidence of vague words like "thing," and sometimes neologisms and senseless "word salad." The entire posterior language area extends into the parietal lobe and is connected to Broca's area by a fibre tract called the arcuate fasciculus. Damage to this tract has been implicated in conduction aphasia, a disorder in which the patient can understand and speak but has difficulty in repeating what is said to him. The suggestion is that, in this condition, language can be comprehended by the posterior zone and spoken by the anterior zone, but it can not be easily shuttled from one to the other.

Distinction between aphasia and apraxia

It is important to note that aphasia is a disorder of language and not of speech (although an apraxia of speech, in which the programming of motor speech output is affected, may accompany aphasia). The writing and reading of aphasic patients, therefore, usually commits the same type of error as their speech, while the reverse is not the case. Isolated disorders of writing (dysgraphia) or, more commonly, reading (dyslexia) may occur as well, but these reflect a disruption of the additional processing required for these activities over and above that required for language.

One particular form of dyslexia deserves mention, as it is a clear example of a disconnection syndrome—a disorder resulting from the disconnection of two areas of the brain rather than from damage to a "centre." This is dyslexia without dysgraphia, or letter-by-letter reading, so called because it is not associated with writing disturbance and because the patients tend to attempt to read by spelling words out loud letter by letter. It usually results from a lesion in the posterior part of the left hemisphere that disconnects the visual areas of the brain from the language areas. This renders the language areas effectively blind, so that they cannot be brought to bear on visible language such as the written word. Writing is unaffected because the right hand is still connected to the left hemisphere, and, if letters can be spoken out loud correctly (which is not always the case), the patient will be able to hear himself say them and reintegrate them into words. Disconnection syndromes are an important concept in understanding behavioral disorders associated with brain damage. The possibility that deficits are caused by disconnection must always be borne in mind.

MEMORY

Memory is one of the most widely studied cognitive functions, and a number of different aspects of memory are recognized. The labels short-term memory, primary memory, and working memory refer to the temporary storage of information that is necessary for the performance of many cognitive tasks. In order to understand this sentence, for example, a reader must maintain the first half of the sentence in working memory while reading the second half. This working memory has been graphically described as the memory one uses to hold a telephone number in mind after looking it up in a directory and while dialing. The capacity of working memory is limited, and it decays if not rehearsed. Long-term memory, secondary memory, and reference memory refer to the storage of information for longer periods. The capacity of long-term memory is very large—in practice unlimited—and it can endure indefinitely. In addition, psychologists distinguish episodic memory, a memory of specific events or episodes normally described by the verb remember, from semantic memory, a knowledge of facts normally said to be known rather than remembered.

Importance of the limbic system

Almost certainly, memory is stored over wide areas of the brain rather than in any single location. However, amnesia, a disorder of memory, can occur after localized bilateral lesions in the limbic system—notably the hippocampus on the medial side of the temporal lobe, some parts of the thalamus, and their connections. This probably implies that these structures, rather than actually constituting a memory store, are important in the laying down of memories and in their recall when needed. Memory impairment resulting from damage in these areas is a disorder of long-term episodic memory and is predominantly an anterograde amnesia—that is, it typically affects the memory of events occurring after the illness or accident causing the amnesia more than it does memories of the past. Substantial retrograde amnesia (loss of the memory of events occurring before the onset of amnesia) rarely if ever occurs without significant anterograde amnesia as a result of brain damage, although it may occur alone in psychiatric illness.

Although amnesia is a disorder of long-term episodic memory and leaves short-term and semantic memory intact, both of the latter can be affected by brain damage. Some parietal lobe lesions may affect short-term memory without affecting long-term memory; this fact has contributed to a revision of the old theory that there are distinct short- and long-term stores, the latter being accessible only via the former. It has been suggested that short-term memory impairment—at least for verbal material—can be further subdivided into auditory and visual domains; however, these disorders manifest themselves in difficulty in understanding spoken and written language rather than in memory impairment (*i.e.*, they appear more like aphasia and dyslexia). Impairment of semantic memory, too, results in an impairment that resembles a loss of concepts or a language deficit more than it resembles what would usually be described as a memory impairment. Some forms of visual agnosia have been interpreted as semantic memory impairment, since the patients are unable to recognize objects such as chairs because they no longer "know" what chairs are or what they look like (or can no longer access that knowledge).

EXECUTIVE FUNCTIONS OF THE FRONTAL LOBES

The frontal lobes are the part of the brain most remote from sensory input and whose functions are most difficult to capture. They can be thought of as the executive that controls and directs the operation of the brain systems dealing with cognitive function. Indeed, the deficits seen after frontal lobe damage have been described as a "dysexecutive syndrome."

Consequences of damage to the frontal lobes

Frontal lobe damage can affect people in any of several ways, and the results are at once subtle and drastic. On the one hand, they may have difficulty initiating behaviour, in extreme cases being virtually unable to move or speak but more often simply having difficulty in getting started on a task. On the other, they may perseverate, being apparently unable to stop a behaviour once started. Rather than appearing apathetic and hypoactive, they are uninhibited, rude, and boorish. Such people may also have difficulty in planning and problem solving and may be incapable of creative thinking. Mild cases of this deficit can be revealed by a difficulty in solving mental arithmetic problems that are couched in words, even though it can be shown that the patient is capable of remembering the question and performing the required calculation. In such cases it appears that the patient simply cannot work out what to do, a difficulty described as a failure to select the appropriate cognitive strategy.

A unifying theme in these disorders is the notion of inadequate control or organization of pieces of behaviour that may in themselves be well formed. Frontal lobe patients are easily distracted. Although their deficits may be superficially less dramatic than those associated with posterior lesions, they can have a drastic effect on everyday function. Irritability and personality change are also frequently seen after frontal lobe damage. (G.Ra.)

NERVOUS SYSTEM DISEASES AND DISORDERS

Everything that the human being senses, considers, and effects and all the unlearned reflexes of the body depend upon the functioning of the nervous system. The skeleton and muscles support and transport the body, the heart sends it nourishment through the blood, and the alimentary system and lungs provide the nutrients; but the nervous system contains the epitome of the human being—the mind—and commands all perception, thought, and action. Its disturbance through disease or other malfunction leads to changes felt throughout the body. The most common or important of those diseases are discussed in this section.

Distinction between neurological and psychiatric illness

A distinction is usually drawn between structural or biochemical diseases of the nervous system (the province of the neurologist) and diseases of the mind (requiring the attention of a psychiatrist). This distinction is not, of course, absolute. Many organic brain diseases cause disorders of thought or mood, while the disorders of function that characterize mental disease are profoundly influenced by chemical factors. This section will be confined to those conditions generally regarded as organic nervous disease.

The first part describes the methods whereby neurologists obtain information about the problem—in other words, the history, the examination of the patient, and the laboratory investigations that can be employed. Next the anatomical sites of neurological disease are described, along with the principles used in localizing a disease within the nervous system. The third part gives an overview of pathological processes. Finally, an account is presented of the diseases of the nervous system, using a general classification based upon the primary or major site of the disease.

This scheme is not always possible to follow closely. For example, multiple sclerosis can affect the white matter of the cerebrum, the optic nerves, the cerebellum, or the spinal cord in any patient, so that allocating the disease to any one section must necessarily be arbitrary. Also, metabolic, toxic, inflammatory, and neoplastic diseases may behave similarly. The rule followed here is that the occurrence of various pathologies at different sites are recorded in the discussion of diseases affecting those sites, but a full description is given only in that part dealing with the site that the disease in question affects most consistently.

Acquisition of data

HISTORY

An old saying in medicine, "Listen to the patient; he is telling you the diagnosis," is especially true in neurology. The patient's description of his symptoms is the most valuable tool that the physician has for learning the nature and location of the disease. The patient who cannot give a history owing to coma or loss of speech presents a difficult challenge indeed.

Following are the symptoms most commonly presented to neurologists, with notes on their localizing value.

Symptoms of cortical or cerebral disease. *Altered consciousness.* One's ability to notice, attend to, and react to the environment is not an on–off phenomenon but a continuum. From full alertness a person can descend through drowsiness to stupor, a condition in which awareness is greatly reduced and the best motor response to stimulation is a groan or other vocal (but not verbal) reaction.

Coma

Deeper levels pass through light coma, in which strong stimulation produces only a clumsy motor response, to deep coma, in which there is only a reflex movement or no response at all. Such depression of consciousness occurs when there is impairment of the functions of the brain-stem reticular activating system or of the whole of the cerebral cortex. Brain-stem disorders can cause coma if the brain stem is compressed by other parts of the brain swollen through disease or if it is afflicted by local disease such as encephalitis, stroke, and concussion.

Diseases of the cortex causing coma include poisoning by sedative drugs, lack of glucose or oxygen in the blood, hemorrhage into the brain, and certain rare infiltrative disorders in which descent through the levels of consciousness occurs over weeks or months. Brief periods of unconsciousness, of which the patient may not be aware, occur in many forms of epilepsy, narcolepsy, repeated attacks of low blood sugar, and reduction in the supply of blood to the brain—particularly the brain stem.

Epilepsy is a condition in which excessive discharges of the neurons of the cerebral gray matter occur, causing maximal activation (rarely inhibition) of parts or all of the brain. This commonly causes visible seizures, but in a variety of epilepsy called petit mal or absence attacks, altered consciousness may be the only symptom. Disorders of sleep include inability to fall asleep or to stay asleep. This is seldom evidence of a neurological disorder and is commonly a psychiatric problem. Increased sleepiness, or hypersomnia, may be due to the causes of drowsiness mentioned above or to narcolepsy (see below *Diseases and disorders: The cranial nerves and brain stem*). Another cause of daytime drowsiness is sleep apnea, a disturbance of nocturnal sleep due to frequent brief episodes of obstructed breathing.

Headache. This is a common complaint of neurology patients. Tension headache is considered to be due to prolonged excessive contraction of the muscles that run front-to-back over the skull; this muscular tension often reflects mental tension. A persistent pressing or pulling pain, often with a throbbing component, is usually described. Migraine headaches may be combined with the foregoing or may be present as a throbbing, pounding pain with marked scalp tenderness, nausea and vomiting, dislike of noise and light, and irritability. (For further discussion of migraine, see below *Diseases and disorders: The cerebrum.*)

When pressure inside the cranium is increased, pain-sensitive structures in and around the brain are distorted and cause pain to be felt in an ill-localized area but often identifiably at the front or back of the head. This traction headache is potentially serious, since it may be caused by brain swelling, infection, bleeding, tumour, or obstructed flow of cerebrospinal fluid. Also, pain may be felt in the head region although the disorder causing the pain is situated elsewhere; an example is the facial pain sometimes felt with lack of blood to the heart. Local disease of such cranial structures as the jaw joints, the paranasal sinuses and teeth, the middle ear, and the skull bones themselves may also generate pain, requiring a careful, probing history in order to be identified as the cause of the headache.

Traction headache

Loss of memory. This symptom may have causes that are trivial or important. Poor concentration owing to preoccupation, fatigue, or depression is the most common cause, but widespread brain disease, vitamin deficiency, epilepsy, and dementia (loss of intellectual power) would have to be considered. When the period of memory loss is well defined, prominent causes are trauma to the head, seizures, poisoning (*e.g.*, with alcohol), and brief episodes of inadequate perfusion of the brain with blood. Some patients with severe mental problems such as hysteria claim to have totally lost their memory for past events and even for their own identities; this symptom is not encountered in people with organic brain disease.

Dementia

Disorders of concentration, attention, planning ability, and forethought—often combined with impaired social behaviour and emotional control and with reduced capacity to learn new things—characterize the problems of patients with dementia, a condition of global impairment of the highest intellectual powers. The most common single cause is Alzheimer's disease. Since dementia is the third most common cause of death (after diseases of the blood vessels and cancers), and since the average age of the Western Hemisphere population is increasing, dementia is attaining great importance in medical and social research. (See also below *Diseases and disorders: The cerebrum.*)

Patients with dementia—and those with almost any more localized brain disorder or general medical disease—are

at risk of developing a related but more acute syndrome called confusion or acute brain syndrome. In this case, patients lose their orientation in time, space, and person; they may show altered levels of consciousness, emotional instability sometimes amounting to terror, physical excitability, and agitation and disorderliness, as well as hallucinations and delusions to which they hold tenaciously despite reasonable counterargument. Of all the causes of acute brain syndrome, generalized metabolic diseases and intoxication with sedative drugs (including alcohol) are the most common.

Aphasia

Language and speech deficits. Aphasia is a failure to use language in communication. It is caused by damage to the part of the brain that controls language function—namely, the area encompassed by the back of the frontal lobe, the front of the parietal lobe, and the upper surface of the temporal lobe (usually on the left hemisphere but on the right in a small proportion of left-handed people; see above *Functions of the human nervous system: Higher cerebral functions*). Patients with aphasia may know exactly what they want to say, but they are unable to express it in spoken (and often written) words. With disease affecting the Wernicke's area farther back on the temporal lobe, the problem may be in comprehending the meaning of spoken or written language, so that normal speech sounds like a foreign tongue. Strokes are the most common cause of aphasia, but any focal brain disease can be responsible.

Similar problems of comprehension are apraxia and agnosia. Apraxia is an inability to perform a purposeful action; agnosia is a failure to comprehend the significance of a nonlanguage stimulus. Shown a comb or a key, an apraxic patient may be able to name it but may not know how to use it. Hearing a trumpet, an agnosic patient may be unable to recognize the origin of the sound.

Dysarthria, or difficulty in articulation, usually has a local cause in the nerves and muscles in and around the mouth or in their central connections. Problems in the production of speech sounds, called dysphonia, often indicate a problem affecting the larynx or the nerves and muscles of that structure. Since the cranial nerves supplying these areas originate in the brain stem, neurological disease of that region may be a cause.

Nonspecific symptoms. Alteration in mood is common in association with neurological disease, either as a result of the pathological process itself or of the patient's reaction to his awareness of disease. Although depression is most common, unusual euphoria or mood swings may occur with disease of the frontal lobes of the brain. Other nonspecific symptoms of brain disease are impairment of recent and (less often) remote memory, concentration, attention, energy, comprehension of concepts, reasoning, logical thinking, and ability to plan ahead. Any or all of these are impaired in patients with dementia (see above).

Pain is another important symptom. Although the central nervous system is not supplied with sensory fibres that report sensations of pain, severe pain can result from thalamic strokes. Also, headache, one of the most common symptoms expressed by patients, has both central and peripheral components, and many disorders affecting the peripheral nerves and muscles are painful. Neuralgias, or attacks of pain along the sensory nerves, are due to irritation of some of the cranial nerves or spinal roots. In each case the quality, severity, timing, location, and accompaniments of the pain may be sufficient to allow precise diagnosis.

Cranial nerves. Symptoms reflecting disease of the cranial nerves are even more varied than those suggesting cortical or cerebral disease.

Damage to the first (olfactory) nerve leads to anosmia, or loss of the sense of smell, on the side supplied by the nerve. Head injuries and compression by tumours are possible causes, though local nasal disease is more common. Hallucinations of smell occur in temporal lobe diseases such as epilepsy or tumour and also in depressive illnesses.

Disorders of the second (optic) nerve cause visual loss in the affected eye. In the early stages of disease, when the process is irritating the nerve rather than decreasing its conducting ability, positive phenomena such as streaks of light may be seen. When the optic pathways are affected within the brain, the precise location of the disease can be determined by testing the pattern of visual loss affecting both eyes. Pain in the eyes is sometimes due to neuritis of the optic nerves, but it is usually caused by ocular disease.

Double vision

When any of the three oculomotor nerves are affected, the eyes are not able to retain parallelism of their axes, so that light falls on different parts of the two retinas and patients complain of diplopia, or double vision. With central lesions, a disorder of ocular posture in which the eyes jerk spontaneously, known as nystagmus, may lead to complaints of jumping images.

Compression or other disease of the fifth (trigeminal) nerve causes complaints of facial numbness. Since some diseases of the brain stem can cause similar problems, precise inquiry and examination of signs localizing the disease to the brain stem are important. In trigeminal neuralgia, jabs of excruciating pain are felt on one side of the lower face, mainly in people over the age of 55 years.

The seventh (facial) nerve is damaged most commonly by swelling within the facial canal in the temporal bone, thought to be due to viral infection. This gives rise to Bell's palsy, a weakness of the muscles of the side of the face in which the mouth and eye cannot be closed tightly. Numerous other conditions affect the facial nerve.

When both divisions of the eighth (vestibulocochlear) nerve are affected by disease, there may be positive symptoms such as ringing in the ear (tinnitus) and a sensation of spinning (vertigo) as well as negative symptoms such as deafness.

Damage to the ninth through 12th cranial nerves, which have their nuclei of origin in the medulla oblongata, causes dysphonia, dysarthria, and dysphagia (difficulty in swallowing). All three are symptoms of the gravest import, since their causes often lead to further paralyses and to an inability to swallow or clear the airway of secretions that may be aspirated into the lungs. Involvement of the 11th (accessory) nerve leads to weakness of the neck muscles. Lesions of the 12th (hypoglossal) nerve, which supplies only the tongue, may have little clinical effect if unilateral, but if both sides are affected, speech and manipulation of food in the mouth are disturbed. (For description of the cranial-nerve pathways, see above *Anatomy of the human nervous system: The central nervous system.*)

Symptoms of the body and limbs. Symptoms expressed in the limbs and trunk and pointing to neurological disease include weakness and wasting of muscles, clumsiness, and unwanted movements. None of these is caused by disease of one particular site, so that only by thorough inquiry can the neurologist localize the problem. Thus, weakness can be due to any of the following: disorder of the upper motor neuron anywhere between the cortex, where it originates, and the ventral horn of the spinal cord; cerebellar disease; lack of energy or motivation as in hypothyroidism, dementia, or depression; disorders of the basal ganglia; or disorders of the motor unit, encompassing the lower motor neuron, the motor end plates, and the muscle fibres. Peripheral nerve diseases, end-plate disorders such as myasthenia gravis, and both genetic and acquired muscle diseases, can also be responsible. Finally, loss of feedback from sensory fibres of a limb also reduces muscular power.

The complaint of clumsiness has a similar list of potential causes. Weakness is a negative symptom—that is, it represents the loss of a normal function. Involuntary movements, however, are new (or positive) events. Chorea is a condition in which the face and distal parts of the limbs make brief, jerky, dissimilar, involuntary, and repetitive movements; the lesion is usually found in the caudate nuclei, where many pathologies may be the cause. Ballismus, a similar but more severe condition, is due to a lesion of the subthalamic nucleus. Patients with athetosis make slower, writhing, sinuous movements intermittently or continuously; dystonias are even slower movements or abnormal postures of the head or the limbs adopted by patients with certain basal ganglion diseases. Tics and habit spasms are of uncertain origin. In such cases, and when no pathology at all can be demonstrated, the condition may be labeled "functional," implying (usually erroneously) a psychological disorder.

Involuntary movement

Alterations of sensation may also be positive or negative; the former include tingling, burning, itching, and pain, while the latter consist of diminution or loss of some or all sensations. Sensations carried by large, heavily myelinated fibres, such as position sense, discriminative light touch, and vibration sense, tend to be affected together, as do those carried by the smaller, thinly myelinated or non-myelinated fibres, including pain, crude light touch, and temperature. As with the complaint of weakness, careful inquiry and examination are necessary to define the exact boundaries of abnormal sensation and thus to diagnose the site of the causative pathology.

Autonomic nerves. A last group of symptoms signifies involvement of the autonomic nervous system. Complaints of alteration in bladder or bowel habit or sensation, of increased or decreased sweating, of faintness (due to a drop in blood pressure after a change in posture), of impaired accommodation of vision, and of altered sexual potency are those most commonly met.

PHYSICAL EXAMINATION

While taking the history, the neurologist notes the patient's level of awareness, posture and gait, demeanour and expression, speech, and, to some extent, personality. He also looks for evidence of weakness, incoordination, wasting of certain muscle groups, and abnormal movements. The formal examination then begins with an examination of higher cerebral functions and proceeds methodically through an evaluation of the cranial nerves, motor systems, and sensory systems.

Higher cerebral functions. In order to evaluate the patient's orientation in place and time, tests of concentration, of recent and remote memory, and of ability to follow simple spoken or written commands, as well as other tests of language, are usually given. Comprehension, reasoning, and planning can be tested, for example, by asking about the similarities and differences between two objects (child/dwarf, fly/tree, wall/fence) or by asking the patient to explain the message or moral contained in a proverb.

Testing comprehension

Tests for apraxias and agnosias are helpful when cortical disease is suspected, as are tests measuring the ability to perform simple drawing and writing tests and to copy simple figures. Standardized tests for examining these functions apply quantitative measurements to any deficit, which can be analyzed further by more sophisticated testing at the hands of a clinical psychologist.

The process continues with examination of the head and neck, looking especially for local tenderness or deformity and for evidence in children of enlargement of the head, which may suggest hydrocephalus. The physician may also use a stethoscope to auscultate (listen to) the major blood vessels in the neck, listening also over the skull for sounds indicating unusual communication between arteries and veins. Irritation of the meninges, as occurs with intracranial infection or bleeding, leads to unusual stiffness on attempts to flex the neck passively, as well as to an inability to straighten the bent knee when the hip is flexed (a condition called Kernig's sign).

Cranial nerves. *Olfactory.* The ability to perceive (not identify) a mild odour, such as coffee, tar, or lemon, is tested.

Optic. The optic nerve head is the only part of the central nervous system accessible to vision; an ophthalmoscope is used for this purpose and to see the retinas and the small arteries and veins that lie upon them. Visual acuity is tested with a standard test card, and the visual field is examined by asking the patient to signal when he sees an object brought in toward the centre of vision from the periphery. A simple machine called a perimeter partly automates and quantifies this examination.

Oculomotor. The three oculomotor nerves are tested together by asking the patient to gaze in different directions on command and to follow a moving object with the eyes only. The character of any double vision is noted. The shape, size, and reactivity of the pupils—both to light and to close objects—are also tested.

Trigeminal. Motor functions are examined by asking the patient to clench the teeth and by testing the jaw reflex by tapping the chin. This is one of the few physiological reflexes that is normally not detected. The sensory functions of the nerve are examined by stimulating the face gently with the finger or cotton wool for light touch, cold steel for temperature, and a pin for scratch or pain sensation. This procedure is done for the three anatomical divisions of the nerve on each side of the face. Finally, cotton wool is touched to the cornea to assess the corneal reflex. Normally, an abrupt blink is produced.

Facial. This motor nerve is examined by asking the patient to screw up the eyes, bare the teeth, and try to whistle. The facial nerve also carries fibres subserving the function of taste on the front of the tongue, so that weak solutions of sugar, salt, lemon, or vinegar can be used to test its function. (Flavour—as opposed to the tastes of sweetness, saltiness, bitterness, and sourness—is mediated exclusively by the olfactory nerve, even for foods inside the mouth.)

Vestibulocochlear. For the cochlear nerve, hearing tests examine the overall acuity to the whispered voice. Rinne's test differentiates the patient's ability to hear the hum of a tuning fork held both beside the ear and with its foot on the mastoid bone of the skull behind the ear. If the sound is louder at the latter site, impairment of the conduction of vibrations through the chain of three small bones in the middle ear is likely, while if the former sound is louder, any deafness is likely due to disease of the inner ear or of the cochlear nerve. Weber's test consists of placing the tuning fork on the forehead; the sound is better perceived either in the ear without nerve deafness or (paradoxically) in the ear affected by mild middle-ear deafness. More sophisticated tests require the equipment found in a hospital or clinical audiometry laboratory.

Hearing tests

Tests of the vestibular nerve are not routinely performed. The usual screening procedure for postural vertigo is to await the appearance of vertigo or nystagmus while tipping the patient's head back and down 45 degrees. Further testing is done in an electronystagmography laboratory. It includes the assessment of nystagmus when the external ear canals are irrigated with warm or cool air or water, when the patient is rotated, or when he is made to gaze in various directions.

Glossopharyngeal and vagus. The usual tests are for the presence of touch sensation on the soft palate and the back of the throat (the latter usually eliciting a gagging reflex), the elevation of the palate on phonation (which should be symmetrical but rises to the stronger side in the presence of weakness on one side), the quality and loudness of the voice, and the normal slowing of the heartbeat when one carotid artery is compressed in the neck at the level of the carotid sinus.

Accessory. The sternocleidomastoid and trapezius muscles, supplied by this nerve, are tested by having the patient push his head forward and shrug his shoulders upward against the examiner's resistance.

Hypoglossal. Atrophy and weakness of the tongue muscles can be assessed by measuring the deviation of the tongue toward the weak side upon protrusion.

Motor systems. The presence of gait and postural disturbances, of abnormal movements, and of atrophy may be noticed when the patient is giving the history. Examination is then formalized and extended under five headings.

Inspection. Inspection of the body may show patterns of muscle atrophy. Depending on the pattern of atrophy, this suggests lesions in nerve roots, in more peripheral locations of the nerves, or in the muscles themselves with no involvement of nerves. Symmetrical, proximal atrophy is more likely to indicate primary muscle disease, while unilateral atrophy (*i.e.*, affecting only those muscles receiving their motor supply from a single nerve) naturally suggests a lesion of the supplying nerve.

Muscle atrophy

Fasciculations are brief, irregular, involuntary twitches of muscles that do not lead to the movement of a joint but that are visible and can be felt by the patient. If accompanied by atrophy and weakness, they may be symptoms of serious underlying motor neuron disease (see below *Diseases and disorders: The peripheral system*). Other abnormal movements, such as chorea and dystonia, are also noted, as are changes in the skin and joints caused by nerve or muscle disease.

Muscle tone. When the examiner flexes or extends the joints in a relaxed limb, a certain resistance, known as tone, is felt. This resistance decreases whenever the reflex arc is damaged (usually at the level of the peripheral motor or sensory nerve), but it may decrease with primary muscle or spinal cord disease. An increase in resistance occurs in the presence of a lesion of the upper motor neurons—that is, anywhere along the pathway from the motor cortex down to the pool of ventral horn neurons in the spinal cord—by which the muscles in question are supplied. This so-called hypertonia may increase against resistance and then suddenly give way ("clasp-knife spasticity"), or it may be constant throughout the range of movement ("plastic" or "lead-pipe" rigidity). In the presence of tremor this latter form has a ratchety feel to it, leading to the name cogwheel rigidity. Rigidity suggests a lesion of the basal ganglia, but spasticity implies disease of the direct corticospinal tracts.

Hypertonia

Power. Power is tested either by examining single muscles in cases where a local or lower motor lesion is suspected or by assessing the patient's strength in flexing or extending joints—in which case a number of muscles are tested at once. The latter method is employed when evidence of an upper motor lesion is being sought.

Reflex activity. Three main types of reflex activity are tested: an increase in the speed and strength of the reflex response, a decrease in response, and the presence of abnormal reflexes. Using a tendon hammer, the examiner taps a suitable tendon with the patient relaxed and observes the response—usually a single brief, brisk contraction of the appropriate muscle. Response is normally enhanced if muscles contract elsewhere in the body. When an upper motor neuron lesion is present, the response is excessive and the muscle may contract repeatedly.

The tendon tap

Tendon reflexes are diminished or absent in the presence of a lesion of the lower motor neuron, of the muscle itself, or of the afferent (sensory) side of the reflex arc. Superficial reflexes can be elicited by stroking the wall of the abdomen with a thin stick; this should cause the underlying muscles to contract. Unlike tendon reflexes, the superficial reflexes disappear in the presence of a corticospinal tract lesion.

The only abnormal reflex routinely detected is the plantar, or Babinski, response. Normally, the great toe curls downward when the examiner draws a stick up the sole of the foot. In the presence of a corticospinal tract lesion, it curls upward instead, and the other toes may fan out.

Coordination. Disease of the cerebellum leads to abnormalities of the rate, range, and force of voluntary movements and to disturbances of posture and gait. The jerky oscillations of the eyes constituting nystagmus are also notable. Tests employed to assess cerebellar function in the limbs include those of rapid alternating movements, the subject being asked to touch, successively, the examiner's finger held before him and his own nose, to run one heel down the opposite shin, or to perform piano-playing movements with the fingers on a resonating surface. The amount of agility and precision of control over the limbs is noted by the examiner.

Sensory systems. Because the examination can be so long and tedious that even the most cooperative patient may give misleading responses, an examiner does not attempt sensory testing except on a brief screening basis until he has a clear idea of the kind of problem for which he is looking. Questions to be answered are: Which (if any) modes of sensation are impaired? To what degree are they impaired? And in which areas? From the results of careful sensory testing it may be possible to localize the site of a lesion in the nervous system with great accuracy. To achieve this localization, it may be necessary to compare sensation in different dermatomes (areas of the body innervated by different spinal segments) or in areas supplied by different parts of the brain or spinal cord.

The stimuli employed include: the examiner's finger or a cotton-wool applicator or paintbrush, for testing sensations of light touch; steel or glass tubes filled with warm and cold water, for temperature; a pin, for superficial pain and scratch sensation; a tuning fork, for vibration; and, for the sense of passive movement of joints, gentle movement of a digit up or down outside the patient's range of vision. Discriminative touch can be tested by determining whether the patient can identify an object placed in his hand, can determine whether he is being touched by one or two ends of a blunt pair of compasses, or can identify where he was touched or what number or letter was drawn on his skin by the examiner. When disease of the contralateral parietal lobe is involved, many of these tests of discriminative sensation show abnormality; in such cases, simultaneous stimulation (usually visual or tactile) on both sides of the body leads to identification of only one stimulus—that on the side opposite the healthy lobe.

LABORATORY INVESTIGATION

Further useful data may be acquired from the results of the tests described below.

Electrical tests. A recording of the inherent electrical rhythms of the brain was first achieved by the German psychiatrist Hans Berger in the late 1920s. Today, electroencephalography is a routine procedure, used mainly to localize the origin of epileptic discharges (Figure 33) but also to localize and, occasionally, indicate the nature of destructive disease of the underlying brain. It is also employed to indicate the degree of generalized brain disease in such metabolic disorders as liver failure, and it may show characteristic patterns in some viral and slow-viral illnesses. It can only confirm a diagnosis of brain death made through other means.

Electroencephalography

From S.G. Bayliss in W. Pryse-Phillips, *Epilepsy* (1969), Butterworth Scientific Ltd.

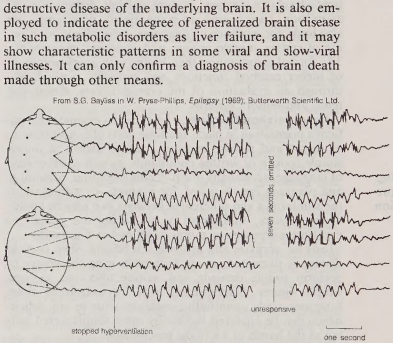


Figure 33: *An electroencephalogram (EEG) from a patient having an attack of petit mal epilepsy.* The sudden onset of abnormal discharges, recordable from all areas of the scalp as waves and spikes on the graph, is accompanied by loss of consciousness, without convulsion, for approximately 20 seconds.

The electroencephalogram (EEG) is produced by placing electrodes on or in the scalp and then recording the changes in electrical potential that take place while the subject is at rest or stimulated by flickering light, noise, or drugs.

Tiny voltages transmitted by the peripheral nerves are amplified in the central nervous system. When multiple stimuli are given and the electrical activity of the relevant cortical area is recorded for 10 to 1,000 milliseconds after each stimulus, consistent potential changes can be recorded by averaging the responses and eliminating background electrical "noise." These potential changes, recorded as waveforms on the EEG, are very similar in all humans. Their absence, delay, or distortion indicates disease in the central conducting pathways, thus allowing further localization of disease (but not indicating the nature of the responsible pathology). Computerization has allowed the generation of "maps" of electrical activity and the more precise localization of abnormal electrical discharges.

Stimulation may be of peripheral nerves using weak electrical shocks (somatosensory evoked potentials, or SEPs), of the auditory apparatus by click stimuli given through headphones (brain-stem evoked potentials, or BAEPs), or of the optic nerve using flashes of light or an alternating checkerboard pattern on a screen (visual evoked potentials, or VEPs). These tests are employed most commonly in the search for sites that show no clinical evidence of

disease (as in multiple sclerosis) and in the assessment of dementias, spinal-cord diseases, and disorders of the visual pathways. BAEPs are of particular value in the diagnosis of tumours at the base of the brain.

Techniques similar to those described above are used to study the function of the retinas (electroretinography) and the posture and movements of the eye (electronystagmography).

Techniques are under development whereby the brain can be harmlessly stimulated through the scalp and skull, either by brief electrical current or magnetic field, and the resulting muscle response recorded. The interval between stimulus and response can be measured and may indicate disease of the motor pathways.

Electromyography

Electrical examination of the peripheral nervous system is also possible. Electromyography (EMG) is the study of muscular electrical activity by means of fine needle electrodes inserted into the muscle. The waveforms recorded with primary disease of muscles differ somewhat from those found when the muscles are deprived of their motor innervation. This allows both improved precision in the detection of muscle involvement and differential diagnosis of the causative pathology. Single-fibre EMG (SFEMG) is a technique in which even fewer muscle fibres are examined. Particular attention is paid to the consistency of activation of single muscle fibres, since this varies widely in diseases of the motor end plate (see below *Diseases and disorders: The peripheral system*).

Measurement of the speed of conduction of impulses along sensory and motor fibres is possible with nerve conduction studies (NCS). These can localize the site or sites of peripheral nerve disease and may even indicate the nature of the disorder affecting them. They are almost painless and greatly augment the findings of clinical examination.

Biochemical tests. Few blood tests are of value in the diagnosis of neurological disease. The serum levels of a muscle enzyme, creatine kinase (CK), are increased in many muscle disorders, particularly the inherited muscular dystrophies and muscle inflammatory disease. Tests showing abnormal hematological and biochemical results may also help diagnose a number of inherited metabolic disorders and, of course, generalized medical conditions that affect the nervous system.

Spinal tap, or lumbar puncture

Study of the pressure and the cellular and biochemical composition of the cerebrospinal fluid is of great value in the diagnosis of central nervous system infections, some tumours, and multiple sclerosis. Cerebrospinal fluid is obtained almost painlessly by inserting a needle through the skin in the small of the back so that it passes deeply between the bony vertebrae into the fluid sac surrounding the spinal cord and nerve roots. (The needle is inserted below the termination of the spinal cord, so that the cord cannot be damaged.) Identification of one or two bands of protein in the fluid is a valuable aid in the diagnosis of multiple sclerosis and of other smouldering inflammatory diseases of the central nervous system.

Pathological examination. A diagnosis may be made by biopsy, the direct examination of surgically removed nerve, muscle, or brain tissue. Special stains are often employed to increase diagnostic accuracy. A number of conditions affecting the central and peripheral nervous systems can be differentiated only by their appearance under the electron microscope.

Radiological tests. *Conventional X rays.* Plain X rays are of relatively minor value in neurological diagnosis. Diseases affecting the skull bones (malformations, chronically raised intracranial pressure, a few metabolic diseases, tumours, and trauma) can be diagnosed with this procedure, as can disorders of the spinal column and a small number of benign cerebral tumours, but X rays employing the injection of iodine-containing "contrast media" or air are far more valuable. Such studies allow better visualization of the spine (myelography), of the fluid-containing ventricles of the brain (ventriculography), or of the arteries or veins within the cranium and neck (angiography and venography). In most cases, however, even contrast X rays give only a silhouette of the lesion or a definition of its blood supply. While this is of great diagnostic value in disorders of the blood vessels themselves (aneurysms, angiomas, large vessel disease), the location of the actual pathology elsewhere must usually be inferred.

X rays employing contrast media

The contrast medium is injected, often under a general anesthetic, into an artery, vein, or, during an operation, the ventricles. Injections into the cerebrospinal fluid at the lumbar area do not normally require anesthesia. All these procedures carry some risk of morbidity, even of mortality, but for many years they have been the mainstay of laboratory investigation of central nervous system disease.

Computerized axial tomography (CAT). The greatest advance in neurological diagnosis since the discovery of X rays occurred in the early 1970s when CAT scanning (also called computerized tomography, or CT, scanning), conceived by William Oldendorf and developed by Godfrey Hounsfield, became generally available. Although often employing contrast media to enhance the quality of the images obtained, this test is barely invasive. It allows visualization of three- to 10-millimetre sections of the brain, skull, spinal cord, and spine (as well as other parts of the body) in two dimensions and with enough clear distinction between black, gray, and white areas of the image to allow pathological diagnosis in many cases.

Magnetic resonance imaging (MRI). While CAT scanning is a pure X-ray technique, other computerized investigations yield data about the form or function of the central nervous system without the use of X rays. In MRI, the patient is placed within a magnetic coil, and radiofrequency energy is applied to the head. These harmless radio waves excite protons that form the nuclei of hydrogen atoms in the brain. The protons then give off measurable electrical energy, which, with the aid of a computer, can be used to construct a map of the tissue. Since MRI hardly visualizes bone, it gives excellent images of the intracranial and intraspinal contents (Figure 34).

By courtesy of Romeo Ethier

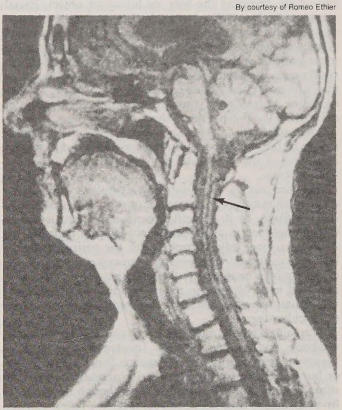


Figure 34: *Magnetic resonance image (MRI) of a patient with syringomyelia.*
An abnormal cavity in the spinal cord, called the syrinx, is indicated by the arrow.

Positron emission tomography (PET). Another noninvasive test, PET, employs inhaled or injected radioisotopes and computer techniques to map the metabolic activity of the brain. This is of particular value in the diagnosis of certain degenerative and metabolic disorders.

Doppler ultrasound studies. High-frequency sound waves can be used in a way similar to radar in order to show the form of deep body structures. In neurological diagnosis, demonstration of the echoes from midline structures and from the ventricular walls has proved valuable, but CAT and other scanning techniques are making such

tests unnecessary. Doppler studies of the carotid arteries in the neck, however, represent valuable noninvasive tests that can give useful information about the size and any deformity of these vessels.

Radioisotope scans. The blood–brain barrier keeps large molecules from passing into the brain or spinal cord from the blood. When this barrier is destroyed—as it is around tumours, blood clots, infarcts, or infections—fluid and dissolved solids can pass into the brain. Some radioisotopes injected into the bloodstream also cross into brain tissue and remain there. Measured by outside detectors, the radioactivity of the isotopes can then produce a map of the areas where the barrier has been destroyed. This technique has been valuable in the detection of the intracranial pathologies mentioned above, although the CAT scan is more accurate. Isotopes are also used to visualize cerebral blood flow in patients with cerebrovascular disease, as well as the flow patterns of cerebrospinal fluid in some cases of dementia and after skull fracture.

Crossing the blood–brain barrier

Localization

The nature and pattern of the symptoms and physical signs of neurological disease allow inferences to be drawn about the sites of the lesions causing them. The main sites are described below, with notes on some of the clinical features that lead to their localization.

LOWER-LEVEL SITES

Muscle. Muscle disease is frequently hereditary—in which case a positive family history may be obtained. One complaint suggesting muscular involvement in the disease is that of weakness, usually symmetrical and mainly affecting the proximal or girdle muscles. This type of weakness is noticed on climbing stairs, arising from a deep easy chair, brushing the hair, or lifting an object. Facial weakness leads to difficulty in whistling and to drooling of saliva. Weak masticatory muscles tire easily, so that food is chewed with difficulty, while bulbar muscle involvement leads to problems with phonation, articulation, and swallowing. Diseased muscles are often atrophied but they may also swell and be tender or subject to cramp. In the condition known as myotonia they continue to contract even when the patient wants them to relax.

Complaints of weakness

Motor end plate. The only symptoms resulting from a failure of the motor nerve impulse to cross to the muscle end plate at the neuromuscular junction are fatigability and weakness.

Peripheral nerves. Diffuse disease affecting the peripheral nerves may have a greater impact on either motor or sensory fibres, or it may affect both to an equal degree. Commonly, nerves are affected according to their length, the longest ones "dying back" from the periphery, being least able to sustain vital metabolic processes. In such cases of generalized neuropathy, the signs tend to be symmetrical and most obvious in the extremities. In other cases, individual nerves are affected as a result of compression or vascular disease.

Complaints when motor nerves are affected include weakness and muscle atrophy. Involvement of sensory nerves leads to numbness, paresthesia (tingling), shooting or burning pains, and hyperesthesia (undue sensitivity to stimuli, which are felt as painful even though innocuous). In both motor and sensory neuropathies, reflex activity is reduced or absent. Examination can show the patterns of weakness and atrophy or of sensory less based on the pathology and on which nerves are involved.

Spinal nerve roots. The symptoms and signs of involvement of spinal roots are the same as for peripheral-nerve involvement except that the territory of involvement conforms to the area supplied by the spinal roots rather than the nerves. Also, generalized symmetrical sensory loss is not seen in these cases.

Spinal cord. The structure of the spinal cord, with long ascending and descending fibre tracts and entering and emerging nerve roots, is reflected in the symptoms and signs of disease. There is often a combination of the signs of root lesions (often including pain) at the site of the pathology with signs of damage to the tracts below that level. For example, injury to the cord at mid-thoracic levels spares the arms which are innervated by fibres originating from higher segments, but it induces characteristic signs (abnormal posture, spastic tone, weakness, increased deep reflexes, and abnormal plantar reflexes) of damage to motor neurons originating below that level—as well as loss of bladder control.

Loss of function in ascending sensory pathways will lead to loss of superficial pain, temperature, crude light touch, and scratch sensation if the spinothalamic tract is damaged, but it will cause loss of sense of joint position, vibration, and discriminative light-touch sensation if the dorsal columns are the site of injury. Because of the crossing of its fibres shortly after they enter the cord, spinothalamic-tract lesions on the left side of the cord lead to loss of sensations on the right side of the body below the lesion. This is not true of lesions of the dorsal columns, which carry fibres originating from the same side of the body.

Loss of sensation

Damage to sympathetic autonomic fibres that run in the cervical portions of the spinal cord may lead to drooping of the eyelid and a smaller pupil on the same side as the injury.

HIGHER-LEVEL SITES

Brain stem. Damage to the brain stem threatens life, since so many of the control centres for bodily functions (for example, consciousness, respiration, and blood pressure), are situated there. As with lesions of the spinal cord, localization of the level of the lesion is made possible by noting which of the cranial nerve functions are affected. The horizontal extent of the lesion can be estimated by determining which of the vertically running pathways are involved.

As one example, a midline lesion of the medulla oblongata is likely to involve the pyramidal tracts (the descending motor pathway) and the medial lemnisci (the ascending tracts relaying sensory impulses from the dorsal columns of the spinal cord). This produces signs of an upper motor-neuron lesion and of dorsal-column-type sensory loss at all levels below the medulla. Such signs could theoretically be produced by a lesion anywhere between the mid-medulla and the third cervical segment of the spinal cord, but the added finding of 12th-nerve palsy with atrophy of the tongue accurately localizes the lesion in the midline of the medulla, low down, since that is where the nucleus of the 12th cranial nerve is situated.

A lesion of one side of the medulla spares the pyramidal tracts and medial lemnisci, but it involves the sympathetic pathways, the fibres entering the cerebellum in its inferior peduncle, some of the eighth, ninth, and 10th cranial nerve nuclei, and the descending nucleus and tract of the fifth cranial nerve on the side of the injury, as well as the ascending fibres of the spinothalamic tract from the opposite side of the body. Major features of the lesion, therefore, include: incoordination of voluntary limb movements, drooping eyelid and small pupil, and loss of light-touch and pinprick-pain sensation over the face (all on the side of the lesion); vertigo and vomiting; and loss of spinothalamic function (light-touch and pinprick pain again) on the opposite side of the body. Similar principles govern the localization of lesions of the brain stem at higher levels.

Cerebellum. With damage to the oldest part of the cerebellum, which lies deep in the midline, a patient has difficulty in maintaining an upright posture and may even be unable to sit up in bed. Nystagmus (jerky movements of the eyes at rest) is also likely. The vermis and anterior lobes of the cerebellum developed later in evolution; lesions there particularly influence gait. The lateral lobes represent the "newest" parts to develop; when they are damaged, ataxia (incoordination) of the limbs is found, so that rapid, alternating movements cannot be performed and all voluntary activity is disordered in rate, range, and force. As a result, arm and leg movements are awkward, irregular, and impaired by a tremor that may be so severe that self-care is impossible despite the absence of significant weakness.

Loss of co-ordinated movement

Basal ganglia and thalamus. Thalamic lesions lead to loss of all sensation on the opposite side of the body,

sometimes accompanied by extreme pain. Since tumours and strokes affecting this region are likely also to damage the fibres in the adjacent internal capsule, signs of damage to upper motor neurons may also be present at all lower levels, thus affecting the cranial nerves as well as the spinal segments. Disorders of eye movement and speech are also sometimes found with thalamic lesions.

Lesions of the hypothalamus have many effects upon the regulation of the body's metabolism, such as water and solute control, sexual activity, and appetite for food.

Basal-ganglion diseases lead to abnormal control over movement, manifesting itself as involuntary movements or as a reduction in the spontaneity or speed of voluntary movement.

Cerebral hemispheres. The frontal lobe is concerned with many of the components of intelligence (foresight, planning, and comprehension), with mood, with motor activity on the opposite side of the body, and (in the case of the dominant hemisphere) with speech production. Swelling of the underside of the frontal lobe may compress the first cranial nerves with resulting loss of smell sensations. Irritation of the frontal cortex may cause either generalized or focal motor epileptic seizures, the latter involving the opposite side of the body.

Damage to the dominant temporal lobe is manifested by difficulty with comprehension of spoken speech. The right temporal lobe (usually nondominant for speech) has a special role in the appreciation of nonlanguage sounds such as music. Irritation of a temporal lobe may lead to auditory or olfactory hallucinations. Memory functions are duplicated in the two temporal lobes; if one is damaged, there is little effect, but bilateral damage leads to a permanent, catastrophic inability to learn new data.

Loss of speech and purposeful movement

Parietal-lobe functions also differ on the two sides. In most people the left parietal lobe shares in the comprehension of spoken and written language and of arithmetic, interprets the difference between right and left, identifies body parts, and is responsible for determining how to perform meaningful motor actions. Damage to this lobe leads to forms of apraxia, the inability to perform purposeful actions. The right parietal lobe is concerned with visuospatial orientation, and damage typically leads to deficits such as dressing apraxia (inability to put on clothes), constructional apraxia (difficulty in creating or copying two- or three-dimensional forms), and a phenomenon called sensory competition, or sensory extinction, which is an inability to recognize two stimuli when both are presented together on opposite sides—most easily demonstrated in the realms of touch and vision. Each parietal lobe is also concerned with so-called cortical sensation or discriminative touch, the analysis and interpretation of touch sensations originating on the other side of the body. Damage can cause a form of agnosia, in which the sensation is present but the interpretation or comprehension is lacking. Irritation of a parietal lobe also leads to tactile hallucinations, the false perception of touch sensations on the other side of the body.

Loss of vision

The occipital lobes are almost exclusively concerned with the reception of visual impulses. Damage to one side leads to homonymous hemianopia, loss of all sight in the field of vision on the other side. This deficit applies to either eye: with a lesion of the right occipital lobe, for example, a patient is blind to any visual stimulus presented from the left side, whether to the right or to the left eye. This may be contrasted with the "blinkers" effect caused by compression of the optic chiasm, usually by a tumour arising out of the pituitary fossa. At the optic chiasm the optic nerve fibres from the nasal halves of the right and left retinas mingle and cross to the opposite side. Since the nasal retinas "see" the temporal fields (the right nasal retina receiving impulses from objects to the right, the left from objects to the left), the subject with a lesion of the optic chiasm is able to see straight ahead but not to either side. This is called bitemporal hemianopia.

Irritation of an occipital lobe causes the subject to see visions. If the lesion is far back in the lobe, the visions may be of unformed lights, colours, or shapes. However, the visions may be vivid and sharply defined pictures (visual hallucinations), as though a videotape of previous visual experiences were being replayed, if the lesion is farther forward and in the area where the parietal, temporal, and occipital lobes adjoin. This area of the cortex appears to be concerned with the analysis and storage of complex perceptions.

Pathologies

Many types of disease affect the nervous system. A short description of these types and an overview of representative disorders follows.

One pathology of the nervous system is genetic. Inherited neurological diseases are relatively common and may affect any site. Examples of such diseases are: Duchenne's and other muscular dystrophies; hereditary motor, sensory, or mixed neuropathies; spinocerebellar degenerations; disorders of closure of the fetal neural tube; numerous metabolic disorders; and maldevelopment or premature degeneration of parts of the nervous system, such as Huntington's disease and a form of Alzheimer's disease. A genetic component also determines a tendency to epileptic seizures.

Bacterial and viral infection

Inflammatory diseases are another neurological pathology. Although the blood–brain barrier plays its part in protecting the nervous system from microorganisms, it may be breached by bacteria, viruses, fungi, and many other organisms. When this occurs, the inherent resistance to infection of the nervous system is low. The major classes of disease are meningitis and encephalitis (infections of the meninges, or covering membranes, of the brain and of the brain itself, respectively) and abscess, which may be situated outside or just below the meninges or in the brain substance. Some viruses, such as the "slow" viruses, lie almost dormant within neural tissue for years before causing its destruction. The measles virus may do this, causing a chronic progressive encephalitis that is usually fatal.

Direct infections of muscles and of peripheral nerves are uncommon except in leprosy. Both the central and peripheral nervous systems may be severely damaged by reaction of the immune system after relatively trivial infections elsewhere in the body. Finally, in some infections such as diphtheria and botulism, a toxin is liberated by the infectious organism, which attacks the function of the nervous system.

Traumatic injury

Traumatic and mechanical injuries are a type that can affect all levels of the nervous system. Serious head injuries can lead to compression, laceration, or bruising of the brain inside the cranium. The compression is commonly due to a clot of blood inside the brain or formed outside or beneath the dura mater (extra- or subdural hematoma), but there is also inherent swelling of the brain tissue following trauma as fluid leaks from small blood vessel spaces into the extravascular space. This is called brain edema. Later consequences, such as seizures and alterations in mental process and personality, indicate the damage done to the brain by major or repeated minor head injuries. Less serious head injuries lead to concussion, a temporary loss of awareness.

Once destroyed, neurons are not replaced. Severed axons sprout growths from the cut end, but they do not form effective connections in the brain or spinal cord. Therefore, destructive injury of, for example, the spinal cord in the neck is followed by permanent loss of voluntary movement and of sensation below the level of injury.

In the peripheral nervous system, axons that have been cut or have degenerated because of disease can grow again. If the nerve remains in continuity, these sprouting axons may eventually reestablish effective connection with muscle fibres or sensory organs, but this reinnervation is often abnormal because of division and misdirection of growing axons.

Cancer

Neoplastic diseases are another pathological process. Both benign and primary and secondary malignant tumours attack the nervous system. The sites of both types include the meninges, the brain itself, and (more rarely) the spinal cord, its roots, and the peripheral nerves. In the latter sites the tumours are usually benign. The brain and spinal cord may also be compressed by masses arising in adjacent areas, such as the pituitary gland, the spinal column, or

the nasopharynx. Tumours declare themselves by destruction of the tissue in which they arise, by compression of neighbouring tissue, and by increasing intracranial pressure. Those arising outside the nervous system may lead to syndromes of brain, spinal-cord, nerve, end-plate, or muscle disease without direct infiltration of these tissues.

A fifth pathology comprises metabolic, toxic, and endocrine disorders. Numerous complications of disease of other organs affect the nervous system. The largest category (but not the most common) comprises the disorders of metabolism, many of which have a genetic basis. The most commonly occurring neural complications are those arising from the effects of exogenous toxic agents such as bacterial toxins, drugs, and other chemicals. Next in frequency are those representing the effects of disordered fluid, of mineral and electrolyte function, or of disease affecting other body systems, such as the endocrine glands (diabetes, thyroid disease), the kidneys, liver, and lung (organ failure), and the blood (anemia, leukemia).

Loss of blood supply

Vascular diseases, including stroke, are an important pathology. The central nervous system has a high metabolic rate and depends upon a liberal blood supply for nutrition and for clearance of metabolic end-products. In the event of the interruption of circulation, function quickly fails, and if circulation is not restored speedily, irreversible damage to the neurons results. (The area of dead nervous tissue is known as an infarct.) The peripheral nervous system is much more tolerant of loss of blood supply, called ischemia.

A further important vascular cause of brain damage is hemorrhage due to rupture of an artery.

Another pathological process includes diseases labeled demyelinating and degenerative. Demyelinating disease is characteristically scattered throughout the brain and spinal cord, with small foci where the myelin is attacked and replaced with glial scar tissue. Nerve fibres running through such areas may remain undamaged, but the lack of insulation normally provided by the myelin leads to a blocking of conduction of electrical impulses, so that the effect is as though the axons had been severed. Clinically, signs of damage to many sites in the nervous system are found, as in multiple sclerosis. In certain very rare diseases, known as leucodystrophies, large areas of demyelination occur in the white matter of the brain as a result of inherited metabolic disorders. Demyelination is also the result of immune attack upon the central nervous system, which may follow viral infections such as measles, and of immune deficiency states such as pernicious anemia.

In the peripheral nervous system the Schwann cells, which form the myelin investing the axons of peripheral nerves, may suffer immune or toxic attack, as in Guillain-Barré syndrome and diphtheria. This leads again to a blockage of electrical conduction. When an injury is primarily to the axons, the Schwann cells are also damaged, producing "secondary demyelination."

Under the label "degeneration" are grouped some nervous system diseases characterized by progressive destruction of neurons without evident cause. Such diseases are Alzheimer's disease, affecting maximally the cerebral cortex; Huntington's and Parkinson's diseases, affecting the basal ganglia and cortex; motor neuron disease, which attacks the corticospinal tracts and ventral-horn cells; spinocerebellar degenerations, involving long tracts in the spinal cord, the cerebellum and its connections, and sometimes peripheral nerves; and the hereditary neuropathies with no known metabolic basis, in which motor, sensory, or both classes of peripheral nerve degenerate and lose their function. Most such diseases develop after a variable period, during which that part of the nervous system subsequently affected apparently functions normally. As research progresses, the metabolic (and often genetic) bases of these diseases are being successively revealed.

Electrical pathologies present a unique problem of classification. Because the nervous system is a biologic electrochemical complex, it is possible to regard every aspect of its function as an electrical manifestation, but it is primarily the epilepsies that are regarded as expressions of disordered electrical activity. Seizures represent occasional, sudden, rapid, local, and excessive electrical discharges of the gray matter of the brain. There are two main classes, those with a focal origin anywhere within the gray matter and those in which no abnormal pathology is present but that manifest an abnormally low threshold for electrical activation. Although certain abnormal movements occasionally have their origin in spinal-cord disease, epilepsy is uniquely a brain disease (see below *Diseases and disorders: The cerebrum*). Narcolepsy, a disorder of sleep mechanisms, is not a variant of epilepsy.

Seizures

It is uncertain whether any diseases of the nervous system can properly be regarded as representing an allergic pathology in the strict sense of the term, but many conditions marked by inflammation of blood vessels, such as the auto-allergic collagen-vascular diseases, do have such a basis. These, through reduction of blood supply to parts of the nervous system, may well induce neurological symptoms.

Diseases and disorders

THE SKULL AND SPINE

Neural tube defects. The primitive neural tube normally closes by the end of the third week of fetal growth, but when it fails to close, severe deficits result. The worst of these is anencephaly, the absence of brain; a cyst replacing the cerebellum is a less severe form of the same problem. At lower levels the spinal canal or cord may also fail to close up. Such defects are known as spina bifida occulta when there is only X-ray evidence of this, meningocele when a meningeal pouch visibly projects through the skin, and meningomyelocele when such a pouch contains elements of the spinal cord or nerve roots. Depending on the level, function of the legs is often severely impaired. Bladder and bowel control is also lost in such cases, and the infants commonly have hydrocephalus as well.

Abnormal growth before birth

Hydrocephalus. This progressive enlargement of the head is caused by obstructed drainage of the cerebrospinal fluid, usually at the level of the aqueduct or fourth ventricular roof. Huge enlargement of the ventricles results at the expense of cerebral tissue; shunting of the fluid is required to prevent gross expansion of the skull and death through attrition of the brain.

Other congenital malformations in which the head size is abnormal include microcephaly and macrocephaly; in the latter case, expansion of the brain usually follows infiltration in metabolic diseases. In hypertelorism the eyes are set unusually far apart, and in craniostenosis the sutures of the skull do not develop, so that the skull grows abnormally along one or another diameter. In hemiatrophy, one-half of the skull and face may not develop as well as the other, in which case the brain also may be unusually small.

Occurring at the junction between skull and neck, platybasia, an abnormal shallowness of the posterior fossa of the skull, is a malformation that may be associated with projection of the vertebral column upward, indenting the base of the skull. (This condition may also occur in association with bony diseases such as osteomalacia and Paget's disease of bone in adult life.) In the Arnold-Chiari malformation, cerebellar or medullary tissue projects downward into the upper cervical spinal canal, causing signs of cerebellar dysfunction, hydrocephalus, or widening of the central canal of the spinal cord with damage to the surrounding fibre tracts. Fusion of the upper cervical vertebrae in the Klippel-Feil anomaly is another malformation, but it does not always produce symptoms.

Fractures. Fractures of the cranial vault are common, but, so long as they are linear and not depressed (and thus not liable to irritate the underlying brain), they usually require no treatment. Far more serious are the complications of extradural or subdural hematomas, or blood clots. Fractures crossing the middle ear and the nasal sinuses provide a portal for the entry of microorganisms into the cranial cavity and are therefore especially dangerous, while those at the base of the skull may damage cranial nerves crossing the fracture line.

Damage to the spinal cord

Fractures of the odontoid, the bony peg that forms a joint between the upper two vertebrae in the neck, may compress and severely damage the spinal cord; the odon-

toid process may also separate with the same consequences in rheumatoid arthritis. Fractures and dislocations of the spine occur most commonly in the neck, with consequent risk of spinal-cord damage; at lower levels the thoracic rib cage makes spinal-cord compression less likely. With compression fractures at lumbar levels, it is the cauda equina, the tail of nerve roots below the level of the spinal cord, that may be damaged, but the strength of the ligaments gives more solid fixation and complications are less common.

In addition to trauma, secondary malignant tumours, infections such as tuberculosis, and intrinsic bone diseases can damage the spine and spinal cord.

Tumours. Tumours of the skull base may compress the lowest cranial nerves or the medulla and upper cervical cord, with the consequences described above.

Vertebral disorders. The most common disorders affecting the spine are degenerative, most often following previous trauma such as heavy work or whiplash accidents or due to some intrinsic tendency of unknown cause. In spondylosis, small, bony spurs called osteophytes project from the vertebral margins, the ligaments hypertrophy, the bone becomes denser, and the disks degenerate and extrude both forward and backward—in the latter case narrowing the spinal canal, again with the risk of compromising the cord. More commonly, the backward protrusion of an intervertebral disk distorts the local ligaments and compresses an emerging nerve root, resulting in pain, weakness, and numbness in the area. Lumbar spinal stenosis is the condition of marked narrowing of the canal over a few segments when the bone, disk, and ligaments protrude into it, compressing the nerve roots of the cauda equina. Pain also occurs when misalignment of the vertebrae causes stretching of the many joint capsules at sites where the vertebrae are contiguous. Spondylolisthesis is a slipping forward of one vertebra onto another, occurring as a congenital deformity or due to trauma.

Prolapsed disk

Infections, tumours, and bone diseases are also responsible for vertebral disorders, causing pain and signs of damage to the roots and perhaps to the cord as well. Although direct infections of the cord are rare, pyogenic or tuberculous epidural spinal abscesses are important and treatable diseases. Tumours are usually secondary to such malignancies as lymphomas or carcinomas of the breast, prostate, or kidney. Benign tumours also occur. Paget's disease, osteomalacia, and osteoporosis may cause softening of the bone, which can then compress the cord or roots.

THE MENINGES AND CEREBROSPINAL FLUID

Obstruction of cerebrospinal fluid

Raised intracranial pressure. The circulation of the cerebrospinal fluid may be obstructed so that it accumulates behind the obstruction. Congenital stenosis, or narrowing, of the aqueduct, tumours encroaching on or blood accumulating within the ventricles, and fibrosis or occlusion of the roof foramina of the fourth ventricle are causes of obstructive hydrocephalus. They lead to massive enlargement of the ventricular system, with atrophy of the surrounding brain, and to a rise in intracranial pressure, with resulting long-tract motor signs, cranial-nerve palsies, visible swelling of the head of the optic nerve in the eye, headache, and vomiting.

In communicating hydrocephalus, the obstruction is to the flow of cerebrospinal fluid up over the convexity of the brain or to absorption at the sagittal venous sinus. Clinical features are similar to those of obstructive hydrocephalus but less severe. Sometimes following bouts of meningitis or blood in the fluid, the initially raised pressure falls (normal-pressure hydrocephalus), but brain damage persists. In such a condition dementia and gait disturbances are the major clinical features. Insertion of a shunt, or drain, may provide some relief.

Any mass lesion in the head (a blood clot, tumour, or abscess, for example) or external compression of the cerebrospinal-fluid pathway (such as the Arnold-Chiari malformation) raises the intracranial pressure, since the brain cannot shrink and compensation is only possible through a reduction in the amount of fluid present in the ventricles or of blood in the vessels. To the hydrocephalic signs mentioned above, then, must be added those of the causal lesion, affecting specific brain functions according to its site and nature. However, benign intracranial hypertension is a condition in which there is increased intracranial pressure in the absence of obstruction to fluid flow or any mass lesion. Instead, it is caused by various metabolic and endocrine diseases but is most commonly seen in people who are very obese.

Cerebral edema signifies the presence of excess fluid within either the cells or the extracellular tissues of the brain. This also causes brain swelling and a rise in intracranial pressure. Head injuries, encephalitis, abscesses, lack of oxygen, strokes, and toxic agents are the most common causes.

Drainage. Cerebrospinal fluid may leak through basal skull fractures, dripping out of the nose or ear, and it may also leak into the tissues when the needle is withdrawn after lumbar puncture (LP). As a result of the reduced pressure in the fluid, the brain is less well supported and pulls upon the meninges, causing what is called post-LP headache. In traumatic cases, patching of the hole in the meninges may be necessary.

Blood clot. Blood clots lying outside or just below the dura mater (called extradural or subdural hematomas) are other feared complications of trauma. Extradural hematomas usually complicate fractures of the temporal bone that rupture the middle meningeal artery. Arterial blood, shed under pressure, rips the dura off the underside of the skull bones, forming a rapidly expanding mass that raises intracranial pressure, compresses the brain, and may cause death unless evacuated surgically. Subdural hematomas are usually less acute, but they have similar characteristics and also require removal in most cases. Chronic subdural hematomas, however, expand very slowly and may only be discovered through the onset of seizures, focal neurological signs, or dementia.

Extradural and subdural hematomas

Meningitis. This is an inflammation of the meningeal coverings of the nervous system, with only secondary, mild involvement of the brain. A host of infectious microorganisms (bacteria, viruses, spirochetes, fungi, protozoa) and some chemical agents may be responsible. Organisms most often reach the meninges by way of the blood, but direct spread may occur if the usual barriers are broken—as is the case with skull fractures, middle-ear or nasal-sinus infection, or congenital defects of the meninges. Clinical features depend upon the organism, the acuteness of the disease, and the resistance and age of the patient, but they usually include lethargy and drowsiness, fever, headache, stiffness of the neck, vomiting, and (in smaller children) seizures.

Since treatment with the precisely correct antibiotic is essential, the most important diagnostic aid is lumbar puncture, whereby the infectious organism may be identified in the cerebrospinal fluid through microscopy and growth culture and its sensitivity to different antibiotics tested in the laboratory. Such indications in the fluid as the amount of protein, the number and type of cells, and the glucose level confirm the type of meningitis (*e.g.*, bacterial, viral).

Patients with nonbacterial, or aseptic, meningitis also have headache, fever, and other meningeal signs, but they are not so obviously ill. Viruses such as mumps, Coxsackie, and ECHO viruses, tuberculosis, fungi, spirochetes, and chemical substances are possible agents.

The prognosis in bacterial meningitis depends upon the type of organism, the general health of the patient, and the adequacy and speed of initiation of treatment, but there is still at least a 5 percent mortality rate. Residual consequences of the disease include cranial nerve palsies (especially loss of hearing), normal-pressure hydrocephalus, and damage to specific brain areas in a small number of cases.

Neoplasms. Tumours affecting the meninges are usually malignant, commonly spreading from cerebral tumours such as medulloblastoma, from distant tumours such as carcinoma of the lung or breast, and from lymphomas and leukemia. Both drugs and radiation therapy are used to slow the tumour's progression.

Benign tumours arising from the meninges are called meningiomas. These occur over the convexity of the brain and on the floor of the cranium, where they compress and damage brain areas or cranial nerves and may cause

Meningiomas

seizures. They seldom raise intracranial pressure, since their slow growth gives the brain time to compensate. Meningiomas show up clearly on radioisotope and CAT scans. They may be removed totally with an excellent prognosis.

THE PERIPHERAL SYSTEM

Neuropathies. Diseases of the peripheral nerves may be genetic or acquired, may progress quickly or slowly, may involve the motor, sensory, or autonomic fibres (or all three), and may affect all nerves symmetrically (usually at the extremities of the body) or just one or more nerves discretely. Thus, numerous classifications exist; the system used in this section takes as its basis the major pathological change taking place—namely, primary damage to the axon or to the surrounding Schwann cell (Figure 35).

Neuronal neuropathies. In the following diseases, the axon or cell body of the ventral-horn neuron or dorsal-root ganglion neuron is affected. Damage to the ventral-horn neurons leads to the typical signs of a lower motor neuron lesion: atrophy of the muscles supplied by the nerves, fasciculation in chronic disease, reduced muscle tone and power, and reduction or loss of reflexes with no change in sensation. Damage to the dorsal-root ganglion neurons also leads to reduced reflexes, in this case, because the afferent, or sensory, limb of the reflex arc is interrupted. Depending upon the size of afferent neuron that is primarily affected, loss of different sensations occurs: joint-position sense, discriminative light touch, and vibration with damage to the larger cells and skin pain, temperature, light touch, and scratch with smaller cell loss. Often all forms of sensation are impaired.

Polio-myelitis

Poliomyelitis is an acute viral infection. Initially it may cause only a brief, febrile illness, but groups of ventral-horn cells of the spinal cord may be destroyed by the virus. This later causes severe pain with further fever, occasional delirium and meningism (due to accompanying encephalitis), and a rapid onset of fasciculations, weakness, and atrophy of muscle groups that may be localized or diffuse, mild or profound, and that may endanger life if the respiratory or bulbar muscles are involved. Only supportive treatment is available for poliomyelitis, but some recovery occurs in those patients (the majority, in fact) who survive the acute stage of the illness. Since the advent of effective immunization programs this disease is now rare in the Western world.

Hereditary motor neuropathies (also known as spinal muscular atrophies and as Werdnig-Hoffman or Kugelberg-Welander diseases) are a diverse group of genetically determined disorders in which signs of ventral-horn disease occur in babies or young people. The usual features are muscle atrophy and weakness, which progress more slowly in the older age groups but which may be quickly lethal if the disorder strikes during the first year of life. Stricken babies show respiratory insufficiency, poor sucking, and severe limpness and weakness of all muscles except those of the face and eyes, but the muscles of the shoulder and pelvic girdles are most affected. At later stages normal motor development is delayed or absent. This muscular weakness and wasting has given such infants the name "floppy babies." Diagnosis of hereditary motor neuropathy must be confirmed by electromyography and muscle biopsy, as there are other possible causes, some responsive to treatment. There is no effective treatment of spinal muscular atrophy. When the disease begins at a later age (five to 15 years) the progress is slower; the disease may pass, leaving chronic mild weakness and secondary skeletal deformities such as scoliosis (rotation of the spine). Less commonly, similar weakness occurs in specific patterns—for example, involving only the facial, shoulder, or calf muscles—but in those cases the progress of the disease is much slower. In some of these cases specific enzyme deficiencies have been identified as the cause, but in most cases the etiological basis is unknown.

Amyo-trophic lateral sclerosis

Motor neuron disease is a lethal progressive disorder of older people, affecting not only neurons of the ventral horns and medullary motor nuclei but also of the corticospinal tracts. This combination gives rise to such diseases as amyotrophic lateral sclerosis (ALS), in which amyotrophy refers to the muscle wasting due to loss of the ventral-horn cells (the lower motor neurons), and lateral sclerosis is the loss of axons in the lateral columns of the spinal cord (the upper motor neurons of the corticospinal tracts). A combination of upper and lower motor neuron signs is found in these diseases, but weakness, atrophy, and fasciculations found in the muscles of two or more limbs is the hallmark. The mind, eyes, and sensory system are unaffected, prompting the comment that the disease allows the patient to observe his own dissolution. While a host of treatments are available for such symptoms as cramps, and while aids to daily living can be provided to help the patient maintain some self-care, the ultimate prognosis is death within a few years—or within one year when the muscles serving speech and swallowing are affected. Since the etiology is unknown, no cure is available.

Pure sensory neuronal neuropathies may be hereditary. A number of them are differentiated by their pattern of genetic transmission and the modalities of sensation mainly affected. Other causes include toxic drugs or other agents, diabetes, herpes zoster, and vitamin deficiency. They also occur in association with distant cancer. Mixed (sensorimotor) neuropathies have similar causes, in most acquired conditions representing a later stage of a sensory disease.

Injury

Nerve injuries function as neuronal neuropathies affecting the axon far from the cell body. Injuries are of three main grades of severity: in neurapraxia there is temporary blockage of impulse conduction, although the axons remain intact; more severe stretch or incision damage interrupts some axons (axonotmesis); and still worse injury actually cuts the nerve (neurotmesis), in which case microsurgery to rejoin the severed nerve ends is essential if any useful function is to be regained. Even this last is a slow process, since new nerve sprouts grow down the nerve framework at the rate of one to two millimetres per day at most.

Demyelinating neuropathies. The following diseases are those in which the Schwann cells, responsible for the formation of myelin, are primarily affected and migrate away from the nerve. This process leaves segments of the axons uncovered, and since the particular insulating property of the myelin is now lost, there is a block in conduction of nerve impulses down the axon.

Genetically acquired diseases include hereditary motor and sensory neuropathies, a group including Charcot-Marie-Tooth disease (also known as peroneal muscular atrophy because of the special involvement of shin muscles). High foot arches, distal motor weakness and atrophy, and reduced reflexes are the main features; sometimes the nerves are greatly thickened. Most of these conditions first appear in childhood, although they allow a normal life span.

Acquired demyelinating neuropathies may arise as com-

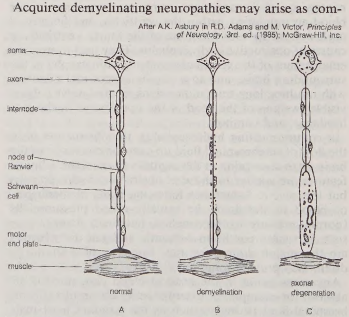


Figure 35: *Two major pathological changes in disease of the motor neuron.*
(A) Normal neuron with intact axon and myelin-forming Schwann cells. (B) Demyelination, or disintegration of the Schwann cells. (C) Axonal degeneration, or disintegration of the nerve fibre.

plications of diphtheria and diabetes, which, partly because of damage to the smallest blood vessels supplying the nerves, are sometimes accompanied by a variety of motor, sensory, autonomic, or mixed neuropathies. Some of these are extremely painful. When sensation is impaired, minor injuries lead to severely deformed, but quite painless, "Charcot" joints. Leprosy (probably still the most common cause of neuropathy in the world), metabolic diseases, cancer, and myeloma or other dysproteinemias also cause mixed demyelinating neuropathies.

Guillain-Barré syndrome

Acute inflammatory neuropathy (the Guillain-Barré syndrome) is another important demyelinating neuropathy. In this disease an autoimmune attack upon the myelin sheath of the motor nerves leads to progressive weakness and reflex loss with only slight sensory changes. The weakness may become so severe that the patient needs mechanical help in breathing, but as long as further complications do not occur, the disease remits spontaneously within weeks. In fact, many patients never develop this degree of weakness at all. In acute, severe cases, blood plasma exchange speeds recovery.

Ischemic neuropathies are those in which local or diffuse blood-vessel occlusion leads to damage of the Schwann cells. The most common example is external compression of a nerve, as when a person's foot "goes to sleep" after the legs have been crossed for too long. In such cases relief of the compression restores the blood supply, and the temporary dysfunction is relieved. Persistent compression, on the other hand, causes the Schwann cells to migrate. This narrows the nerve at the site of pressure, although the axon remains intact. Recovery may take months.

Carpal tunnel syndrome

Common nerve-compression syndromes include the carpal tunnel syndrome, in which the median nerve is compressed at the wrist. This causes pain, numbness, tingling, and weakness of the fingers and thumb, especially at night and on waking. The cubital tunnel syndrome is a similar problem affecting the ulnar nerve at the elbow. Compression of spinal nerve roots by, for example, prolapsed intervertebral disks, are further examples. Numerous nerve-compression syndromes can be diagnosed clinically and localized with the aid of electrodiagnostic studies, allowing precise surgical intervention to release the entrapped nerve. Ischemic neuropathies are also complications of a number of systemic diseases, such as diabetes mellitus and polyarteritis nodosa. In such cases the treatment is that of the underlying disorder.

Autonomic neuropathies may be hereditary, as in Riley-Day syndrome, or acquired, as in complications of partial nerve injuries, diabetes mellitus, tabes dorsalis, the Guillain-Barré syndrome, and other toxic or metabolic disorders (among which alcoholism and drug therapy are the most common). Damage to the sympathetic or parasympathetic pathways in the hypothalamus or brain stem may produce similar symptoms—for example, faintness due to disordered regulation of blood pressure and heart rate, disturbances of bladder and bowel control, impotence, and impaired visual accommodation. Some relief may be obtained from medications that replace a deficient neurotransmitter, expand the blood volume, or compress the limbs so that blood no longer pools in the veins.

Neuralgia is the pain caused by nerve disease. It is usually a severe, constant burning when following an attack of herpes zoster (shingles), but it may also be brief and stabbing in certain conditions affecting the cranial nerves (see below *The cranial nerves and brain stem: Trigeminal nerve*). The relatively common condition known as neuralgic amyotrophy consists of severe pain around the shoulders, followed by selective weakness and atrophy of muscles supplied by nerves of the brachial plexus. This form of neuritis may follow mild infections. The muscles eventually recover.

Myasthenia gravis

Disease of the neuromuscular junction. Myasthenia gravis is the most common disease of the neuromuscular junction. At this site the motor nerve impulse normally triggers the release of the neurotransmitter acetylcholine, which diffuses across the synaptic gap between the terminal of the nerve and the specialized end-plate region of the muscle-fibre membrane. (For discussions of synaptic transmission and neurotransmitter action, see above *Form and function of nervous systems: Transmission of information in the nervous system.*) In myasthenia, receptors in the end-plate region are partially coated with a specific antibody, so that the acetylcholine molecules are blocked, depolarization of the muscle fibre cannot occur, and the muscle does not contract. There is also a reduction in the amount of acetylcholine released from the nerve terminal. As a result, muscle contraction is possible after a period of rest, but sustained contractions quickly become weaker. This fatigability is especially present in the eye muscles, leading to drooping of the lids on looking upward and to imbalance of the ocular muscles, which causes diplopia (double vision). The muscles of the throat, limbs, and respiration may also become involved, creating a dangerous situation.

Diagnosis of myasthenia gravis is made by electrical studies of neuromuscular transmission, which show decreasing response, and by single-fibre electromyography (see above *Acquisition of data: Laboratory investigation*). Treatment involves the removal of the thymus gland (which may produce the antibody), drugs to augment the effect of acetylcholine, and suppression of the immune system. These treatments allow a prognosis of recovery in 60 percent of patients within five years.

Failure of neuromuscular transmission may also occur as a complication of certain drug therapies or of remote cancer, usually of the lung (as in the Lambert-Eaton syndrome). It may also be caused by the toxins of the botulism bacterium *Clostridium botulinus* and of certain species of ticks that attach themselves to the skin. Administration of antitoxin for botulism or removal of the tick, with full supportive hospital care in each case, are effective treatments.

Diseases of muscle. In primary muscle diseases the motor neurons supplying the muscles are not affected, the problem being of and in the muscles themselves. However, motor neuron diseases do cause secondary effects in the muscles.

Genetic dystrophies. The genetic dystrophies are diseases of muscle that progress at differing rates and affect different muscle groups. The best-known, most serious, and perhaps most common is Duchenne's muscular dystrophy (DMD), which ordinarily affects only males, although it is transmitted by females. By the age of three the boy begins to walk clumsily; thereafter, progressive failure to run, jump, and climb like his peers occurs, leading eventually to a loss of the ability to walk by the mid-teens and death in the early 20s. Because of the infiltration of degenerating muscles with fat, little atrophy may be noticed until late in the course of the disease, leading to the alternate term pseudo-hypertrophic muscular dystrophy. Diagnosis is confirmed by estimation of the blood-serum levels of creatine kinase, an enzyme released from degenerating muscle, and also by electromyography and muscle biopsy. The cause is unknown, and no specific treatment is available, but genetic probes and subsequent genetic counselling are used to determine whether a case represents a new mutation or has been transmitted by a carrier mother to her son. Intense rehabilitative efforts are also necessary, since boys with DMD have normal intelligence and can live a relatively full life, although for only a short time.

Duchenne's muscular dystrophy

Facioscapulohumeral dystrophy usually causes problems only in or after the early teens. It has a more benign prognosis, the weakness and wasting being predominantly of the face, shoulder girdle, and arms. Other conditions grouped under the heading limb-girdle dystrophies also show slower progression and may not declare themselves until adult life. Oculopharyngeal dystrophies first strike the eye muscles, causing drooping of the eyelids and weakness or paralysis of the muscles moving the eyes. Later involvement of the face, bulbar muscles, and limb girdles is common.

Myotonic dystrophy is characterized by weakness and wasting of the face and girdle muscles. In addition, there occurs a failure of muscles to relax after a strong contraction, so that, for example, the patient cannot easily let go after shaking hands. As with many of the conditions of dystrophy, involvement of other body systems is common.

Because the expression of the disease is so variable, some patients having minimal symptoms that pose no threat to life, its prevalence is higher than that of DMD. In myotonia congenita the same failure of relaxation occurs but without the wasting features of dystrophy. Indeed, patients with myotonia congenita have strong and well-developed muscles. Relaxation can be obtained with drugs such as diphenylhydantoin and quinine.

Myopathies

Other inherited muscle diseases. Congenital myopathies begin with weakness and poor muscle development in the early years of life, but generally they are not progressive. Diagnosis is achieved by microscopic examination of muscle biopsies. Lipid storage myopathies are associated with disorders of the metabolism of carnitine, a substance that muscle cells use to convert fatty acids into fuel. In these conditions variable severe weakness of the body musculature progresses slowly throughout life. Muscle biopsy specimens show accumulation of fat in the fibres. In the glycogen storage diseases it is glycogen that accumulates in muscle fibre, owing to a deficiency of an enzyme that helps degrade glycogen into lactic acid for the production of energy. Beginning in childhood, complaints of fatigue, aching, and occasional severe muscle cramps on exercise are usual. Diagnosis is confirmed by demonstrating that the exercising muscles do not produce lactic acid as they should.

Myoglobin is a substance that resembles the hemoglobin in blood and that performs a similar function as a repository of oxygen within the muscles. When muscles are damaged from any cause, myoglobin may spill into the blood and thence into the urine. This condition, called myoglobinuria, can also occur as an inherited metabolic defect, either on its own or in association with muscle disorders. Malignant hyperthermia is a dangerous metabolic muscle disease characterized by high fever and extreme rigidity of muscles, usually provoked by certain anesthetics or muscle-relaxant drugs given during surgery. It constitutes an extreme emergency; rapid cooling of the patient, correction of the accumulation of lactic acid in the blood (the result of intense muscle contraction), and administration of dantrolene sodium to relax the muscles are necessary.

In familial periodic paralyses episodes of weakness of variable duration and severity occur in association with abnormally high or low serum levels of potassium. Some attacks are precipitated by a period of rest following heavy exercise, others by carbohydrate or alcohol ingestion. Depending on the type of paralysis, potassium, glucose, and diuretics constitute the usual treatments.

Acquired diseases of muscle. Myoglobinuria may follow excessive exertion of healthy muscles, crush injury, or toxic damage from drugs or chemicals. It is also a feature of some of the inherited diseases mentioned above. With myoglobin present in urine, there is a danger that it may precipitate in the tubules of the kidney and cause renal failure. Muscle weakness and atrophy may also complicate the administration of many drugs (including cortisone and its derivatives), disease of the thyroid and parathyroid glands, and metabolic bone diseases. Primary tumours of muscle are rare.

Inflammatory muscle disease, called myositis, is seen in association with some viral infections, causing swelling, pain, and weakness, and in trichinosis and other tapeworm infestations, in which allergic skin rashes commonly accompany the same symptoms. Most serious is dermatomyositis, an autoimmune disease characterized by swelling, weakness, and tenderness of the proximal, facial, neck, and bulbar muscles in both children and adults. A skin rash is also present, mainly around the eyes but also on the face and extensor surfaces of the limbs. Diagnosis relies upon electromyography, serum enzyme levels, and sometimes muscle biopsy. Treatment with steroid and immunosuppressant drugs has markedly improved the prognosis for recovery. Closely related conditions without the rash are found in association with collagen-vascular diseases such as scleroderma and polyarteritis or with distant cancers. The response to treatment in these variants is less satisfactory.

Polymyalgia rheumatica is another autoimmune disease. It mainly affects women over the age of 55 years, who complain of severe muscle stiffness (especially after sleep) and of malaise, weight loss, muscle tenderness, and slight fever. In some cases frank inflammation of arteries, particularly of the branches of the carotids, is the most notable problem. Diagnosis is urgent, since blindness may follow if the ophthalmic arteries are involved—as is often the case. The blood sedimentation rate is much increased, and anemia is common. Treatment with steroid drugs produces excellent relief within a day, but it must be continued indefinitely.

THE SPINAL CORD

Spinocerebellar degenerations. These are genetically determined conditions in which evidence of dysfunction of the dorsal columns or the corticospinal and spinocerebellar tracts of the cord appears, usually in the first 20 years of life. They cause difficulty in position sensation, gait, limb power, balance, and coordination. (For further discussion, see below *The cerebellum: Genetic diseases.*)

Myelitis

Inflammation. Inflammation of the spinal cord, known as myelitis, is most commonly due to viral infection such as mononucleosis, mumps, and herpes zoster. It is rarely bacterial, although abscesses outside the dura mater (*e.g.*, tuberculosis) do occur. Severe pain in a girdle around the trunk, loss of motor, sensory, and bladder functions below the level of the attack, meningism, and fever are the main features. Myelitis may also be caused by autoimmune attack following such viral infections as measles and chicken pox or after such immunologic challenges as vaccination. Tabes dorsalis, now uncommon, is an infection of the dorsal-root ganglia by the spirochete bacterium that causes syphilis. Degeneration of the dorsal columns, severe girdle pains, and loss of position sense are the main features, though they often appear together with signs of spirochetal infection elsewhere in the central nervous system.

Paralysis

Trauma. Damage to the spinal cord occurs in association with spinal fractures and fracture-dislocations. The degree to which functions of the cord are affected varies with the severity of the injury. There may be only transient weakness and hyperactive reflexes due to damage to the corticospinal tracts, or there may be full-blown paraplegia with signs of damage to the motor and sensory fibres at the level of injury as well as loss of all sensation below the lesion. Accompanying paralysis, due to damage to descending motor tracts, is at first flaccid and later becomes spastic. After such an injury at high cervical levels, the diaphragm is paralyzed, and the resulting ventilatory failure is life-threatening. Since only minimal regeneration of neurons is possible in the central nervous system, the prognosis for recovery is hopeless and only supportive treatment is available.

Tumours. Tumours within the substance of the cord are labeled intrinsic, those outside but compressing it, extrinsic. Common intrinsic tumours include ependymomas and astrocytomas, which are malignant, and angiomas and cysts, which are benign. Extrinsic tumours include malignant secondary invasion by cancer of the breast, lung, kidney, or prostate gland as well as benign neurofibromas and meningiomas. Other tumours arising outside the dura include lymphomas, lipomas, and chordomas. All of these produce signs of spinal nerve root irritation, with pain and tingling, at the level of the tumour; signs of spinal cord involvement occur later. In all cases diagnosis is confirmed by myelography, usually with CAT or MRI scanning. Raised protein levels occur in the cerebrospinal fluid, but they are not specific to one type of cancer. Malignant cells themselves may be detected in the fluid, allowing precise diagnosis. Surgery and radiation therapy are the principal treatments.

Subacute combined degeneration of the cord. This is a condition resulting from deficiency of vitamin B_{12} from any cause, most often pernicious anemia. Its name indicates its insidious progression and the degeneration of two tracts, the corticospinal and the dorsal columns, which lose myelin and acquire a pale stain from dyes applied when the cord is examined post mortem. Much of the damage is to the large dorsal-root ganglion neurons; their peripheral processes (*i.e.*, the peripheral nerve fibres) are

also demyelinated, so that signs of peripheral neuropathy are superimposed onto the spinal symptoms. Replacement treatment with vitamin B_{12} often leads to improvement.

Vascular disease. Diseases of the blood vessels are surprisingly uncommon in the spinal cord, which contains long segments with a tenuous arterial supply, as in the mid-thoracic area. When blockages do occur, severe atherothrombotic disease of the aorta is a likely cause, as is previous aortic or thoracic surgery, with its risk of interruption of arteries supplying the cord. Compression of arteries by tumour tissue or a prolapsed disk is a rare cause; bleeding from an arteriovenous malformation is another.

Signs of acute, painful, and severe damage to the anterior three-quarters of the cord are usual, this being the area supplied by the single ventral spinal artery. Since the dorsal columns and the dorsal-root entry zone are supplied by three or more dorsal spinal arteries (an arrangement that confers some protection against ischemia) those regions usually escape damage.

Months or years after radiation therapy for such cancers as carcinoma of the breast, small-vessel disease may affect the cord. In this radiation myelopathy a slow but relentless deterioration of the roots and tracts at the irradiated level of the cord leads to spastic weakness of the legs and to less obvious sensory changes.

Syringomyelia. This condition frequently complicates obstructions of the roof foramina of the fourth ventricle. Pressure waves, transmitted through the cerebrospinal fluid down the central canal, enlarge the canal and ultimately lead to a cavity, or syrinx, branching out from the canal and enlarging over years. As a result, sensory fibres, running from the dorsal-root entry zone both to the opposite spinothalamic tract and to ventral-horn neurons at the same level, are interrupted. In addition, compression of the corticospinal tracts occurs. Interruption of the dorsal-root–ventral-horn connection, which mediates reflex activity, results in loss of stretch reflexes and atrophy of some muscles innervated at that level. Interruption of the spinothalamic fibres, which transmit sensory impulses from both sides of the body to the thalamus, leads to loss of the sensations of light touch, temperature, and skin pain, as well as signs of an upper motor neuron lesion below the level of the cavity. Despite the marked sensory changes, which may lead to the patient's burning himself without feeling any pain at all, some perception, such as position sense, is retained. This is an example of dissociated sensory loss, which is also found in some brain-stem lesions, transection of one-half of the spinal cord, and certain peripheral neuropathies.

Diagnosis of syringomyelia is best made by CAT scan combined with myelography or by MRI scanning (Figure 34), but since the cervical spinal canal is often widened in this condition, even a plain X ray of the cervical spine may be enough for diagnosis. Surgical therapy, aimed at draining the cavity and preventing pressure waves from distending it further, may lead to remarkable improvement in some cases, even after severe destruction of the cord.

Multiple sclerosis

Demyelinating disease. This condition frequently affects the spinal cord, and in older patients the cord may be the only clinically evident site of involvement in multiple sclerosis. The corticospinal tracts and dorsal columns are chiefly affected. In a variant of multiple sclerosis called Devic's disease, a band of spinal-cord inflammation and demyelination and optic-nerve involvement are the only features. In some patients with multiple sclerosis, clinical signs of disease of the cord are lacking, but measurement of somatosensory or motor-evoked potentials shows abnormalities indicating that disease is actually present.

Myoclonus. Brief, involuntary jerks of the whole trunk and of the limbs, or of one or two limbs alone, may occur in spinal myoclonus. Many diffuse, metabolic, or local structural causes are possible, but myoclonus more commonly originates in the brain stem or cerebral hemispheres.

THE CRANIAL NERVES AND BRAIN STEM

Olfactory nerve. The olfactory nerve is seldom disordered, but head injuries and pressure from tumours on the floor of the anterior cranial fossa may reduce smell sensitivity or cause complete loss. Patients complain of loss of taste, as all tastes except saltiness, sweetness, bitterness, and sourness are appreciated by the sense of smell.

Optic nerve. Visual-field deficits can occur with disease of the optic nerve or of the pathways traveling back to the occipital lobe. Optic neuritis is occasionally inherited, but it also occurs in some infections and particularly in demyelinating disease. Drug or chemical toxicity are rare causes, and in older people it may result from ischemia. Optic neuritis leads to total or partial loss of vision. Recovery may occur, depending upon the cause and its potential for treatment. It is often difficult to distinguish between compression of the nerve by a tumour or by an aneurysm. With any of these lesions, the nerve eventually loses myelin, causing optic atrophy, or pallor of the nerve head, which can be seen with the ophthalmoscope. Papilledema is a swelling of the nerve head with fluid as a result of raised intracranial pressure from any cause (Figure 36). Vascular diseases of the retina include occlusion of the retinal arteries and veins as well as temporary obstruction of a retinal arteriole by a blood clot from the arteries in the neck.

Lesions of the visual pathways are caused by upward pressure on the optic chiasm, by pituitary tumours or aneurysms and, farther back in the nerve pathway, by strokes or tumours.

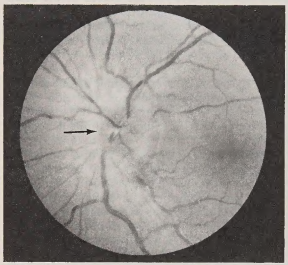


Figure 36: Photograph of the retina, showing (arrow) swelling of the head of the optic nerve. This swelling, called papilledema, is caused by raised pressure within the skull.

Oculomotor, trochlear, and abducens nerves. These nerves may be compressed by mass lesions anywhere along their course or by diabetes, vascular disease, head injury, local infection, and neuropathy. In the brain stem, multiple sclerosis, stroke, Wernicke's disease (see below *Brain stem*), and tumours are possible causes. Depending upon the nerve or nerves involved, various forms of double vision occur; if the oculomotor nerve is affected, the pupil will probably be enlarged as well. Muscle and end-plate diseases may mimic the appearance of discrete oculomotor nerve palsies. In Horner's syndrome interruption of the long sympathetic fibres passing from the brain stem to the pupil leads to drooping of the eyelid and a small pupil.

Horner's syndrome

Argyll Robertson pupils are small and irregular pupils that do not react to light but do constrict on accommodation to close vision. They have traditionally been associated with syphilis, but other brain-stem diseases may also be responsible. Adie's pupil constricts very slowly in light and also dilates slowly when the light is removed. It is not a sign of serious disease.

The two eyes may together fail to move in one or another direction. This gaze palsy may be quite fixed in progressive external ophthalmoplegia, a disorder of the central nervous mechanisms controlling gaze. Other neurological problems, such as parkinsonism, dementia, or neuropathy, may be associated with this condition. Local lesions of the brain stem may also cause paralysis of eye movement, as may severe myasthenia and myopathies affecting the eye muscles.

The jerky eye movements of nystagmus usually signify

brain-stem, vestibular, or cerebellar disease, but they may also be complications of very poor eyesight or may occur as a congenital defect.

Trigeminal nerve. Numbness in the face is commonly due to compression of this nerve, often by a tumour in the cranial cavity or nasopharynx, but it is also caused by brain-stem disorders. Neuralgia of the trigeminal nerve, called tic douloureux, is an intense, repetitive, irregular stabbing pain felt in the lower half of one side of the face. It occurs in elderly people. While the actual pathology of tic douloureux is in dispute, many patients are relieved by microsurgical removal of a loop of normal artery where it impinges upon the nerve at its exit from the brain stem. In most cases, however, drugs such as carbamazepine, diphenylhydantoin, or baclofen relieve the pain so well that no other treatment is needed.

Tic douloureux

Facial nerve. Bell's palsy is the most common lesion of the facial nerve. An abrupt weakness of all the facial muscles on one side, it is often accompanied by pain around the ear, unusual loudness of sounds heard in the ear on the same side, and loss of taste on the front of the tongue. Many patients believe that they have had a stroke, a conclusion corrected when it is seen that they cannot close the eye on the affected side.

The herpes simplex virus can be implicated in some cases of facial palsy. Other causes include lesions of the brain stem (see below) and of the angle between the cerebellum and pons; middle-ear infections; skull base fractures; and diseases affecting the parotid gland. In the Guillain-Barré syndrome, facial weakness on both sides is an important sign.

In hemifacial spasm repetitive twitching of one side of the face occurs. As with tic douloureux, irritation of the nerve as it leaves the brain stem appears to be a cause, and in many cases relief is obtained through surgical decompression.

Vestibulocochlear nerve. Deafness, if not caused by middle-ear disease, suggests damage to the cochlear portion of this nerve, while vertigo, an abnormal sensation of rotation, is a prominent symptom of vestibular-nerve disease. Compression of the nerve at the cerebello-pontine angle by, for example, a benign tumour of Schwann cells, an aneurysm, or meningioma, as well as certain systemic diseases, drug toxicity, small strokes, and Ménière's disease, are the more common neurological causes of hearing loss. In Ménière's disease accumulation of fluid in the inner ear produces increasing deafness and tinnitus, or ringing in the ears. Acute attacks bring intermittent bouts of vertigo. Both medical and surgical therapies are available.

Ménière's disease

The diffuse connections of fibres subserving hearing in the brain make central nervous causes of deafness rather uncommon. Any condition affecting the inner ear or cochlear nerve may give rise to tinnitus. Abnormally high blood flow in the region may do the same, but then the sound has a pulsating quality.

Benign postural vertigo is the term describing brief severe attacks of vertigo induced by movement, especially turning in bed. The condition is unpleasant but benign, occurring at any age and ceasing spontaneously after some months. It is less persistent than vestibular neuronitis, in which prostrating vertigo persists for some days, probably as a result of viral infection of the inner ear or vestibular nerve.

Bulbar nerves. (In this context, the term bulbar refers to the medulla oblongata, which looks like a swelling, or bulb, at the top of the spinal cord.) Diseases of the ninth through 12th nerves show themselves mainly through such motor dysfunctions as impairment of swallowing and speech and weakness of the neck muscles. Bulbar palsy is dangerous because inhalation of saliva or food may cause choking and asphyxia. A nasal tone to the voice and weakness of coughing are early signs. Causes of bulbar palsy include diseases of the brain stem (see below) and of the bulbar nerves themselves. The most important of these latter are motor neuropathies, such as diphtheria, poliomyelitis, and botulism, motor neuron diseases, and compression of the nerves by tumours. Myasthenia gravis and some muscle diseases cause similar signs.

Brain stem. Brain-stem lesions produce a multitude of syndromes according to the site and nature of the pathology. In Moebius' syndrome, the abducens and facial nerves, which originate in the brain stem, may not develop from birth. Encephalitis may affect the brain stem only, with consequent signs of damage to cranial nerves, to cerebellar connections, to the long ascending and descending tracts crowded together in the pons and medulla, and to the reticular activating system and short tracts within the brain stem that subserve the functions of consciousness and the coordination of eye movements. Brain-stem strokes frequently produce clear-cut syndromes that can be sharply localized. Malignant tumours such as gliomas also affect this region, and multiple sclerosis is another common cause of brain-stem dysfunction. In syringobulbia a cavity forms within the brain stem in association with syringomyelia (see above *The spinal cord*) and produces cranial-nerve palsies and both cerebellar and long-tract symptoms.

Wernicke's disease is caused by a deficiency of thiamine (vitamin B_1). It is seen most often in alcoholics who show such symptoms as ocular palsies, nystagmus, memory disturbance, and peripheral neuropathy. The eye symptoms are most readily corrected by the administration of thiamine. Wernicke's disease

Too-rapid correction of severe sodium depletion may lead to edema, or accumulation of fluid, in the central nervous system. Since many motor nerve fibres cross over and intertwine in the pons, the resulting swelling may lead to their compression and dysfunction, a condition known as central pontine myelinolysis because of the resulting demyelination. Depressed consciousness and spastic paralysis of the limbs are the chief manifestations; death frequently follows.

Disorders of sleep. The raphe nuclei of the pons and the locus ceruleus, which mediate sleep, are situated in the brain stem. Sleep consists of two rather different phases: rapid eye movement (REM) sleep and non-REM, or slow-wave, sleep. The latter phase is further divided into different stages during which the person progresses from drowsiness through deeper and deeper levels of relaxation, with decreasing ability to be aroused and with the appearance of progressively slower waveforms on an EEG. In REM sleep, periods of which punctuate slow-wave sleep during a normal night, dreaming occurs. Paradoxically, although the subject appears deeply asleep, there is much fast activity on the EEG, and numerous brief, small-amplitude movements are made by the eyes and the body musculature.

Narcolepsy is a disorder in which, with little warning, irresistible sleepiness overcomes a person during the day. In one form there are vivid hallucinations on awakening or going to sleep, temporary but profound sleep paralysis on awakening that does not affect breathing, and sudden, brief loss of muscle power in the limbs and trunk during emotional moments such as laughter (cataplexy). In this form of narcolepsy it is as though components of REM sleep were intruding into the daytime, waking hours. Narcolepsy is often hereditary. Treatment of the disorder with stimulants and tricyclic drugs is often remarkably effective. No structural disease of the brain has been detected in this condition. Narcolepsy

Other, even more common, sleep disorders include: insomnia, which is usually psychologically mediated but which, like hypersomnia, may also complicate hypothalamic disease; and sleepwalking and night terrors, which occur in the deepest sleep stages even though the person obviously has some awareness of his surroundings. The causes of these phenomena are poorly understood, but structural disease of the nervous system is not responsible.

Brain death. This is synonymous with brain-stem death, since the centres for the control of such essential body functions as consciousness, respiration, and blood pressure are situated within the brain stem. In many countries strict criteria for diagnosis of brain death have been established by common consent among neurological, neurosurgical, religious, ethical, and judicial experts. These include the presence of deep coma with an established cause, the absence of any brain-stem functions such as spontaneous respiration, pupillary reactions, eye movements, and gag and cough reflexes, and the exclusion of low body tem-

perature and drugs as relevant to the comatose state. The EEG is a useful (but not essential) confirmatory test. When such criteria are scrupulously applied and brain-stem death is confirmed, the heart always stops beating within a day or two, even when other vital functions are artificially maintained.

THE CEREBELLUM

The clinical features of cerebellar disorders are given above (see *Localization: Higher-level sites*).

Genetic diseases. Spinocerebellar degenerations are inherited atrophies of parts of the central nervous system and of peripheral nerves. They commonly affect the cerebellum and its connections, as well as the nuclei in the medulla known as the olives, the centres for control of eye movements, the optic nerves, the dorsal columns of the spinal cord, and the corticospinal tracts. Onset is usually in the first two decades of life, but there is great variability both in the age at onset and in the expression of any of the diseases. Some patients show only minimal signs, although most conditions are slowly progressive. Many syndromes are recognized according to the combination of signs produced. The prototype is Friedreich's ataxia, in which the optic nerves, dorsal columns, corticospinal tracts, and cerebellum are affected and in which a peripheral neuropathy is also found, along with skeletal deformities, high arched feet, and rotation of the spine.

Friedreich's ataxia

Inflammatory diseases. These comprise abscesses, which usually complicate chronic infections of the middle ear through the spread of infection along the veins draining back into the posterior fossa, cerebellitis, found in association with some viral infections in children, and tuberculomas, quiescent inflammatory masses acting as tumours by raising intracranial pressure and by creating symptoms of cerebellar dysfunction.

Vascular disorders. Cerebellar hemorrhage occurs in patients with high blood pressure, causing sudden headache, neck stiffness, and cerebellar signs, often with evidence of compression of the brain stem on the side of the bleeding. Prompt surgical evacuation of the blood clot may be life-saving, and the availability of CAT scanning has allowed this diagnosis to be made more accurately than before. Infarcts in the territory of the cerebellar arteries also involve part of the medulla or pons. The prognosis for functional recovery seems better with infarcts in the distribution area of the vertebrobasilar artery than in the carotid circulation.

Demyelinating disease. Demyelination frequently affects the cerebellum and its connections. Indeed, Jean-Martin Charcot, the French neurologist of the late 19th century, defined a triad of signs of cerebellar disease (nystagmus, ataxia, and scanning speech), which he considered diagnostic of multiple sclerosis. (For discussion of multiple sclerosis, see below *Unlocalized or multifocal disorders: Demyelinating diseases*.)

Metabolic diseases. Chronic alcoholism, toxicity of diphenylhydantoin (a drug used in epilepsy), thiamine and nicotinic acid deficiencies, and hypothyroidism, are all responsible for cerebellar dysfunction. In all of these, typical signs of truncal and limb incoordination, or ataxia, are detectable, and in most, treatment reverses the deficits more or less completely. Numerous inherited metabolic defects of metal, lipid, or amino acid metabolism (see below, *Unlocalized or multifocal disorders*) and some diseases marked by serum protein abnormalities also cause signs of cerebellar disease.

Neoplasms. Benign tumours, usually Schwannomas on the vestibular part of the vestibulocochlear nerve, may compress the cerebellar peduncles and lead to dysfunction on one side, but malignant astrocytomas and secondary deposits from distant cancers are more common. In children, medulloblastomas are fast-growing malignant tumours that destroy the central part of the cerebellum and cause severe gait ataxia as an early sign, while astrocytomas grow much more slowly and may be little more than a cyst that can be completely removed, leading to a relatively good prognosis.

Through an unknown mechanism, cancers located elsewhere may lead to degeneration of the cortex of the cerebellum without actually invading it.

THE BASAL GANGLIA

Parkinson's disease. This disease is caused by degeneration of the cells of the substantia nigra and locus ceruleus (both pigmented nuclei in the brain stem) and of their connections with the basal ganglia. The basal ganglia are nuclear masses situated above the brain stem and concerned with the initiation and patterning of voluntary movements. This motor control system employs both dopamine and acetylcholine as chemical transmitters of nerve impulses, and in parkinsonism there is a relative deficiency of the former as a result of the degeneration of neurons in the substantia nigra. This leads to inhibition of the activity within the basal ganglia. Slowness of movement, rigidity of the muscles of the body, stooped and flexed posture, and repetitive tremor of the limbs are the main clinical features of Parkinson's disease, but depression and loss of intellectual agility are also common. Most cases occur in late middle age. The cause is unknown, although encephalitis in early life, many drugs and toxic chemicals, brain trauma, cerebral anoxia, and other degenerative diseases of the nervous system (*e.g.*, progressive supranuclear palsy) cause similar or identical symptoms.

Treatment with levodopa

A tremendous advance in treatment of Parkinson's disease was the introduction in the 1970s of levodopa, or L-dopa, a precursor of dopamine that can be given orally and that crosses the blood–brain barrier into the brain, where it encourages the synthesis of the deficient transmitter. Other treatment approaches are to reduce the activity in the basal ganglia, through anticholinergic drugs, of acetylcholine (which is antagonistic to dopamine); to use such drugs as bromocriptine and pergolide to augment the responsiveness of the receptor sites where dopamine normally exerts its effect; to increase dopamine release using amantidine; and to block the action of the enzyme that breaks down dopamine by selective inhibitor drugs such as deprenyl. As a result of these approaches, the patient with Parkinson's disease can now expect many more years of functional activity than was thought possible in the 1960s, although progression of the disease cannot be halted. In severe cases the patient is eventually disabled by a combination of the disease and side effects of treatment.

Dystonias. These sustained muscular contractions, which produce abnormal postures of the face, head, trunk, and limbs, are caused by disease of the basal ganglia. Other abnormal involuntary movements, such as vocalizations, tremors, and body jerks, may also occur. The number and classification, and the biochemical and anatomical bases, of these movements are not clear. Diagnosis is difficult since many of the movements occur only intermittently and the influence of emotional states and normal activity upon them often leads to the incorrect diagnosis of hysteria. Both generalized dystonias affecting the limb and trunk muscles (*e.g.*, dystonia musculorum deformans) and focal dystonias (*e.g.*, writer's cramp, orofaciomandibular dystonia, torticollis) are seen. Generalized dystonia is an inherited condition in which persistent and often painful twisting and writhing movements of any muscle group occurs, usually in children. Their intensity may be so great as to make self-care impossible. While a number of drugs have been found effective in reducing the movements, none is consistent, and surgery on the thalamus is needed in the most severe cases. The surgical operation performed—destruction of the ventrolateral nucleus of the thalamus by local freezing—relieves muscle rigidity. It is also used to reduce tremors in severe Parkinson's disease and to incapacitate benign essential tremor. The ventrolateral nucleus has a modulating influence on the motor system, but it is not known precisely why surgery on the nucleus works in these situations.

Tics are related to dystonia, but they consist of brief, purposeless, stereotyped movements or utterances of unknown cause. At worst, sudden, explosive speech or movements occur repeatedly, as in children with the syndrome of Gilles de la Tourette. The range of drug therapy of potential value is as wide in this condition as with dystonias, and success is as uncommon.

Chorea. Brief, variable, small-amplitude, and involuntary dancelike movements are usually seen with disease of the caudate nuclei, which are part of the basal ganglia.

Huntington's disease

Huntington's disease is the most feared cause of chorea, since this inherited, dementing illness leads to early death but seldom declares itself until after the early procreative years. The discovery of the responsible chromosome has made possible effective genetic counseling and presymptomatic diagnosis. Early hallmarks of the disease are personality change, such as irritability and depression, and a liability to alcohol abuse. This is followed by intellectual deterioration with paranoid thinking and brief, involuntary, semi-purposive, jerky movements of the limbs and face—or, less commonly, to progressive rigidity of the body musculature. While treatment with phenothiazine or butyrophenone drugs is helpful for the movements, the mental symptoms progress inexorably.

Chorea also occurs in a nondementing, inherited form, as a complication of rheumatic fever in children (Sydenham's chorea) and of pregnancy (chorea gravidarum) in a few systemic diseases (*e.g.,* hyperthyroidism, lupus erythematosus), and as a toxic effect of drugs (*e.g.,* oral contraceptives and levodopa). In a more severe form called hemiballismus, caused by a small infarct of the subthalamic nucleus, wild, flinging movements of one side of the body exhaust the patient. Patients respond to drug therapy as in Huntington's disease.

Tardive dyskinesia is the name given to a syndrome of choreic movements affecting the face, eyes, tongue, and trunk, which usually appear after prolonged treatment with antipsychotic drugs such as the phenothiazines. Treatment with reserpine or amantidine may be partially successful.

Wilson's disease

Wilson's disease, an inherited condition, is characterized by cirrhosis of the liver and degeneration of the lenticular nuclei of the basal ganglia. The movement disorders produced by this condition include chorea, dystonia, athetosis (continuous, serpentine, writhing, and twisting movements around the long axes of the limbs), and tremor. Also, brown pigment is deposited around the edge of the cornea, and behavioral and intellectual disturbances are common. The disorder is due to the deposition of copper in the brain, corneas, and liver (urinary levels are also high)—all as a result of an inborn error of metabolism leading to failure of the liver to excrete copper normally. Treatment with d-penicillamine and a low-copper diet shows striking success in preventing progress and often reverses the course of the disease. Genetic counseling is another vital part of therapy.

Athetosis is also a complication of strokes, anoxia (particularly at birth), and hemolytic disease of the newborn (in which bilirubin derived from damaged red cells is deposited in the basal ganglia, causing the formation of glial scar tissue).

Essential tremor. In this common inherited disorder, which can occur at any age, movements are interrupted by a regular oscillation of the limbs, as during writing. The tremor is usually absent at rest and often affects the head and voice. It is frequently confused with parkinsonism, but the other features of that condition are not present. Alcohol reduces the problem, but β-adrenergic blocking drugs and primidone are more effective treatments.

THE CEREBRUM

Concussion

Craniocerebral trauma. The concussive and shearing stresses of head injury may cause concussion (a brief loss of consciousness without permanent consequences), contusion of the brain (most often of the tips of the frontal and temporal lobes, called contre-coup injury), or laceration of the brain tissue. In the last two cases, neurological deficits are detected at the time of injury, and with laceration (as in a depressed fracture of the skull) or bleeding into the brain, the eventual incidence of seizures is high. This is called posttraumatic epilepsy.

Complications of head injury include the development of extradural hematomas, often from tearing of the middle meningeal artery. Arterial blood, pumped into the space between the dura and the inside of the skull, acts as a fast-expanding mass lesion, compressing the brain downward through the tentorium or the foramen magnum. This is a lethal complication unless quickly relieved by surgical removal of the clot. Subdural hematomas are usually slower in development and may sometimes take weeks to form; they follow the rupture of small veins bridging the gap between the surface of the brain and the meninges. While compressive symptoms similar to those of extradural hematomas can occur, in most of these cases they are subacute or chronic, producing headache, seizures, or intellectual decline. Removal of the clot is the usual treatment.

Other complications include cranial nerve palsies, subarachnoid hemorrhage, thrombosis of a carotid artery, and cerebrospinal fluid leakage, which may lead to intracranial infection. Focal deficits are also common with brain tissue damage. Later consequences include dementia, seizures, and the posttraumatic syndrome of irritability, fatigue, headaches, insomnia, loss of concentration, poor memory, and loss of energy. Repeated minor head injuries, as occurs in some boxers, may also lead to dementia and to a Parkinson's-like syndrome.

Cerebral palsy. This term encompasses all the conditions that damage the brain around or before the time of birth—other than obviously developmental causes. Approximately six cases occur in every 1,000 live births in the Western world. Hypoxia and asphyxia during a prolonged and difficult labour are the most common causes, but improvements in obstetrical care have reduced the incidence of the condition. It is manifest by a delay in the motor development of the infant, who shows such clinical evidence of damage to the motor systems as spasticity, weakness of the limbs, and athetosis or ataxia. Sensory, visual, and cognitive defects may be detected later. Mental retardation occurs in about half of these children.

Mental retardation. Retardation signifies incomplete or insufficient general development of mental capacity, encompassing a global delay in the normal development of motor, language, and social adaptive skills. It has numerous causes. Before birth, chromosomal and developmental diseases, genetic and other metabolic disorders, and intrauterine infections or toxicity are important causes, while at the time of birth, asphyxia and hemolytic disease are prominent. In the postnatal period, nutritional deficits, infections such as meningitis, encephalitis, and the postinfectious syndromes, trauma, and toxins are the most frequent causes. Apart from delays noted in early learning and, eventually, substandard school performance, behavioral abnormalities and impaired emotional control are also common. Continuing advances in the understanding and early diagnosis of genetic diseases and in obstetrical care may further reduce the incidence of mental retardation, but it still represents a severe economic and emotional burden both for the family and for society.

Down's syndrome

Down's syndrome is the best known of the chromosomal disorders producing mental retardation. More than one in every 1,000 live-born children in the West suffer from this condition. Clinical features include short stature, smallness of the head, obliquely slanted eyes, a flattened face, wide hands with a single transverse palmar crease, short digits, and floppy muscles. The degree of mental retardation is variable. The brain is slightly smaller than normal, and the appearance of the neurons and perhaps the myelin are also abnormal (Figure 37). After the age of 30, neuropathological features common in Alzheimer's disease are almost always detectable in Down's syndrome patients. Discovery of the abnormal chromosome causing the syndrome allows prenatal diagnosis by examination of the amniotic fluid.

Dementia. This decline in intellectual capacity is caused by organic disease of the brain. Single deficits such as aphasia, an inability to use language, are not sufficient for a diagnosis of dementia, which requires evidence of diffuse, bilateral brain involvement. Common early clinical features include rigidity and blunting of personality, loss of interests, impairment of attention and concentration, difficulty with comprehension, and difficulty in handling abstract concepts. Later, increasing impairment of the capacity to retain new information, social withdrawal, unnecessary repetition of words and actions, and volatile emotions are signs of the disintegration of the mind. As dementia progresses, language ability begins to fail, the patient neglects to care for himself appropriately, and neurological signs appear on clinical examination.

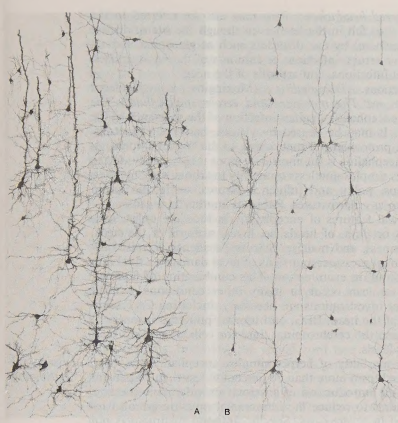


Figure 37. Drawings of neurons from the occipital cortex of the brain, showing neuropathology of Down's syndrome. (A) Normal. (B) Down's syndrome, with loss of dendrites and spines.
By courtesy of L.E. Becker and F.W. Chan

Alzheimer's disease

The most common cause of dementia is Alzheimer's disease, but the absence of a specific test for this condition (apart from the major procedure of brain biopsy) makes the diagnosis one of exclusion. Biopsy may reveal characteristic changes of neurons in the cerebral cortex. The entire cortex is affected, although the brunt of the disease falls on the frontal lobe. Other areas of the brain are also affected, such as the hippocampus and amygdala, the brain stem, and the basal forebrain (the basal nucleus of Meynert). Alzheimer's disease carries a slight familial tendency, but the etiology of the disease is not known. Research continues on many fronts, including intensive surveys of possible environmental causes. The disease is increasingly common with old age. There is no specific therapy for the condition. Augmentation of brain acetylcholine (the neurotransmitter concerned in memory processes) is not very effective.

Multi-infarct dementia is the next most common type. It is the result of numerous small strokes, the cumulative effects of which impair the function of so much of the brain that the patient has truly global intellectual impairment. Clinical diagnosis is confirmed by demonstration of the infarcted areas on CAT scanning.

The multitude of other causes of dementia can be separated into three groups. (1) General medical illnesses include states of vitamin deficiency, intoxications, endocrine disorders, and metabolic diseases. (2) Underlying neurological disorders, among whose features dementia may appear, include some genetic diseases, brain inflammation, trauma, primary and secondary tumours, degenerative diseases, severe multiple sclerosis, and, less commonly, widespread disease of the larger or smaller arteries. (3) In a final category are some conditions of uncertain cause; normal-pressure hydrocephalus, Pick's disease, and progressive supranuclear palsy are examples.

A major condition that must be distinguished from dementia in all cases is depressive illness. Since the two may coexist, correct diagnosis may be difficult.

Epilepsy. Epilepsy is a tendency toward recurrent seizures. One seizure alone is not sufficient for the diagnosis. (The nature of the condition is described above; see *Pathologies.*) Epilepsy is estimated to affect between 1 and 2 percent of the population. The most useful classification divides seizures between those of unknown cause without any detectable brain abnormality (idiopathic, or primary, epilepsy) and those caused by structural lesions in the brain (symptomatic, or secondary, epilepsy). Another system, the International Classification of the Epilepsies, defines two major categories: generalized seizures (roughly corresponding to primary epilepsy) and partial seizures (corresponding to secondary epilepsy). Numerous subcategories are also defined.

Primary epilepsy. In the primary group, onset is in the early years of life, and there is a genetic component in causation. One primary type is grand mal, or tonic-clonic, attacks, in which the subject loses consciousness without warning, falls, and stiffens, with all muscles contracting maximally. He then begins a series of rapid but slowing jerks of the whole body that cease in approximately a minute, leaving him limp and still unconscious. The person awakes a few minutes thereafter, usually sleeps for a while, and is then back to normal unless further seizures occur.

Grand mal attacks

A second form is petit mal epilepsy, also known as absence attacks, during which the subject is unaware of his surroundings for a few seconds. The person may show little abnormal behaviour, except that he usually stops whatever he is doing, and his eyelids flutter. Such attacks may occur hundreds of times daily in an uncontrolled case (Figure 33).

Myoclonic epilepsies constitute a third form of primary epilepsy. In these cases, single or repeated brief shocklike contractions of all body muscles occur.

Although genetic factors are important, any person could be made to have a seizure, usually of grand mal type. Sleep deprivation, extreme fatigue, drug toxicity, certain metabolic disturbances, and withdrawal from drugs or alcohol are potent precipitants of seizure, and, when they can be incriminated, neither underlying brain disease nor the need for drug treatment need be considered.

Secondary epilepsy. The secondary epilepsies have even more varied presentations, since, in these, spontaneous electrical activation of any brain area can be the basis of the seizure. Both the causative brain diseases and the clinical varieties of seizure are innumerable. In one group, consciousness is retained while abnormal sensations, visual hallucinations, or local muscle contractions occur. In another group, caused by lesions within the temporal or frontal lobes, there are distortions of memory leading to illusions, abnormal sensations, hallucinations of smell or hearing, limb jerking or abnormal posture, and psychological symptoms in any combination. Any of these attacks may lead to seizures resembling grand mal attacks.

Diagnosis and treatment. The task of the neurologist is to confirm that the symptoms of the patient are in fact caused by abnormal electrical discharges, to determine whether they represent primary or secondary epilepsies, and, if the latter, from where in the brain they arise and the nature of the causative pathology. In patients whose seizures begin in adult life, secondary epilepsies must be assumed until proved otherwise. After clinical assessment careful investigation is almost always required. This includes EEG (perhaps with television monitoring), CAT scanning, and often other tests for underlying infectious, metabolic, or cancerous conditions.

Drug therapy

Treatment of epilepsy depends upon the nature of the attacks, since some drugs that suppress one form of seizure may actually worsen another. For the primary generalized epilepsies, valproic acid, ethosuximide, clonazepam, diphenylhydantoin, and carbamazepine are the drugs of first choice. For the secondary epilepsies, carbamazepine, diphenylhydantoin, and primidone are preferred. These drugs have different modes of action. Some selectively block the high-frequency electrical discharges that lead to seizure activity, while others stimulate the inhibitory effect of the neurotransmitter gamma-aminobutyric acid (GABA).

In cases where control of seizures proves difficult, repeated estimations of the concentration of the drug in the serum are necessary as are appropriate blood tests to detect unwanted effects on the blood and other organs in the body, such as the liver. Surgical therapy is reserved for cases in which the seizures are uncontrolled by drugs and in which a single focal origin of the seizures

is demonstrated. There are few such cases, and over 80 percent of patients with seizures achieve excellent control through faithful adherence to a regime of drug therapy. When epilepsy complicates severe brain damage, however, control may be impossible.

Headache. Diagnosis of a type of headache can usually be achieved by a complete history and physical examination without laboratory tests. There are four major varieties of headache, each with its own type and severity of pain, temporal relationship, site and pattern of radiation toward other areas, nature of aggravating or relieving factors, and associated symptoms.

Vascular headaches. These include migraine and its variants as well as headaches due to abnormal stretching of the arterial walls in the cranium as a result of vessel-
Migraine wall disease. Migraine headaches recur periodically; often a family history of the ailment can be obtained. The pain is typically severe, throbbing or pounding, felt on one or both sides of the head, and made worse by activity, noise, or bright lights. In classic migraine, visual phenomena such as zigzag lights in the visual fields precede the onset of pain. In complicated migraine, visual loss, weakness of a limb or of one side of the body, speech disturbances, or confusion may accompany and outlast the headache. Nausea and vomiting, pallor, irritability, and prostration usually accompany migraines of any variety. In a variant called cluster headache, excruciatingly severe pain is felt in and around one eye, lasting an hour or so and frequently waking the patient from sleep in the early morning. Such attacks occur in clusters, the pain occurring 10 or 20 times over a month or so, with months of freedom until the next cluster begins.

The treatment of migraines involves a careful search for the factors that precipitate them. Foods such as cheese and chocolate, beer and red wine, and those containing nitrite or monosodium glutamate are the most frequent culprits; their removal from the diet may be sufficient to relieve the patient permanently, but total success is uncommon. Other factors include excessive or deficient sleep, physical and psychological stresses, oral contraceptives, and the menstrual cycle in many cases. Drug therapy (such as ergotamine, anti-emetic agents, or even inhaled oxygen, and pain-relieving agents) may be necessary in acute attacks. As preventive measures, tricyclic drugs, adrenergic blocking agents, lithium, and numerous other classes of drug are available. In elderly patients brief episodes of brain dysfunction resembling small strokes may occur, apparently due to arterial spasm during migraine; in younger patients with severe migraine such spasm may very rarely cause such a reduction of blood supply to parts of the brain that permanent deficits occur.

Vascular headaches may be complications of fever, hangover, lack of oxygen, low blood sugar, and ingestion of certain drugs; they are also typical of cranial arteritis, a variant of polymyalgia rheumatica. In all these conditions treatment is directed at the underlying cause.

Tension headaches. These are continuous and generalized pains felt from front to back or all around the head; they are generally less severe than migraines. While emotional stress and letdown after such stress are the most common causes, arthritis of the joints of the neck may also contribute. Tension headaches alone are often experienced by migraine sufferers, and a combined form of headache also exists. Treatment is of the psychological cause when detectable, but chronic tension headache may be self-perpetuating.

Traction headaches. These are caused by the distortion
Intracranial of intracranial pain-sensitive structures. They have a much
pressure more serious import, as intracranial bleeding or tumours, brain infections, obstruction to the flow of cerebrospinal fluid, and low pressure in the fluid due to leakage after lumbar puncture are typical causes.

Such headaches are moderately but increasingly severe, involve the whole head, may have a throbbing component, are worse with movement and coughing and on awakening, and improve as the day progresses but recur for hours daily. They are often accompanied by focal neurological signs and signs of raised intracranial pressure. Diagnosis demands a full investigation.

Referred headaches. Pain may also be referred to the head (*i.e.*, felt in the head even though the site of disease is elsewhere) by eye disorders such as glaucoma and refractive errors, infections or tumours of the nasal sinuses, dental infections, and arthritis of the neck.

Infections. *Encephalitis.* (Meningitis is considered above; see *The meninges and cerebrospinal fluid.*) The term encephalitis signifies infection of the substance of the brain. It may be caused by viruses, bacteria, rickettsias, fungi, protozoans, or metazoans. In the Western world, viral encephalitis is the most common; it is typically due to herpes simplex and less commonly to arboviruses, measles, mumps, polio, and influenza viruses, or to the group known as enteroviruses. Rabies is another rare cause.

Typical features of encephalitis include the onset, over hours or days, of headache, fever, stiffness of the neck, drowsiness, and malaise. Seizures, evidence of raised intracranial pressure, and signs of focal damage to the brain are found on examination. This combination of findings, however, can occur in many other conditions, so that further investigations are necessary, including CAT scanning of the head, EEG, and lumbar puncture in order to examine the cerebrospinal fluid for cells, organisms, and sugar levels.

The mortality of herpes simplex encephalitis has been reduced from more than 60 percent to less than 20 percent with the introduction of acyclovir or vidarabine therapy. Measures to reduce the intracranial pressure are also required in severe cases. Specific antiviral treatment is not available for other forms of viral encephalitis.

Abscess. Cerebral abscess is due to bacterial infection that may be introduced from the bloodstream in cases of generalized or distant infection or from contiguous infection following a skull fracture. The infection produces a pus-filled abscess, usually localized close to the site of the original infection. The clinical features are the same as with viral encephalitis, but removal of cerebrospinal fluid by lumbar puncture is dangerous because swelling may cause the brain to herniate downward, with fatal compression of the vital centres. In many cases, evidence of the source of the invading organisms—such as chronic lung suppuration, congenital heart disease, or sinus or ear infections—suggests the diagnosis. Efforts can then be made to localize and typify the infection by EEG and CAT scanning.

Infection travels along the course of the intracranial Cortical thrombo-
veins, which themselves are infected and which thrombose, or clot. Such cortical thrombophlebitis can occur in the venous channels of the dura mater, resulting in infarcts of the surrounding brain and damage to contiguous cranial nerves. This condition is seen especially in children suffering from malnutrition and dehydration, but it also complicates some blood diseases and may occur in pregnancy. The symptoms resemble those of cerebral abscess, but there is a greater likelihood of seizures. phlebitis

As treatment, antibiotics are chosen according to the nature of the organism likely to be responsible, and surgical removal can follow encapsulation of the abscess within scar tissue. Anticoagulants may be used in cortical thrombophlebitis.

Abscesses also occur both outside and just below the dural membranes enclosing the central nervous systems, usually arising by spread of local infection.

AIDS. The acquired immune deficiency syndrome, or AIDS, virus causes an infection that greatly diminishes the body's cell-mediated immune system, thus disposing it to infections that healthy people seldom contract. Many viral infections as well as tubercular, toxoplasmic, fungal, and spirochetal infections of the brain or meninges occur as a result. Neurological complications include encephalitis, due to these superadded infections, or progressive dementia, directly due to invasion of the brain by the AIDS virus.

Following common viral infections such as measles, during bacterial endocarditis (a bacterial infection of the heart valves), or after vaccination against such diseases as smallpox, an acute neurological illness with meningeal irritation, fever, reduction in consciousness, seizures, focal signs, and evidence of raised intracranial pressure may occur. This is known as acute toxic encephalopathy and

is thought to represent an acute allergic reaction of the immune system to the preceding infection. In Reye's syndrome, a variation occurring in children, the same features are found, along with persistent vomiting that accompanies an acute degenerative change in the liver. There is some evidence that aspirin may precipitate the condition.

In yet another related syndrome, acute allergic encephalomyelitis, a similar illness occurs, again in the second week after vaccination or viral infection. This illness appears with signs of encephalitis and inflammation of the spinal cord or nerve roots. Damage to the myelin sheaths in the central nervous system is the basis of the disorder. Treatment with steroid drugs (related to cortisone) is sometimes effective, but many patients die during the acute stages of the illness.

Syphilis. This disease follows infection with the spirochete *Treponema pallidum,* almost invariably as a result of sexual contact or infection of the fetus in utero. Primary syphilis produces a chancre, or sore, at the site of infection; weeks later, secondary syphilis develops with a skin rash and signs of mild meningitis, but, in the third stage, signs indicate that the spirochete has invaded the substance of the nervous system. One syndrome is tabes dorsalis, involving the spinal cord (see above *The spinal cord: Inflammation*). Another is general paresis of the insane, an outmoded term for chronic syphilitic encephalitis, which causes progressive dementia and signs of focal damage to many brain areas. These two conditions may coexist. Diagnosis is confirmed by serological tests in the blood and by examination of the cerebrospinal fluid. Treatment with penicillin stops the progress of the disease and may relieve some of the more florid signs.

Progressive dementia

Slow viruses. In 1957, an unusual disease called kuru was described in the Fore tribe of New Guinea. Its means of spread was traced to ritual cannibalism, and its features included abnormal involuntary movements, dementia, and serious disturbance of motor functions. The disease was invariably fatal. A transmissible agent with a very long incubation period of years was shown to be the cause. This and similar agents are known as slow viruses, although they have properties quite distinct from those of conventional viruses.

Creutzfeldt-Jakob disease is a rare cause of rapidly developing dementia in adults, with added signs of multifocal disturbance of the brain and spinal cord. This condition has been transmitted between humans through such means as a corneal transplant taken from a person who unknowingly had the infection. The disease is fatal, and no treatment is known to affect its course. The transmissible agent resembles that of kuru.

Subacute sclerosing panencephalitis is characterized by slowly increasing loss of mental abilities, brief, shocklike jerks of the body, weakness, and spastic muscles. It affects children and young people. The measles virus is the responsible agent, probably evoking an abnormal response of the patient's immune system.

Progressive multifocal leukoencephalopathy is another fatal disease of the brain occuring in patients whose immune system is suppressed by drugs or disease. Progressive loss of myelin occurs in the white matter of the brain, cerebellum, and spinal cord. A polyoma virus that does not normally cause disease in man is responsible.

Neoplasms and nonmetastatic syndromes. Tumours affect the brain directly and indirectly. Their direct effects are mediated through replacement or compression of tissue, in each case impairing the function of the compressed part and often first appearing through epileptic seizures. Indirect effects include raised intracranial pressure, which is particularly common in the case of tumours arising within or compressing the ventricular system. A useful classification separates the benign tumours, which do not spread within the brain or metastasize (seed themselves) to distant sites, from malignant tumours, which do have these characteristics.

Benign tumours. Benign intracranial tumours include neurofibromas (technically tumours of the myelin-forming Schwann cells), which grow on cranial nerves. The most common are tumours of the vestibulocochlear nerve, tumours of the skull, and meningiomas. Pituitary adenomas arise within the pituitary fossa. By compressing the underside of the optic chiasm, they cause deficits in the visual fields, and they raise the intracranial pressure through compression of the hypothalamus and third ventricle. In addition, many secrete hormones, which may stimulate such reactions as abnormal growth and lactation. These signs may be the first evidence of pituitary adenoma. Surgical removal, approaching through the nose or through craniotomy (opening up the cranial cavity), is often required and may lead to cure, but small tumours of the pituitary may be suppressed by the drug bromocriptine.

Pituitary adenoma

Craniopharyngiomas arise from a vestigial remnant of tissue in the roof of the mouth and extend upward to produce effects similar to those of pituitary tumours. Since they often contain calcium, they may be seen on plain skull X rays. Craniotomy is necessary for their removal. Colloid cysts are found within the ventricles. Although seldom causing symptoms, on account of their small size, they occasionally block the flow of cerebrospinal fluid, causing an acute rise in intracranial pressure that results in headache and loss of consciousness.

Other benign intracranial masses include parasitic cysts, granulomas, tuberculomas, and dermoid cysts. These may arise in any part of the brain or beside it, in which case there may also be involvement of the skull bones. Infective tumours are now uncommon in the Western world.

Malignant tumours. Malignant tumours of the brain are more common than benign ones; the most frequent of all are the gliomas, which arise from the neuroglial cells. They are of varying degrees of malignancy as judged by their speed of growth and tendency to spread. Astrocytomas arise anywhere; destroying the function of the tissues that they invade and replace, they also cause seizures and eventually signs of raised intracranial pressure. The prognosis for astrocytomas arising in the cerebellum and for the least malignant of the others is fair after surgical removal and radiation therapy, but in the case of the most malignant, the glioblastoma multiforme, life beyond a year after diagnosis is exceptional.

Astrocytoma

Medulloblastomas and ependymomas are other varieties of glioma arising, respectively, in the brain stem and in the walls of the ventricles. The former are described above (see *The cerebellum: Neoplasms*). The latter also grow in the posterior fossa in young people, but more slowly. Because of their site of origin, they tend to cause early increase in intracranial pressure, with signs of brain-stem and cerebellar dysfunction. Surgical removal is seldom complete, but radiation therapy is able to shrink the tumour and slow its growth.

Oligodendrogliomas occur anywhere in the cerebrum and are particularly liable to cause epileptic seizures. They often contain calcium, which may allow their detection in plain skull X rays. Teratomas and pinealomas are more common in young men; arising from the region of the pineal gland and damaging the hypothalamus and upper brain stem, they disturb the control of eye movement, obstruct the flow of cerebrospinal fluid, and cause cerebellar dysfunction. Their behaviour may resemble that of a benign or of a malignant tumour. Lymphomas such as Hodgkin's disease rarely invade the brain, though they may compress it; but reticulum cell sarcomas (microgliomas) do invade diffusely and cause headache, seizures, change in personality, and various focal signs.

In all such cases, whether benign or malignant, tumours are suspected from the history of headache, seizures, and focal neurological problems; diagnosis is then confirmed by CAT or radioisotope scanning. Surgery is usually necessary in order to confirm the nature of the tumour, to relieve increased pressure, and to remove all or part of the mass itself. In malignancies this at least makes subsequent radiation therapy more effective, but in the gliomas the prognosis is poor in most cases despite such treatments. The swelling surrounding these tumours can often be greatly reduced by a steroid drug with rapid but temporary relief of symptoms.

Malignant tumours arising elsewhere in the body may metastasize to the brain; common sites of origin of such secondary tumours are the lung, breast, thyroid, and kidney. These are usually multiple tumours, so that surgical

removal is usually fruitless, although radiation therapy may shrink them and slow their growth.

Nonmetastatic syndromes are constellations of clinical features reflecting damage to the nervous system as a result of cancer elsewhere in the body that has not actually spread to the brain or spinal cord. How this arises has not been fully elucidated. Dementia, a syndrome resembling encephalitis, cerebellar degeneration, signs of transverse damage to the spinal cord, peripheral neuropathy, disease of the end plate somewhat resembling myasthenia, and weakness and wasting of muscles are common presentations of these syndromes.

Stroke. *Anatomy and collateral supply.* Blood follows two avenues to the brain: the two internal carotid arteries, which divide intracranially into a number of branches (the largest being the anterior and middle cerebral arteries); and the vertebral arteries, which fuse at the base of the brain and then divide again to form the posterior cerebral arteries (Figure 38). There are many communications between vessels inside and outside the head, and, in some places, two arteries supply the same territory. Despite this generous blood supply the huge requirements of the brain for blood and the fact that the last branches of arteries anastomose, or join together, very little, if at all, make the supply quite precarious. To help smooth out the different rates of cerebral blood flow caused by variations in heartbeat, respiration, blood pressure, and posture, a system of autoregulation exists whereby the cerebral blood vessels vary their size in response to such changes.

The carotid and vertebral arteries

Yet, in diseased states, the blood supply to parts of the brain still often fails. The effects vary from minor, transient slowing of activity, due to slight reduction in local blood flow, to severe, permanent loss of function when blood supply is completely lost. These failures of blood supply are strokes.

(Data) From R.D. Adams and M. Victor, *Principles of Neurology*, 3rd ed., copyright © 1985 by McGraw-Hill, Inc., (art) reproduced by permission of Catherine Parker Anthony and Gary A. Thibodeau, *Textbook of Anatomy & Physiology*, 12th ed. (1987), Times Mirror/Mosby College Publishing, St. Louis; adapted from K. Brodmann, "Feinere Anatomie des Grosshirns," in *Handbuch der Neurologie* (1910), Springer-Verlag, Berlin

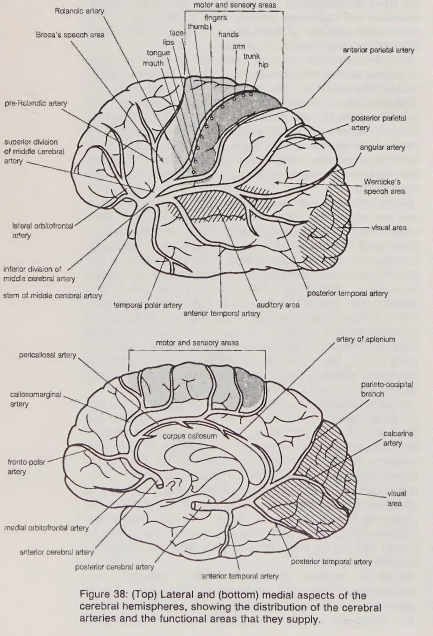


Figure 38: (Top) Lateral and (bottom) medial aspects of the cerebral hemispheres, showing the distribution of the cerebral arteries and the functional areas that they supply.

Pathogenesis and classification. The two main types of stroke are (1) those in which a blood vessel supplying a part of the brain is occluded briefly or permanently and (2) those in which the vessel bleeds as well, so that the loss of blood supplying the tissue is aggravated by a blood clot compressing it.

Occlusive strokes are further divided by clinicians into four groups: (1) Transient ischemic attacks (TIAs) are the mildest, the symptoms lasting only for minutes or hours. They are usually caused by small emboli, such as fragments composed of blood cells or cholesterol, that are swept into the brain's circulation from the arteries of the neck or elsewhere. (2) Reversible ischemic neurological deficits may have the same pathological basis, but the symptoms last for up to three weeks. (3) Evolving strokes show a stuttering or progressive deterioration. Blockage of the larger arteries in the brain or neck is usually responsible. (4) Completed strokes represent the final result not just of relative reduction in blood supply (ischemia) but of the death of brain tissue as a result of severe starvation of blood (infarction).

Transient ischemic attack

The most common pathological change causing stroke is atherosclerosis of the large- and medium-sized arteries in the neck and brain, which causes ulcers in the wall of the artery, narrowing of the lumen, or blockage of the vessel by a combination of these changes and blood clot. Small-vessel disease is the next most common, in which the thickening and degeneration of the walls of the arterioles are usually due to high blood pressure. Other vessel-wall diseases include inflammatory changes, as in collagen-vascular diseases or after deep X-ray treatment; spasm, as in severe migraine; splitting of the wall of the artery; and direct injury. Larger emboli causing more than just a TIA may arise in the larger arteries and from the valves or lining membrane of the heart.

Among other mechanisms for stroke are a severe global decrease in cerebral blood flow, as may occur with a severe hemorrhage or heart attack; diversion of blood to other arteries, as a result of a narrowing or blockage of a vertebral artery in the neck; cerebral anoxia, a severe reduction in the amount of oxygen in the blood; and abnormal viscosity of the blood due to excess numbers of cells or to increased protein concentration in the blood.

Hemorrhagic strokes are usually due to small-vessel disease in patients with high blood pressure. Such intracerebral hemorrhage occurs most often in the deep white matter of the brain, brain stem, and cerebellum. The incidence of such strokes has been reduced in part by the introduction of more effective treatments for hypertension. Bleeding also occurs when a defect in the wall of an artery, called an aneurysm, gives way. When this occurs at the sites of branching of the larger arteries inside the head, blood spills into the subarachnoid space, causing subarachnoid hemorrhage. Bleeding may also occur with malformations of arteries and veins, into an infarct, and with blood diseases that impair coagulation.

Hemorrhage

Clinical syndromes. The features of TIAs (and of any stroke syndrome) depend on which part of the brain has been affected. Transient loss of vision in one eye, like a graying-out or as if a curtain were being pulled over it, is one common manifestation of ischemia of the retina. Similar brief episodes of numbness or weakness of a limb or difficulty in speech suggests an attack in the carotid-artery territory, while brief reduction in consciousness, vertigo, slurred speech, impaired vision in both eyes, or imbalance point to ischemia in the vertebrobasilar circulation.

Infarction of the brain occurs most often during sleep, the patient awakening to find that he has lost the function of that part of his body supplied by the occluded vessel. The most common site of stroke is in the territory of the middle cerebral artery. The usual symptoms are aphasia and other disorders of higher cerebral functioning, hemiparesis (weakness of the face and arm more than of the leg on the other side of the body), and loss of sensation in the same areas. Blockage of the internal carotid artery in the neck produces a similar picture. Because there is extensive

Symptoms of stroke

communication between the anterior cerebral arteries on both sides, the area of the brain supplied by the anterior cerebral artery on the occluded side may escape damage. Anterior cerebral artery infarcts produce weakness and sensory change on the opposite side of the body, but the leg is more affected than the arm. Posterior cerebral infarcts cause loss of vision in the opposite half of the visual field and sometimes difficulty in the comprehension of speech (called receptive aphasia).

An infarct of the area of brain supplied by the basilar artery is usually fatal because of severe damage to the vital control centres in the brain stem.

Small, deep infarcts in the white matter also occur. The small cavities of damaged tissue, called lacunes, cause a number of syndromes in which the damage is restricted to, for example, pure weakness or pure sensory dysfunction on one side of the body.

Intracerebral hemorrhage most commonly occurs in the putamen and leads to sudden headache, severe hemiparesis, loss of consciousness, and deviation of the eyes to one side. Bleeding into the pons causes paresis of all limbs and loss of consciousness. Bleeding into the cerebellum produces typical signs of incoordination with headache and stiffness of the neck.

Massive cerebral infarction or hemorrhage, with swelling of the brain, is often fatal. With less severe brain damage a surprising degree of recovery occurs, so that a hemiplegic patient learns to walk again although use of the hand remains poor. The mechanism of this recovery process, which can continue for up to six months, is not well understood.

Subarachnoid hemorrhage (SAH) caused by rupture of an aneurysm, leads to a sudden, explosive headache, with a stiff neck, sometimes a seizure or loss of consciousness, and, depending on the damage done by the blood pumped out of the artery, focal signs of brain damage. Up to half the patients with SAH die within two months as a result of the initial or subsequent bleeding.

Diagnosis and treatment. The diagnosis of cerebrovascular disease is achieved by clinical evaluation, but it has been greatly improved by CAT scanning, which not only shows the site of the stroke but also allows determination of the amount of bleeding (if any) and thus indicates the nature of the stroke. Additional tests include angiography, for localizing an aneurysm or detecting the site and nature of disease in the arteries of the neck, and a battery of tests aimed at determining whether any underlying disease (*e.g.,* diabetes, blood cell or clotting disease, infections) might have led to the stroke.

The treatment of stroke patients is initially directed toward support of the cardiac and metabolic systems, no treatment being known to reverse the ill effects of ischemia. High blood pressure is controlled, acutely raised intracranial pressure lowered, and, in rare cases, anticoagulant drugs prescribed. Rehabilitative efforts start as soon as the patient's condition is stable. Risk factors such as smoking and diabetes are also tackled. Also appropriate in some cases, depending on the nature of the stroke, may be such specific treatments as the clipping or isolation of a cerebral aneurysm and, perhaps, surgical evacuation of a blood clot or clearing-out of the roughened lining of the major arteries in the neck.

Drugs such as aspirin, which inhibit the tendency of platelets to cause clotting in the bloodstream, have proved effective in the prevention of stroke and fatal heart attacks after TIAs in men.

UNLOCALIZED OR MULTIFOCAL DISORDERS

Many disorders of the nervous system cannot be localized to a single site, or they represent the distant effects of disease of other parts of the body.

Effects of systemic disease. *Endocrine diseases.* Disorders of the hypothalamus may lead to symptoms of autonomic dysfunction, sleep disturbance, and diabetes insipidus (in which large volumes of dilute urine are secreted). Pituitary adenomas may cause acromegaly, in which peripheral-nerve compression may also occur. Overactivity of the thyroid gland causes tremor, muscle weakness, and disturbances of eye movements, while underactivity leads to mental dulling, deafness, difficulty in relaxing muscles, and median-nerve compression. Muscle weakness is seen in overaction of the parathyroid gland; underactivity is associated with seizures. Muscle weakness is also one of the features of adrenal gland dysfunction (both Addison's and Cushing's diseases); both of these conditions also induce abnormal mental states.

Complications of diabetes mellitus

Diabetes mellitus causes many neurological complications, including peripheral neuropathy (with features of autonomic failure), painful nerve root lesions in the lumbosacral plexus, acceleration of the rate of atherosclerosis with an increased chance of stroke, and damage to the retinas. Hyperinsulinism reduces blood-sugar levels, which may cause coma. Use of oral contraceptives slightly increases the risk of stroke.

Organ failure. When the function of the liver, lung, heart, or kidney fails, the nervous system is affected. With liver failure the typical picture is of dementia or of a confused state, with aphasia, dysarthria, and a flapping tremor of the limbs progressing to coma in severe cases.

Kidney failure is often associated with high blood pressure, which may lead to acute brain edema (distension with fluid) with visual loss and coma. Chronic kidney failure is likely to produce peripheral neuropathy as well as symptoms similar to those of liver failure but with increased likelihood of epileptic seizures. Dementia is a complication of dialysis in areas where the aluminum content of the dialysis fluid is high.

Chronic respiratory failure is another cause of tremor, confusion, and raised intracranial pressure. Heart failure may also produce a confused state, and it may predispose an individual to stroke.

Blood diseases. Leukemia and polycythemia also affect the nervous system, the former mainly through infiltration of the meninges or brain and the latter by increasing the risk of stroke. Anemia due to deficiency of vitamin B_{12} is the cause of subacute combined degeneration of the spinal cord. Severe anemia may be associated with an increased risk of stroke.

Metabolic disease. Many biochemical disorders affect the nervous system, usually not in isolation. Most of them are genetically determined, and only a few are treatable. They can be classified into seven groups.

Phenylketonuria

Protein and amino acid disorders. Phenylketonuria is a disorder of the conversion of the amino acid phenylalanine (a building block of protein) into tyrosine. Among other neurological signs, it leads to a delay in mental and motor development. It can be diagnosed within days of birth by a simple urine test and treated with a diet low in phenylalanine, which may allow more normal intellectual development to proceed. Other so-called aminoacidurias, which cause psychomotor delay and a variety of neurological and musculoskeletal problems, include hyperglycinemia, hyperammonemia, Hartnup and Lowe's diseases, maple syrup urine disease (so called because of the distinctive smell of the urine), and homocystinuria (a condition that predisposes to strokes).

Disorders of fat and fatty acid metabolism. Many of the conditions mentioned in this and the next section are caused by a genetically determined enzyme failure within cells, which leads to the accumulation of substances that would normally be metabolized. They are called lysosomal diseases after the lysosome, the structure in the cell that contains these substances, and give rise to signs of neurological involvement at birth or, at latest, in the early years of childhood.

Sphingolipidoses are typical examples. They include gangliosidoses (of which the best known is Tay-Sachs disease), sulfatidoses (*e.g.,* metachromatic leucodystrophy), and such conditions as Krabbe's, Fabry's, Gaucher's, Farber's, and Nieman-Pick diseases. In these conditions psychomotor retardation and, variously, seizures, retinal abnormalities, peripheral neuropathies, and musculoskeletal deformities are prominent features. Sudanophilic leucodystrophies are characterized by defective formation of myelin (the insulating substance surrounding nerve fibres), with marked cerebellar and corticospinal-tract dysfunction. Adrenoleucodystrophy occurs only in males; it leads to blindness, motor weakness, spasticity, and signs

of adrenal-gland failure. In Refsum's syndrome peripheral neuropathy and retinal and cerebellar signs accompany a dry, scaly skin rash. This condition is of interest because restriction of dietary phytanic acid, a substance found in green vegetables, slows the progress of the disease.

Inherited deficiencies of blood lipoproteins are also associated with peripheral neuropathy, retinal degeneration, and other motor and skeletal deformities. In analphalipoproteinemia, the tonsils are swollen by accumulations of cholesterol, while in beta-lipoproteinemia, excessive fat in the stools suggests the diagnosis. Lipofuschinosis is a disorder in which lipids are stored in the retinas and nervous system, causing visual impairment, seizures, intellectual decline, and spastic weakness and ending in death.

Disorders of carbohydrate metabolism. Galactosemia develops when infants are unable to metabolize galactose, or milk sugar. Cataracts, floppiness of the limbs, and psychomotor delay occur unless substitutes for milk are given. In glycogen-storage diseases glycogen cannot be metabolized to yield lactic acid and energy, so that it accumulates within muscle, liver, and other tissues. In mucopolysaccharidoses and mucolipidoses (both lysosomal disorders), fatty and carbohydrate materials are deposited in the nervous system and in other tissues; severe mental retardation, motor and ocular signs, and skeletal abnormalities are prominent features within this group.

Vitamin deficiencies

Deficiency states. The effects of deficiency of vitamin A are mainly on the retina and skin, but components of the vitamin B group are essential for normal development and functioning of the nervous system. The Wernicke-Korsakoff syndrome (common in alcoholics) consists of disorders of eye movement, cerebellar incoordination, failure of the formation of new memories, and peripheral neuropathy, all due to deficiency of thiamine (vitamin B_1). Beriberi is the name given to the occurrence of the neuropathy alone. In each case, replacement of the vitamin may lead to substantial improvement. When other vitamins (niacin, pyridoxine, and so forth) are deficient, the symptoms are similar, and signs of spinal cord disease may occur.

Subacute necrotizing encephalopathy, also called Leigh's disease, is a lethal disorder of infancy marked by psychomotor delay, myoclonic jerks, paralyses of eye movements, and respiratory disorders. The precise biochemical defect is unknown, but thiamine metabolism is likely to be involved. Seizures in early childhood are the main feature of pyridoxine dependency, an inherited abnormal metabolic requirement for the vitamin.

Deficiency of vitamin D causes rickets, the bony softening of which may have secondary effects on the nervous system, and weakness of the proximal muscles.

Fluid, mineral, and electrolyte disorders. Inappropriate secretion of antidiuretic hormone from the pituitary gland leads to confused states and seizures; it may complicate almost any intracranial disease, especially subarachnoid hemorrhage. High or low levels of electrolytes such as sodium, potassium, calcium, and magnesium, as well as disorders of acid–base metabolism, also have neurological effects such as confusion, seizures, muscle weakness, tetany (spasm and irritability of muscles), and cramps.

Porphyria

Porphyria is a disorder of heme, the pigment in red blood cells. It occurs in a number of forms, the most important (acute intermittent porphyria) leading to attacks of acute abdominal or limb pains, marked weakness due to peripheral neuropathy, epileptic seizures, severely confused states, and increased pigmentation of the skin with abnormal sensitivity to sunlight. Attacks are sometimes precipitated by certain drugs, such as barbiturates and some antibiotics.

Among inherited disorders are: Menkes' disease, a familial disorder of copper metabolism presenting with seizures and the growth of abnormal hair; Hallervorden-Spatz disease, a condition marked by the deposition of iron in the basal ganglia that produces rigidity, weakness, and abnormal movements; the Lesch-Nyhan syndrome of raised levels of uric acid in the blood with abnormal movements, spastic weakness, mental retardation, and a tendency to self-mutilation; and familial hypoparathyroidism, in which the basal ganglia calcify, causing choreic movements.

Neurocutaneous syndromes. A number of genetically determined disorders of the ectoderm (the outside layer of cells in the embryo, from which the skin and the nervous system develop) are grouped together—slightly artificially—as the neurocutaneous syndromes. Five of these are mentioned below. (Down's syndrome is described above; see *The cerebrum: Mental retardation.*)

Neurofibromatosis

Neurofibromatosis (von Recklinghausen's disease) presents such features as café-au-lait spots on the skin, the formation of fibrous tumours on nerves and, in some cases, of various tumors in the brain, rotation of the spine, tumours of endocrine glands such as the adrenal gland, and other skeletal deformities. The Elephant Man, protected at the London Hospital in the 1880s, is thought by some to have suffered from this condition, his skin thickened by huge numbers of nerve and skin tumours. This disease is relatively common, but many patients have only minimal symptoms.

Ataxia-telangiectasia (the Louis-Bar syndrome) comprises cerebellar incoordination and choreic movements, overgrowth of blood vessels on the conjunctivas (eye membranes), and disorders of the immune system.

In von Hippel-Lindau disease, tumours of blood vessels grow in the brain, especially in the cerebellum and retina, and in other organs.

The Sturge-Weber syndrome is characterized by a large red ("port-wine") overgrowth of blood vessels in the skin over the upper face and by a growth of the underlying brain. The latter effect may cause seizures, spastic weakness, and visual-field deficits.

Tuberous sclerosis is characterized by epileptic seizures, a facial rash resembling acne, and the growth of many benign tumours in the lining membrane of the ventricles of the brain and in other organs.

Toxic effects of drugs, metals, and common poisons. Perhaps due to the complexity of the metabolic systems and to the rapid metabolic rate of the nervous system, the brain is highly susceptible to damage from chemical substances derived both internally and from the environment. Endogenous (internally derived) poisons are the products of organ failure and abnormal metabolism. Among the externally derived poisons are bacterial toxins, such as those in tetanus, which lead to increased excitability of the ventral-horn cells of the spinal cord, with muscular rigidity resulting; diphtheria, which produce severe loss of myelin from motor nerves, causing limp weakness of the throat and body muscles; and botulism and tick paralysis, which prevent normal transmission of impulses between nerve and muscle.

Heavy metals (such as arsenic, lead, thallium, gold, manganese, and mercury), synthetic chemicals (such as the organophosphates, gasoline, and toluene), the alcohols (especially ethyl and methyl alcohol), ionizing radiation, and a huge range of drugs can all be toxic to the nervous system. In addition, water overload can cause seizures, and oxygen, under high pressure, can induce depression of brain function.

The neurological syndromes that occur as a result of toxicity are remarkably varied. Toxic encephalopathy, characterized by reduced consciousness, seizures, and delirium, is seen in poisoning with alcohols, all sedatives, and many other chemicals and drugs—the last usually taken in overdose or for a prolonged period. Seizures, dementia, and drowsiness can also occur in isolation as drug and chemical toxicity, and the withdrawal from sedatives (including alcohol) may also be a cause of seizures. Syndromes of damage to the basal ganglia, including acute dystonias, chorea, and parkinsonism, occur with overdose or prolonged use of, or idiosyncrasy to, many drugs and as a result of poisoning by such heavy metals as mercury and manganese. Other agents selectively damage the cerebellum; diphenylhydantoin and ethyl alcohol are the best-known examples. Signs of damage to the spinal cord may appear following electric shock, deep X-ray treatments, or exposure to heavy metals and some drugs. Subacute combined degeneration of the spinal cord may be induced when drugs lead to a deficiency of vitamin B_{12}.

Drug overdose and withdrawal

Meningeal irritation often followed injection of air into the subarachnoid space when this was performed as a

diagnostic test; it also occurs with some drugs given by mouth or by subarachnoid injection. Fungal meningitis may complicate chronic suppression of the body's immune system. Raised intracranial pressure, due to an increase in the water content of the brain, occurs with cortisone-like drugs, and headaches of migraine type are frequently precipitated by foods and drugs.

The list of drugs and other agents capable of causing damage to cranial nerves or peripheral nerves is very long. It is of interest that some of these agents affect only one of the cranial nerves; thus, the birth control pill has been incriminated in Bell's palsy, a facial weakness caused by dysfunction of the facial nerve, but trichlorethylene (a solvent) and stilbamidine (a drug) cause numbness of the face by affecting the trigeminal nerve. The cochlear and vestibular portions of the vestibulocochlear nerve are also susceptible in different ways to toxicity from the group of aminoglycoside antibiotics.

In the peripheral nervous system the autonomic nerves may be damaged alone or in conjunction with other nerves. The transmission of impulses at the autonomic ganglia may also be blocked by many drugs used to reduce blood pressure. In part, this is a pharmacological response (in other words, it is the effect sought in the first place), but when this effect occurs with anticonvulsants, antidepressants, or sedatives, the effect is highly undesirable. A drop in blood pressure on standing up is the most common clinical effect.

Toxic symptoms affecting the muscles include cramps, weakness, and atrophy, or muscles may even degenerate acutely. The range of chemicals and drugs producing such effects is wide. Drugs may also reduce levels of potassium in the blood, resulting in secondary weakness of muscles. Blockade at the neuromuscular junction is an unwanted effect of some antibiotics and quinine.

Finally, within a miscellaneous group of problems, it should be mentioned that lymphomas may follow prolonged suppression of the immune system or treatment with diphenylhydantoin, that inflammation of the arteries (autoimmune vasculitis) arises as a complication of treatment with some drugs and as toxicity from chemical exposure, and that even drugs used normally can produce unusual effects in singular circumstances (for example, dangerously low blood sugar levels causing brain damage may occur in a diabetic patient taking his normal insulin dose but missing meals).

Demyelinating diseases. Demyelinating diseases must be differentiated from dysmyelinating diseases. In the former, normal myelin is damaged; in the latter group, the myelin is probably abnormal in the first place, as in leucodystrophies and other metabolic disorders involving fat or fatty acids (see above).

Demyelination can occur after trivial viral infections or vaccinations, but multiple sclerosis (MS) is the most important example and is discussed here.

Multiple sclerosis

Multiple sclerosis is a relatively common disease in temperate climates, with a prevalence of between 50 and 100 per 100,000 population in most areas where such figures have been gathered since 1970. Females are affected somewhat more often than males, and most patients develop the first signs within 10 years of their 30th birthday. Pathologically, multiple scattered areas of myelin breakdown, called plaques, are found within the white matter in the central (not peripheral) nervous system. The actual nerve fibres, the axons, remain intact but no longer conduct impulses adequately. The cause of this demyelination is not known, but people with certain genetically determined immunologic characteristics seem to be over-represented among the MS populations. Also, the influence of an outside agent is strongly suggested by variability between regions of the same geographic area and by the fact that people who migrate from an area of low MS prevalence to one of high prevalence before the age of 14 years take on, as it were, the higher risk of their new area. This increased risk does not occur if such a move is made after that age or if migration is in the other direction. The nature of the agent is unknown, epidemiological and clinical studies conflicting in suggestions that the virus of measles or of canine distemper is responsible.

Some typical clinical patterns of MS are:

1. Onset in young adult life, with inflammation of one optic nerve causing pain and diminished sight for a few days or weeks, followed by recovery. There is a transient appearance of scattered neurological signs in subsequent years.

2. The same as above, but with the initial signs suggesting lesions not only in the optic nerve but also in the spinal cord, cerebellum, or brain stem and in the deep cerebral white matter. A tendency to further relapses and remissions may leave more or less evidence of past attacks.

3. Severe and progressive involvement of any part of the nervous system, with further relapses and persistent deficits after subsequent attacks, leading to "chronic progressive multiple sclerosis."

4. The slower progression of signs mainly or only at spinal-cord level in patients who are usually over the age of 50.

Typical clinical features (varying with the site of the plaques) include eye pain and visual dimming (optic nerve); double vision, nystagmus, disturbances of speech, and facial numbness or pain (brain stem); incoordination of gait and of the limbs (cerebellum and cerebellar connections); spasticity, weakness, and increased deep tendon reflexes (corticospinal tracts at any level from the cerebral white matter down to the spinal cord); frequency and urgency of bladder emptying (corticospinal tracts); and alteration in sensation, especially involving the senses of joint position and discriminative touch (dorsal columns in the spinal cord or their upward connections in the brain stem or subcortical white matter). In severe cases, intellect and memory are impaired.

Diagnosis and treatment of MS

Diagnosis of multiple sclerosis depends upon the demonstration of physical signs that imply the presence of plaques in multiple areas of the central nervous system. When this cannot be done clinically, electrical survey of the nervous system, using evoked potential testing, may be useful. In the cerebrospinal fluid the detection of oligoclonal bands in the gamma-globulin fraction of the protein is also suggestive. Overall, the diagnosis is essentially clinical; if laboratory support is not forthcoming, observation of the patient's course over subsequent months or years may allow it to be made with confidence.

The outcome of the disease cannot be foretold from the initial symptoms. In some 20 percent of cases there is no disability 10 years after the onset, while other patients are rapidly disabled. Mean survival from onset is now well over 30 years.

Treatments of specific complaints, such as spasticity and cramping of the limbs, bladder symptoms, and facial pain, is relatively easy; the prevention of relapses or progression is extremely difficult. Measures that suppress the activity of the body's immune system, such as steroid (cortisone-like) drugs and specific immunosuppressants, are the mainstays of therapy. The chronicity of the disease and its potentially devastating effects during the relative youth of many of the patients has made multiple sclerosis a fertile field for scientifically unsupported claims. (W.E.M.P.-P.)

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The Netherlands

One of the smaller countries of Europe, the Kingdom of The Netherlands (Dutch: Koninkrijk der Nederlanden) is a parliamentary democracy under a constitutional monarch. The Netherlands has often been known abroad as Holland (from Houtland, or "Wooded Land"). This name was originally given to one of the medieval cores of what later became the state and is still used for 2 of its 12 provinces (Noord-Holland and Zuid-Holland). The irregular outline of The Netherlands, not unlike a piece of a jigsaw puzzle, encloses some 16,164 square miles (41,864 square kilometres) of mostly flat land, which lies between the North Sea on the north and west, Germany on the east, and Belgium to the south. Large parts of the total area consist of water. Excluding the territorial waters, the land area amounts to about 13,255 square miles. The kingdom includes the former colonies of the Netherlands Antilles and Aruba.

Some 2,500 square miles of this country consist of reclaimed land, the result of a process of careful water management dating back to medieval times. Along the coasts, land was reclaimed from the sea, and, in the interior, lakes and marshes were drained. The reclaimed tracts, known as polders, are usually surrounded by dikes. Initially, manpower and horsepower were used to drain the land and were replaced later by windmills. The largest schemes were carried out in the second half of the 19th century and in the 20th century, when steam pumps and, later, electric or diesel pumps came into use.

The Netherlands is today one of the world's most densely populated nations. Even so, it continues to attract immigrants, who, with their families, constitute about one-tenth of all Netherlanders. More than one-third of the population is crowded into the Randstad ("Rim City"), a U-shaped urban belt near the western coast that includes Amsterdam, The Hague, and Rotterdam. The country has developed a reputation for social and cultural experimentation and liberal social policies. This independence of outlook has strong roots in the 16th and 17th centuries, when Dutch merchant ships sailed the world and helped lay the foundations of a great trading nation characterized by a vigorous spirit of enterprise. In later centuries, burgeoning trade and commercial growth further stimulated development of the country.

With Belgium and Luxembourg, The Netherlands is a member of the economic union known as Benelux, in which capital, goods, and people can freely circulate. This union, in fact, served as a model for the larger European Union (EU), of which the Benelux nations are members. The country is also a member of the North Atlantic Treaty Organization (NATO) and the Organisation for Economic Co-operation and Development (OECD).

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Physical and human geography

THE LAND

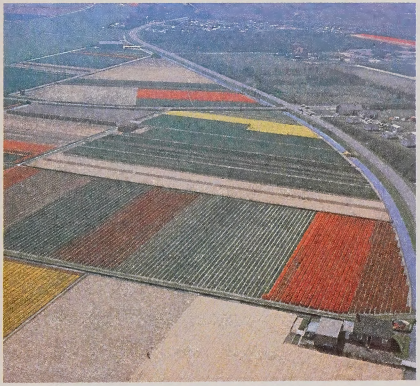
Relief. If The Netherlands were to lose the protection of its dunes and dikes, the most densely populated part of the country would be inundated (largely by the sea, but also in part by the rivers). This highly developed part of The Netherlands, which generally does not lie higher than about three feet (one metre) above sea level, covers more than half the total area of the country. About half of this area (some 27 percent of the total area of the country) actually lies below sea level. The Dutch refer to this area in the north and west as the Low Netherlands, while the area covering the south and east is termed the High Netherlands.

The Low Netherlands consists mainly of polders, where the landscape not only lies at a very low altitude but is also very flat in appearance. On such land, building is possible only after concrete piles, sometimes as long as 65 feet, have been driven into the sand layer.

The Zuiderzee project

The Zuiderzee was originally an estuary of the Rhine. By natural action it then became a shallow inland sea, biting deep into the land, and eventually it was hollowed into an almost circular shape by the action of winds and tides. In 1920 work was begun on the Zuiderzee project, of which the IJsselmeer Dam (Afsluitdijk), begun in 1927, was a part. This 19-mile-long dam, or dike, running northeastward to connect the provinces of Noord-Holland and Friesland, was completed in 1932 to finally seal off the Zuiderzee from the Waddenzee and the North Sea. In the IJsselmeer, or IJssel Lake, formed from the southern part of the Zuiderzee, four large polders with a total area of about 650 square miles were constructed around a freshwater basin fed by the IJssel and other rivers and linked with the sea by sluices and locks in the barrier dam.

Russ Kinne/Comstock



Flower cultivation in the polders of South Holland near the border with North Holland in The Netherlands.

The first two polders created—Wieringermeer and North East (Noordoost) Polder, drained before and during World War II—are used mostly for agriculture. The two polders reclaimed in the 1950s and '60s—South Flevoland Polder (Zuidelijk) and East Flevoland Polder (Oostelijk)—are used for residential, industrial, and recreational purposes. Among the cities that have developed there are Lelystad and Almere; the former is the capital of the new province of Flevoland, created in 1986 from the two Flevoland polders and North East Polder.

In the southwest, the disastrous gales and spring tide of Feb. 1, 1953, which flooded 400,000 acres (162,000 hectares) of land and killed 1,800 people, accelerated the implementation of the Delta Plan, which aims to close the sea inlets of the southwestern delta, mostly in the province of Zeeland. These delta works were designed to shorten the coastline by 450 miles, combat the salination of the soil, and allow the development of the islands of the area through roads that were constructed over 10 dams and two bridges built between 1960 and 1987. The largest of these dams, crossing the five-mile-wide East Schelde (Oosterschelde) estuary, has been built in the form of a storm-surge barrier incorporating 61 openings that can be closed in the event of flood. The barrier is normally open, allowing salt water to enter the estuary and about 75 percent of the tidal movement to be maintained, limiting damage to the natural environment in the East Schelde. In the interests of the commerce of the ports of Rotterdam and Antwerp, no dams were constructed in the New Waterway, which links Rotterdam to the North Sea, or the West Schelde, an approach to Antwerp, Belg. The dikes along these waterways consequently had to be strengthened.

The New Waterway

A region with a very specific character has been formed by the great rivers—Rhine, Lek, Waal, and Maas (Meuse)—which flow from east to west through the central part of the country. The landscape in this area is characterized by high dikes along wide rivers, orchards along the levees formed by the rivers, and numerous large bridges over which pass the roads and railways that connect the central Netherlands with the southern provinces.

In the High Netherlands, the layers of sand and gravel in the eastern part of the country were pushed sideways and upward in some places by ice tongues of the Saale Glacial Stage, forming elongated ridges, which may reach a height of more than 330 feet. These form a recreational area, Veluwe, which is of national significance. The southern part of Limburg province, in the border zone of the Ardennes, is the only part of the country where altitudes well over 350 feet occur. The Netherlands' highest point, the Vaalserberg, in the extreme southeastern corner, rises to 1,053 feet.

Soils. Only in the last Pleistocene Ice Age did the Scandinavian ice sheet cover the northern half of The Netherlands. After this period (about 10,000 years ago), a large area in the north of what is now The Netherlands was left covered by moraine (glacial accumulation of earth and rock debris). In the centre and south, the Rhine and Maas unloaded thick layers of sand and gravel transported from the European mountain chains. Later, during the Holocene Epoch, clay was deposited in the sheltered lagoons behind the coastal dunes, and peat soil often subsequently developed in these areas. If the peat soil was washed away by the sea or dug away by humans (for the production of fuel and salt), lakes were created. Many of these were reclaimed in later centuries (as mentioned above), while others now form highly valued outdoor recreational areas.

Climate. The climate is temperate, with gentle winters, cool summers, and rainfall in every season. Southerly and westerly winds predominate, and the sea moderates the climate through onshore winds and the effect of the Gulf Stream.

The position of The Netherlands—between the area of high-pressure air masses centred on the Azores and the low-pressure region centred on Iceland—makes the country an area of collision between warm and polar air masses, thus creating unsettled weather. Winds meet with little resistance over the flat country, though the hills in the south diminish by more than half the 13-mile-per-hour wind velocity that prevails along the coast. On average, frost occurs 60 days per year. July temperatures average about 63° F (17° C), and those of January average 35° F (2° C). The rainfall averages 31 inches (790 millimetres), with only about 25 clear days per year. The average rainfall is highest in summer (August) and autumn and lowest in springtime. The country is known—not least through the magnificent landscapes of Dutch painters—for its heavy clouds, and on an average day three-fifths of the sky is clouded.

Average temperatures and rainfall

Plant and animal life. Most wild Dutch plant species are of the Atlantic district within the Euro-Siberian phytogeo-


Scale 1: 1,695,000
1 inch equals approx. 27 miles
0 5 10 15 20 25 30 mls
0 5 10 15 20 25 30 40 km
Lambert Conformal Conic Projection
WEST FRISIAN ISLANDS
TERSCHELLING ISLAND
VLIELAND ISLAND
VLIELAND NATIONAL PARK
TEXEL ISLAND
AMELAND ISLAND
SCHIERMONNIKOOG ISLAND
ROTTUMERPLAAT ISLAND
ROTTUMEROOG ISLAND
Waddenzee
Vlie
Texelse Stroom
Marsdiep
Eierlandse Gat
Ameland Inlet
Zoutkamperlaag
Pinkegat
Lauwers Zee
Dollard
Eems
Ems-Dollard Estuary
Borkum
Emden
GRONINGEN
Groningen
Stadskanaal
Winschoten
Veendam
Delfzijl
FRIESLAND
Leeuwarden
Franeker
Drachten
Sneek
Lake Slotermeer
Lake Tjeukemeer
Lake Fluessen
Lake Koevorden
Heerenveen
Joure
Balk
Lemmer
Stavoren
Ijsselmeer
Ijsselmeer Dam
Den Helder
Den Oever
Afsluitdijk
Enkhuizen
Hoorn
Medemblik
Lelystad
Almere
Amsterdam
Haarlem
Zaandam
Alkmaar
Heiloo
Castricum
Beverwijk
Velsen-Zuid
IJmuiden
Marker Lake
Edam
Volendam
Purmerend
Monnickendam
Zaanstad
NORTH SEA
NOORD-HOLLAND
NORTHEAST POLDER
Stavoren
Emmeloord
Urk
Noordoostpolder
Meppel
Hoogeveen
Schoonebeek
Emmen
DRENTHE
Coevorden
Hardenberg
Sachsenheim
Kampen
Ommen
Zwolle
OVERIJSSEL
Vriezenveen
Hellendoorn
Almelo
Nijverdal
Hengelo
Enschede
Haaksbergen
Oldenzaal
Losser
Bentheim
Nordhorn
Lingen
Meppen
Papenburg
Leer
Aurich
Wilhelmshaven
Oldenburg
Bremen
Delmenhorst
Verden
Nienburg
Minden
Bad Oeynhausen
Herford
Bielefeld
Osnabrück
Rheine
Ibbenbüren
Münster
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Epinal
Remiremont
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Chinon
Tours
Amboise
Blois
Vendôme
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Dreux
Evreux
Pont-Audemer
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Le Havre
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Best . . . . . 51 30 N 5 24 E
Beuningen . . . . . 51 52 N 5 47 E
Beverwijk . . . . . 52 29 N 4 39 E
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Boxtel . . . . . 51 35 N 5 19 E
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De Bilt . . . . . 52 07 N 5 11 E
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Den Bosch, see 's-Hertogenbosch
Den Haag, see The Hague
Den Helder . . . . . 52 58 N 4 46 E
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Rhine (Rhein or Rijn), *river* . . . . . 51 58 N 4 05 E
Rottumeroog Island . . . . . 53 33 N 6 35 E
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Schelde (Escaut or Scheldt), *river* . . . . . 51 22 N 4 15 E
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South Beveland (Zuidbeveland), *area* . . . . . 51 29 N 3 50 E
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West Frisian (West Friese) Islands . . . . . 53 22 N 5 20 E
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graphic region. Gradients of salt and winter temperature variations cause relatively minor zonal differences in both wild and garden plants from the coast to more continental regions. The effects of altitude are negligible. Vegetation from coastal sand dunes, muddy coastal areas, slightly brackish lakes, and river deltas is especially scarce in the surrounding countries. Lakes, marshes, peatland, woods, heaths, and agricultural areas determine the general floral species. Clay, peat, and sand are important soil factors for the inland vegetation regions.

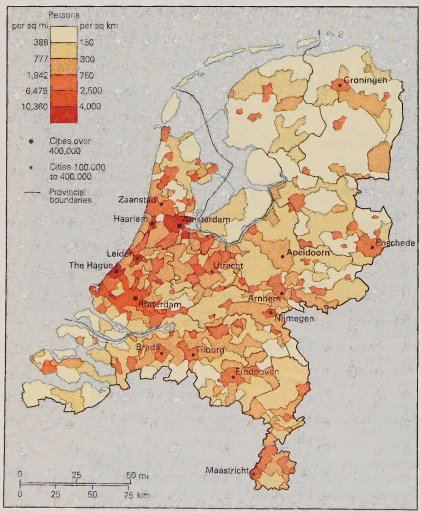
Animal life is relegated by region according to vegetation. Seabirds and other sea life, such as mollusks, are found especially in the muddy Waddenzee area and in Zeeland. Migrating birds pass in huge numbers through The Netherlands or remain for a summer or winter stay. Species of water, marsh, and pasture birds are numerous. Larger mammals, such as roe deer, red deer, fox, and badger, are mostly restricted to nature reserves. Some species like boar, beaver, fallow deer, mouflon, and muskrat have been introduced locally or reintroduced. Reptiles and amphibians are endangered. Numerous species of river fish and river lobsters have become scarce because of water pollution. There is a diversity of brackish and freshwater animals inhabiting the many lakes, canals, and drainage ditches, but the vulnerable species of the nutritionally deficient waters have become rare.

Nature reserves have been formed by governmental and private organizations. Well-known reserves include the Naardermeer of Amsterdam, the Hoge Veluwe National Park, and the Oostvaardersplassen in South Flevoland. Some endangered species are protected by law.

Settlement patterns. Modern urbanization in The Netherlands has taken place mainly in the 20th century. In 1900 more than half the population was still living in villages or towns of fewer than 10,000 inhabitants. By the late 20th century this figure had decreased to about 13 percent. There has, nevertheless, been a decrease in the city proper population of the large metropolitan centres. These city regions are now becoming economic and cultural centres, their populations having spread outward in search of newer housing and greater living space in suburbs, new residential quarters of rural settlements, and new towns. In the 1960s and '70s the authorities stimulated this development by subsidizing house building in a number of so-called growth nuclei and by moving several groupings of public offices from the western core area to more rural areas in the north, east, and south of the country. More recently, however, government planning policy has aimed at again concentrating the population in and around the existing cities, especially in the western provinces.

The growth of urban centres

In this part of the country the bulk of the Dutch population is concentrated in the urban core known as the Randstad Holland, comprising such cities as Rotterdam, The Hague, Leiden, Haarlem, Amsterdam, Hilversum, and Utrecht. Extensions of the Randstad stretch toward the east (Arnhem, Nijmegen) and the south (Breda, Tilburg, Eindhoven), thus forming the so-called Central Netherlands Urban Ring. Other urban centres are Groningen in the northeast, Enschede and Hengelo in the east, and Maastricht and Heerlen in the southeast. It is government policy to keep traditional towns and cities separated by strips of agricultural or recreational land.



Population density of The Netherlands.

THE PEOPLE

Ethnic composition. Popular belief holds that the Dutch are a mixture of Frisians, Saxons, and Franks. In fact, research has made plausible the contention that the autochthonous inhabitants of the region were a mixture of pre-Germanic and Germanic population groups who in the course of time had converged on the main deltaic region of western Europe. There emerged from these groups in the 7th and 8th centuries some major polities based on certain ethnic and cultural unities that then came to be identified as Frisians, Saxons, and Franks.

The Dutch Republic originated from medieval statelets, and its legal successor, The Kingdom of The Netherlands, has attracted countless immigrants through the centuries. A strong impetus was the principle of freedom of thought, which engendered the tolerance that developed in the 16th and 17th centuries. These sentiments were—and are—most manifest in the prosperous commercial and industrial centres in the western provinces, which attracted many members of persecuted religious or political minorities. Among these were southern lowlanders, French Huguenots, and Portuguese Jews, along with many people who sought to improve their economic situation, such as Germans and non-Iberian Jews. In the 20th century, immigrants from the former Dutch overseas colonies added to the influx; they include Indonesians and peoples from the Moluccas and from Suriname on the northeast coast of South America.

Tradition of tolerance

The heritage of Dutch humanism. The considerable hospitality exhibited by the Dutch is to a large extent rooted in the spirit of humanism that was typical of the Dutch Republic of the 16th to the 18th centuries. Figures such as Erasmus in the 16th century and Hugo Grotius in the 17th century epitomize that spirit. It can be characterized as an amalgam of religious piety tempered by an awareness of scientific progress. It resulted in a rather pragmatic mode of thinking that has dominated Dutch bourgeois culture from the 16th century onward, coexisting with growing commercial acumen. Evolving Dutch society came to encompass a diversity of religious traditions, from rigid Calvinism and a more tolerant Protestantism to conformist Roman Catholicism.

Roughly speaking, the present Dutch population can be divided into three almost equal groups relative to religion: Roman Catholics (predominantly in the provinces of Noord-Brabant and Limburg), Protestants (particularly the Dutch Reformed Church), and the nonreligious. Although religious ardour and church attendance have slackened notably since about 1900, the educational institutions and political parties that evolved in the late 19th and early 20th centuries along denominational lines still play a considerable role vis-à-vis the more or less secularized parties and institutions that sprang from socialist, liberal, and conservative movements. The most constant factor in the body politic has for years been the so-called Christian Democrats—comprising Roman Catholics as well as Protestants—who traditionally dominate the centre of the parliamentary spectrum.

These more or less converging societal groupings have not completely obliterated a range of age-old regional cultural distinctions. They are sometimes vividly preserved, as in the case of the northern province of Friesland, which proudly conserves the ancient Frisian culture. With more recent immigration new cultural groups are becoming significant.

Linguistic composition. The language in the whole of the country is Dutch, or Nederlands, a Germanic language that is also spoken by the inhabitants of northern Belgium

(there called Flemish). Afrikaans, an official language of South Africa, is a variant of the Dutch spoken by 17th-century emigrants from Holland and Zeeland. Apart from Dutch, the inhabitants of the northern province of Friesland also speak their own language, which is closer to English than to either Dutch or German. In the major cities especially, many people are fluent in several languages, reflecting the nation's geographic position, its history of occupation, and its attraction for tourists. English, French, and German are among the languages commonly heard.

Dutch fluency in languages

Demographic trends. Although The Netherlands is one of the world's most densely populated countries, its growth rate has been slight in the 20th century. Birth and death rates are both among the world's lowest, causing a somewhat older society, and most population increase results from immigration. As a result of the postwar government policy mentioned above, however, emigrants had exceeded immigrants by an average of almost 20,000 each year from 1947 to 1954. Thereafter the economy and labour potential of the more industrialized European countries attracted an increasing number of Spaniards, Yugoslavs, Turks, and Moroccans, so that the balance remained more or less static. Since 1970 there has been a continuous immigrant surplus, with a peak in 1975 as a result of a large number of arrivals from Suriname (just before its independence). In the early 1990s more than 4 percent of The Netherlands' population was made up of foreign residents (excluding the tens of thousands of persons of Dutch nationality originating from former colonies). Muslims made up more than 2.5 percent of the population and Hindus and Buddhists another .5 percent.

For many years prior to 1970, internal migration showed a constant flow from the more rural provinces in the north, east, and south toward the more strongly urbanized western part of the country. After 1970, however, the trend toward migration to the west was reversed. Subsequent emigration was mainly from Zuid-Holland and Noord-Holland (the most heavily populated provinces) toward Utrecht and the less densely populated provinces, where the government has stimulated industrial growth—Groningen, Friesland, Drenthe, Gelderland, and Zeeland.

THE ECONOMY

Since World War II The Netherlands has become a highly industrialized nation occupying a central position in the economic life of western Europe. Although agriculture accounts for a small percentage of the national income and labour force, it remains a highly specialized contributor to Dutch exports. Because of the scarcity of mineral resources—with the important exception of natural gas—the country is dependent on large imports of basic materials.

State role in the economy

The Netherlands has a market economy, but the state is a major participant in such corporations as The Netherlands Railways, the Dutch State Mines, The Royal Netherlands Blast Furnaces and Steel Works, KLM Royal Dutch Airlines, and The Netherlands Natural Gas Company. The state thus has a direct, continuous influence on the management of some sectors of the economy and especially on investment policy. The government also employs a substantial percentage of the total labour force.

The Dutch economy nevertheless remains basically in private hands. Postwar industrial development has been consciously stimulated by government policy, and state subsidies have been granted to attract industry toward the relatively underdeveloped northern provinces, as well as Limburg and certain other pockets of economic stagnation. Despite these subsidies, the western provinces remain the centre of new industry, especially in the services sector.

Dutch employers are organized mainly in separate but closely cooperating organizations: one Roman Catholic and Protestant and one nondenominational. The labour force had a tripartite organization before the Socialist and Roman Catholic unions merged, leaving the Protestant union and a few small independent organizations far behind in membership. Employer organizations and labour unions are represented on the Joint Industrial Labour Council, established in 1945 for collective bargaining, and on the Socio-Economic Council, which serves mainly to advise the government.

Energy. With the increasing use of oil and natural gas, coal mining (concentrated in southern Limburg) was discontinued in 1974 because of the rising cost of production. The Netherlands imports several million tons of coal annually to meet domestic and industrial needs, including those of such industrial installations as the steel works of IJmuiden at the mouth of the North Sea Canal.

The production of crude oil, of which there are minimal deposits, covers only a small part of Dutch requirements. The wells are located in southeastern Drenthe, near Schoonebeek, and in Zuid-Holland. Large amounts of crude oil are imported for refining in The Netherlands, and much of the refined petroleum is exported.

The discovery of natural gas in 1959 had a tremendous influence on the development of the Dutch economy. The gas fields are in the northeastern Netherlands—with the largest field at Slochteren in the province of Groningen—and beneath the Dutch sector of the North Sea. Under the Geneva Convention of 1958, The Netherlands was allocated a 22,000-square-mile block of the continental shelf of the North Sea, an area larger than the country itself. Almost half of the natural gas produced is exported to Germany, Belgium, France, Switzerland, and Italy, helping to improve the balance of payments in the economic sector in which The Netherlands has usually had its largest deficit. The natural gas finds began a trend of Dutch industries toward using the fuel, among them the aluminium smelter at Delfzijl in Groningen. Purchase, transport, and sale of the gas are in the hands of The Netherlands Natural Gas Company, a limited company in which shares are held by Dutch and American firms and the Dutch state. Since it is the government's policy to reserve as much natural gas as possible for domestic use in future decades, the amount of imported coal again increased in the 1980s.

Agriculture. The country's agricultural land is divided into grassland, arable farmland, and horticultural land. Dutch dairy farming is highly developed: the milk yield per acre of grassland and the yield per cow are among the highest in the world. A good percentage of the total milk production is exported after being processed into such dairy products as butter, cheese, and condensed milk. Meat and eggs are produced in intensively farmed livestock holdings where enormous numbers of pigs, calves, and poultry are kept in large sheds and fed mainly on imported fodder. Most cereals for human consumption as well as fodder are imported.

Intense development of dairying and horticulture

Horticulture carried on under glass is of special importance. The export of hothouse tomatoes, cucumbers, lettuce, cut flowers, and house plants has greatly increased, and The Netherlands now contains almost half of the total European horticultural area under glass. Open-air horticulture also produces fruit, vegetables, cut flowers, and bulbs, the latter from the world-famous colourful bulb fields. Fishing is of minimal importance.

Industry. Dutch industrial development began relatively late, about 1870, and production rose even during the depression of the 1930s. Further development became a priority after World War II, when ascending population figures and growing farm-labour surpluses necessitated tens of thousands of additional jobs each year. Manufacturing industries accounted for about 20 percent of the labour force in the early 1990s, with the metal industry as the largest employer. The food, beverage, and tobacco manufacturing industries, based as they are on the highly productive agriculture sector, ranked second in employment but first in production value. Other important producers included the chemical, petroleum products, and electrical and electronics industries. Dutch industry has been able to redevelop commercial aircraft since World War II, and automobile manufacturing has been expanded. In contrast, employment in textile manufacturing and shipbuilding has decreased. The government has encouraged new industrial development in the fields of microelectronics, aerospace, and biotechnology.

Finance and trade. Commercial banking in The Netherlands is in the hands of a few large concerns, and there has been a trend toward mergers of banks and insurance companies. The General Netherlands Bank and the Amsterdam-Rotterdam Bank handle the majority of Dutch

Banking

financial business between them; these two institutions merged in 1990. A second large bank was created through the consolidation of the Postbank and the Netherlands Traders' Bank. The state-owned Netherlands Central Bank supervises the banking system. The Amsterdam Stock Exchange, one of the oldest in the world, was founded in the early 1600s.

Trade is conducted mainly with Europe and North America. The European Community (EC; also called the Common Market) is, of course, the dominant factor in foreign trade. In 1958 (just before the Common Market was established) some 40 percent of Dutch exports went to West Germany, Belgium, Luxembourg, France, and Italy, but by the late 20th century these nations and the EC as a whole accounted for about 75 percent of exports. The largest import source was Germany, followed by other EC countries and the United States.

Transportation. In The Netherlands transportation is of special importance because the country functions as a gateway for the traffic of goods between western Europe and the rest of the world. Trade flows through Dutch harbours, continuing its passage by river vessel, train, truck, and pipeline. Maritime traffic accounts for more than half of the total amount of goods loaded and unloaded in The Netherlands, and, indeed, the whole southern part of the North Sea may be likened to an immense traffic square, fed as it is by the Thames, Rhine, Maas, and Schelde rivers, with links into the hinterland of the continent that make it one of the greatest commercial arteries of the world. Rotterdam has the country's best-equipped modern harbour.

Europoort

Europoort, the region between Rotterdam and the North Sea, can easily be reached by the biggest oceangoing ships; it serves as an approach via the New Waterway to Rotterdam harbour, which handles more tonnage than any other harbour in the world. In petroleum processing, too, Rotterdam is one of the world's leading centres. A trench about 4,000 feet wide at a depth of 74 feet extends 27 miles into the North Sea to facilitate the entry of supertankers with 350,000-ton capacities. The number of rivercraft is probably unsurpassed by any other country.

Other important ports, though dwarfed by Rotterdam-Europoort, are Amsterdam, and, on the Western Schelde, Flushing and Terneuzen. KLM Royal Dutch Airlines initiated scheduled service between Amsterdam and London in 1920 and now has a worldwide network. Amsterdam Airport (Schiphol)—on the site of the former Haarlem Lake at about 13 feet below sea level—is one of Europe's largest airports. Smaller airports of international importance are Rotterdam Airport (Zestienhoven) and, in southern Limburg, Maastricht Airport (Beek).

In internal traffic the motor vehicle, accommodated by a comprehensive road network, dominates both passenger and goods transport, despite the fact that there is a dense and modern railway network. The length of the railroad track, however, is even surpassed by a network of inland waterways made up of some 3,000 miles of rivers and canals and linked with Belgian, French, and German systems. Besides such natural waterways as the Rhine, Lek, Waal, and Maas, many artificial waterways—the Juliana Canal (in southern Limburg), the Amsterdam-Rhine River Canal (between Amsterdam and Tiel), the Maas-Waal Canal (west of Nijmegen), and others—connect the major ports on the coast with the hinterland.

ADMINISTRATION AND SOCIAL CONDITIONS

The Kingdom of The Netherlands is a constitutional monarchy. The monarchy is hereditary in both the male and female lines.

Government. The constitution, which dates from 1814, declares that the head of state, the monarch, is inviolable and thereby embodies the concept of ministerial responsibility. It further provides that no government may remain in power against the will of Parliament. The States-General (Staten-Generaal), as Parliament is officially known, consists of two houses, a First Chamber, whose 75 members are elected by the members of the councils of the provinces, and a directly elected Second Chamber of 150 members. Both houses share legislative power with the government, officially known as the Crown (Kroon), defined as the head of state acting in conjunction with the ministers. The two houses control government policy. The First Chamber can only approve or reject legislation but does not have the power to propose or amend it.

Every four years, after elections to the Second Chamber have been held, the government resigns, and a process of bargaining starts between elected party leaders aspiring to form a government that will be assured of the support of a parliamentary majority. It usually takes a few months of maneuvering before a *formateur,* as the main architect of such a coalition is known, is ready to accept a royal invitation to form a government. The head of state then formally appoints the ministers. In the event of political crises resulting in the fall of the government before the end of a four-year period, the same process of bargaining takes place. The monarch, acting on the advice of the ministries, has the right to dissolve one or both chambers, at which time new elections are held.

Formation of the government

In local government, the most important institutions are the municipalities (*gemeenten*). Since World War II their number has been reduced to about 635 as a result of redivisions. Each municipality is run by a directly elected council of from 7 to 45 members, depending on the size of the population. This council is presided over by a *burgemeester* (mayor), who is appointed by the government and serves as chairman of the executive, the members of which are elected by and from the council. In those areas to which the councils' own ordinances are applicable, the municipalities are autonomous. In many instances, national legislation or provincial ordinances provide for the cooperation of municipal authorities.

The country is divided into 12 provinces: Groningen, Friesland, Drenthe, Overijssel, Flevoland, Gelderland, Utrecht, Noord-Holland, Zuid-Holland, Zeeland, Noord-Brabant, and Limburg. Their administrative system has the same structure as the municipal one: directly elected councils (*staten*) which elect the members of the executive, except for the chairman, who is appointed by the government. The main functions of the provinces include controlling the municipalities within their borders and controlling the district water-control boards (*waterschappen*).

Political life. The Second Chamber, the provincial councils, and the municipal councils are elected according to a system of proportional representation. In general elections for the Second Chamber, it can take as little as 0.66 percent of the overall vote to get one of the seats in the chamber. As a result, a large number of parties and political movements are represented in Parliament.

Justice. In The Netherlands the ordinary administration of justice is entrusted exclusively to judges appointed for life; there is no jury system. There are cantonal courts (*kantongerechten*), which exercise jurisdiction in a whole range of minor civil and criminal cases. More important cases are handled by one of the district courts (*rechtbanken*), which also can hear appeals from cantonal court decisions. Appeals against decisions from the district courts are heard by one of five courts of appeal (*gerechtshoven*). The Supreme Court (Hoge Raad) ensures a uniform application of the law, but it cannot determine constitutionality. In the legislative process itself, the government and Parliament together pass judgment on the constitutionality of a bill under consideration. Laws that are at variance with the nation's international agreements cannot be enforced by the courts.

The Supreme Court

Voting age and military obligation. The franchise is extended to all Dutch citizens who have reached the age of 18, except for a few special groups, such as the mentally impaired. The Dutch armed forces consist of an army, a navy, and an air force. All male citizens were liable for military service at the age of 18 until 1996, when conscription ended.

Education. All primary, secondary, and higher education is provided by either governmental (municipal or state) or private institutions. The latter are, with a few exceptions, run by Protestant and Roman Catholic organizations. All private schools are, when they conform to legally fixed standards, financed from governmental funds on an equal footing with their public (*openbare*) counterparts. Dutch secondary education consists of several

tracks. Among these are the five-year Higher General Education track, the mandatory preparation for institutions of higher education other than the university; and the six-year Preparatory Scientific Secondary Education track, which is mandatory for university admittance.

The system of higher education is a binary one. There are about 85 institutions for Higher Professional Education. These are called polytechnics, and they cover many professional fields complementary to the 13 universities. They are all publicly financed. Nine of them cover a general range of disciplines: the four state universities—of Leiden (founded 1575), Groningen (1614), Utrecht (1636), and Limburg at Maastricht (1976)—and the (former municipal) University of Amsterdam (1632), the Erasmus University at Rotterdam (1973), the (Protestant) Free University at Amsterdam (1880), and the Roman Catholic universities of Nijmegen (1923) and of Brabant at Tilburg (1927). The other governmental universities are more specialized: the universities of technology at Delft (1842), Eindhoven (1956), and Enschede (Twente University; 1961) and the Agricultural University at Wageningen (1918). In addition, the Open University established in 1984, provides for both university and vocational education through correspondence courses.

Health and welfare. Since World War II The Netherlands has developed an elaborate system of social security, providing all its citizens with universal health care and old age and unemployment benefits. All citizens are entitled to four national insurance schemes, including the General Old Age Pensions Act, the General Widows and Orphans Act, the Exceptional Medical Expenses Act, and General Disablement Benefits. There also are four employee insurance schemes, including the Sickness Benefits Act, the Disablement Insurance Act, the Compulsory Health Insurance Act, and the Unemployment Insurance Act. The system is supplemented by a number of social services, the most important ones being the General Family Allowance Act, which provides for family allowances for children up to age 17 and under certain circumstances for older children (including those not entitled to student grants), and the National Assistance Act, under which benefits are paid to claimants who have too little or no income.

National insurance schemes

Housing. A severe housing shortage began developing after the mid-20th century and became the source for political controversy. By the 1970s, in the face of continually growing demand, even an unprecedented boom of housing construction paled. Demographic changes led to a rapid increase in the number of households, and rising standards of living fueled the consumption of space per person. This crisis abated by the mid-1970s, only to be replaced by a financial one.

Rent controls, as well as alternative investment opportunities and the introduction of the social security of the welfare state, reduced the private rental sector from more than 60 percent in 1947 to less than 15 percent by the late 1980s. The expansion of the postwar housing stock was made possible only by massive investment in subsidized rental housing, which now accounts for more than 40 percent of the stock. Concurrently, the generously subsidized homeowner sector expanded to more than 45 percent.

Environmental control. In The Netherlands, as in all industrialized countries, the increasing pollution of both the natural and man-made environments is a major problem. Pollution in The Netherlands has certain specific aspects that are closely linked to the country's geography. For example, the maritime situation, together with the low-lying character of the coastlands, gives rise to a serious salination problem. The great European rivers, the Rhine, Maas, and Schelde, transport many waste products to The Netherlands and into the adjoining North Sea. High population density and its associated intensive land use also increase the concentration of all forms of pollution.

Government policy concentrates increasingly on combating negative environmental effects, preferably by tackling their source. Thus commuters are encouraged to travel by public transport, farmers are induced to reduce the use of pesticides and artificial fertilizers, and industries are regulated to promote cleaner production processes and to reduce emissions of pollutants into the air, water, and soil. Environmental control measures require costly sacrifices from both the individual taxpayer and industry.

CULTURAL LIFE

The cultural life in The Netherlands is varied and lively. Dutch painting and crafts are world-renowned, and Dutch painters are among the greatest the world has ever known. The Dutch themselves take great pride in their cultural heritage, and the government is heavily involved in subsidizing the arts, while not involving itself directly in artistic control of cultural enterprises. Indeed, the long-enduring tradition of Dutch freedom of expression has undoubtedly played a significant role in the flowering of Dutch culture through the ages.

Dutch tradition in the arts

The arts. *Painting and sculpture.* The history of Dutch painting offers such a deep, rich lode of names that only a few can be touched on here. Certainly among the most revered are those of Rembrandt and Vincent van Gogh. Rembrandt, painting in the 17th century, became a master of light and shadow, a technique reflected in his landscapes as well as such portraits as his monumental "The Night Watch." Van Gogh, born in the 19th century, was a powerful influence in the development of modern art.

Among other great painters of the Low Countries are Jan van Eyck, the founder of the Flemish school; the allegorical Hiëronymus Bosch; the portraitist Frans Hals and landscapists Aelbert Cuyp and Jacob van Ruisdael; still-life artists such as Jan Vermeer, Willem Heda, and Willem Kalf; and the geometrically inclined Piet Mondrian. For a broader discussion of Dutch painting, see PAINTING, THE HISTORY OF WESTERN.

Literature and the performing arts. Dutch literature, and theatre as well, has always been handicapped by the smallness of the proportion of the human race that speaks Dutch. Perhaps the greatest name of Dutch letters was that of the Renaissance humanist Erasmus. For more information, see DUTCH LITERATURE. The nation's performing arts are widely encouraged and supported. The National Ballet at Amsterdam and the Netherlands Dance Theatre at The Hague are internationally renowned. Theatre companies are all private foundations, though the state and the municipalities provide financial assistance. The Dutch film industry is not highly developed.

Ballet and theatre

Music. The Netherlands has not produced composers of the stature of some of its neighbouring countries, although it has built a fine reputation for performance. The Amsterdam Concertgebouw Orchestra is world-famous, and the Residentie Orchestra at The Hague and the Rotterdam Philharmonic Orchestra also have fine reputations. Various other towns have orchestras and choral groups, and there is a Dutch National Opera Company. Noted musical events include the World Music Festival at Kerkrade and the North Sea Jazz Festival at The Hague.

Cultural institutions. The Netherlands has a rich range of state-supported museums. The most famous is the Rijksmuseum at Amsterdam, noted for its collection of works by the great 17th-century Dutch masters (especially Rembrandt). Other major museums endowed by the state include the Mauritshuis at The Hague, Het Loo (the former royal palace) at Apeldoorn, and the Stedelijk Museum in Amsterdam, recognized for its collection of contemporary paintings. Two museums, the Rijksmuseum Vincent van Gogh in Amsterdam and the Rijksmuseum Kröller-Müller in Otterloo (Veluwe), are renowned for their collections of paintings by van Gogh. The most popular folk museums are the Openluchtmuseum (Open Air Museum) at Arnhem and the Zuiderzeemuseum at Enkhuizen.

Recreation. Favourite regions for open-air recreation are the sea coasts with their wide sandy beaches and the many interior lakes in the western and northern parts of the country. They are frequented by both Dutch and foreign visitors. The Dutch people also are attracted to hilly areas, such as the Veluwe and the southern part of Limburg province, while foreign visitors come in droves to the old cities in the western part of the country, with Amsterdam ranking as the most popular site. Favourite foreign vacation spots for the Dutch are the Mediterranean coasts during the summer holidays and the Alps during winter holidays.

Press and broadcasting. The constitution guarantees freedom of the press but does not allow journalists to protect their sources. The Dutch press has a long-standing reputation for high-quality reporting, newspapers having been printed in Amsterdam as early as 1618. One of the oldest newspapers in Europe is the *Oprechte Haerlemse Courant,* now called the *Haarlems Dagblad,* which was founded in 1656. By far the greatest circulation is enjoyed by *De Telegraaf* from Amsterdam (right of centre). The most widely read newspapers in political and intellectual circles are the *NRC Handelsblad* in Rotterdam (liberal) and *De Volkskrant* in Amsterdam (left of centre).

Radio and television

The majority of radio and television transmissions are produced by eight associations, all under private initiative. There are Roman Catholic, Protestant, Socialist, and independent broadcasting organizations, each of which publishes for its supporters a comprehensive weekly that lists all the Dutch and a fair number of foreign programs. All these stations operate within the framework of the Netherlands Broadcasting Corporation, which is responsible for the programming of unreserved airtime. Religious organizations, political parties, and small factional groups are granted some reserved broadcasting time. The government itself has no influence on the programs. Advertising is restricted and is controlled by a separate foundation. All broadcasting is financed by a licensing fee and by the yield from television and radio advertising. A commercial Dutch-owned television station, based in Luxembourg, can be received in most parts of the country thanks to the extremely dense Dutch cable television network.

For statistical data on the land and people of The Netherlands, see the *Britannica World Data* section in the BRITANNICA BOOK OF THE YEAR. (M.W.H./H.Me.)

History of the Low Countries (to 1579)

For historical purposes, the name Low Countries is generally understood to include the territory of what is today the Kingdom of The Netherlands, Belgium, and Luxembourg, as well as parts of northern France. However, Belgium, although it was not constituted as an independent kingdom until 1831, became a distinct entity after 1585, when the southern provinces were definitively reconquered by Spain and separated from the northern sector. For a brief period, from 1814 to 1830, an attempt was made to unite the Low Countries into one kingdom again, but both regions by this time had developed cultures too different to form a single entity under a central government. Here, therefore, the history of the Low Countries will be surveyed as a whole to the late 16th century. The later individual histories of Belgium and Luxembourg are treated in the separate articles on those countries.

PREHISTORY

In most stages of the prehistory of the Low Countries the regions north of the lower courses of the Rhine and Meuse (Mass) rivers were part of a North European culture area, while those to the south had close relations to central and western Europe.

Lower and Middle Paleolithic (250,000–35,000 BP). The earliest well-dated remains of human habitation in the region are flint objects that reflect the Levalloisian stone-flaking technique. Found in the loess-covered Belvedere quarry near Maastricht on the Netherlands-Belgium border, these objects have been dated to about 250,000 years BP, correlating with an early interstadial period during the Saale Glacial Stage. The remains of human industry discovered in river deposits near Mons, Belg., may even be slightly older than the findings at the quarry. Hand axes from the late Saalian stage and other artifacts derived from ice-borne deposits have been recovered in the central and northern Netherlands and are characterized as late Acheulian.

The Mousterian culture (*c.* 80,000–35,000 BP) has been documented in the Ardennes caves in southern Belgium and in open excavation sites in The Netherlands' North Brabant and Belgian Limburg. Mousterian tool culture is associated with Neanderthal man, and the skeletal remains of that form have been found in several Belgian caves (at Spy near Namur and at Engis near Liège) in the 19th century.

Upper Paleolithic (35,000–10,000 BP). Aurignacian, Gravettien (upper Perigordian), and Magdalenian assemblages found in the Ardennes caves represent the northernmost fringes of the inhabited zone of Europe until about 13,000 BP. The open site of Maisières Canal in Hainaut province, Belg., is exceptional for its preservation of glacial fauna (from about 28,000 BP) in later river deposits. Several late Magdalenian sites (hunting stands) were discovered in southern (Belgian and Dutch) Limburg. A wide uninhabited area separated the Magdalenian sites from sites of the Hamburgian tradition (emanating from western Germany) in the northern Netherlands. The latter included reindeer-hunting peoples who were the first colonists of the North European Plain at the end of the last (Weichsel) ice age. Later cultural traditions (including the Federmesser, Creswellian, and Ahrensburgian) formed the basis for the cultures of the succeeding Mesolithic period.

Ardennes cave findings

Mesolithic (10,000 BP–4000 BC). (BC dates in this section are all based on radiocarbon measurements calibrated to real centuries before Christ). The distribution of hundreds of flint scatters often characterized by microliths (tiny blade tools) distinguish southern and northern cultural spheres, separated by the main rivers. Bone implements from the period have been dredged or fished up from locales in the North Sea and Rotterdam harbour. Outstanding among the relics of the period is a dugout pine canoe found at Pesse in Drenthe province; dating to 8500 BP, it is the oldest vessel known. Among the culture groups of the period were the Maglemesians of the northern cultural sphere. Their implements are often decorated with designs. Another culture group of the period, the Tardenoisian, occupied sandy regions and plateaus; their remains included arrowheads and other objects incorporating microliths.

Neolithic (4000–2900 BC). Farmers of the Linear Pottery culture, settling on the loess of Dutch Limburg and Belgium around 6500 BP, were among the first to bring Neolithic lifeways to the region. Large-scale excavations in Sittard, Geleen, Elsloo, and Stein in The Netherlands and at sites including Rosmeer and Darion in Belgium have rendered considerable remains from this early Neolithic group. This northwesternmost branch of the culture met with other communities that left, by contrast, few relics and are identified only by minimal scatters of their characteristic pottery, called Hoguette and Limburg. These early communities had widespread internal contacts, documented by remains that include adzes made of exotic stone, and external contacts with late Mesolithic communities to the north, especially along the Meuse River.

Other cultures briefly rose up (Blicquy in Belgium and Rössen in Germany) and in their turn were succeeded about 4100 BC by the northwesternmost branch of the Michelsberg culture in Belgium and, somewhat later, the Funnel-neck Beaker culture in The Netherlands. The evolution of these groups represents principally a transformation in the style of material culture of native communities. Among the most significant Michelsberg remains are the extensive fields of deep flint mines at Spiennes in Hainaut and Rijckholt in Dutch Limburg. Contacts by the Michelsberg with late Mesolithic hunter-gatherers north of the loess zone gave rise to semiagricultural communities, as evidenced by relics from about 4000 BC found in the Netherlands delta at Swifterbant in Flevoland and Hazendonkborn and Bergschenhoekborn in Zuid-Holland.

The late Neolithic (3300–2900 BC) is characterized in the eastern Netherlands, especially in Drenthe, by the Funnel-neck Beaker culture, which is particularly distinguished by megalithic burial monuments (the so-called *hunebedden*), the origins of which are still unknown. Composed of large stone blocks left behind by receding glaciers, these monuments mark collective tombs and may extend for up to 160 feet (about 50 metres) in length. In addition to the beakers for which the culture is named, the remains include collared flasks, buckets, and bowls—often decorated with horizontal and vertical grooves—and polished stone and flint tools. Southern Belgium was reached in this period by the northern fringes of the French Seine-Oise-

Funnel-neck Beaker culture

Marne culture. A third cultural entity has been identified in the Netherlands delta as the Vlaardingen group; it comprises fully agrarian as well as semiagrarian settlements.

Transitional between the Neolithic and Bronze ages is the beaker phase (2900–2000 BC). A distinguishing characteristic of the culture is its change to exclusively individual burial, in which specific grave goods (battle-axes, daggers, beakers) were included; the body, arranged in a flexed posture, was placed in an east-west orientation. This custom is assumed to indirectly reflect essential changes in society, possibly brought about by technological innovations, such as the plow, the wheel, and the cart, which might have caused a restructuring of the agrarian system.

The Bronze Age (2000–700 BC). The early Bronze Age in the region was characterized by a continuation of the beaker tradition, the beginnings of bronze imports (from central and northern Europe and the British Isles), and a modest local bronze industry. The origin of cremation and the burial of ashes in urns in the southern Netherlands and Belgium (Hilversum culture) can be related to close contacts with Wessex, in Britain.

Finds from the middle Bronze Age (1500–1100 BC) reflect the establishment of an essentially more advanced agricultural system: remains of some 80- to 130-foot-long farmhouses, including stable sections, provide evidence of true mixed farming, including manuring, care for winter fodder, and, presumably, the use of straw in stables. Cattle were by far the dominant livestock. This contrasts sharply with the Neolithic cultures, in which agricultural activities are presumed to have been less interrelated. Burial during the period was under barrows, now surrounded by post circles, with human remains either extended in coffins (common to the northern Netherlands) or cremated in urns (as in the south).

While settlement tradition continued, changes in burial custom took place around 1100 BC, with urn burial now taking place in small, individual barrows surrounded by ditches of various types. A northern sphere connected with Westphalia, a central sphere in Noord-Brabant/Limburg connected with the Rhineland, and a southern Flemish group are distinct examples of this type of burial. Modest native bronze industries have been identified in the north (Hunze-Eems industry) as well as along the Meuse in Limburg, while bronze weapons and implements were imported from Great Britain and various other sources.

The Iron Age (*c.* 700 BC to Roman times). The Iron Age in the Low Countries is characterized by Celtic and Germanic influences. In the south, Hallstatt (Celtic) and La Tène traditions can be traced through prestigious warrior chieftain graves at such sites as Court Saint Etienne (Hainaut, Belg.), Eigenbilzen (Belg.), and Oss (Neth.), which were stocked with chariots and harnesses, bronze weapons, implements, and even wine services. These traditions are also reflected in fortified hilltop settlements, in pottery styles, and in ornaments and other artifacts. On the sands to the north people had to cope with a deteriorating environment, especially impoverishment of the soils, podzolization, and wind erosion. They responded to these conditions with a more diversified agriculture and the more protective system of Celtic fields (small plots with low earthen banks formed around them). Other illustrations of renewed adaptability were demonstrated by the colonization of newly formed salt marshes and the building of artificial dwelling mounds called *terpen* in the north, the new settlement of creek and peat landscapes of the western river estuaries, salt production along the coast, and the breeding of horses elsewhere. (L.P.L.K.)

Celtic fields

ANCIENT AND EARLY MEDIEVAL TIMES

The Roman period. At the time of the Roman conquest (1st century BC), the Low Countries were inhabited by a number of Celtic tribes to the south and west of the Rhine and by a number of Germanic tribes to the north. Cultural and ethnic influences in both directions, however, make it difficult to draw the line between Celtic and Germanic peoples. On the coast of northern France and in Flanders lived the Morini; to the north of them, between the Schelde River and the sea, the Menapii; in Artois, the Nervii; between the Schelde and the Rhine, the Eburones and the Aduatuci; and, in what is now Luxembourg, the Treveri. North of the Rhine, the Frisii (Frisians) were the principal inhabitants, although the arrival of the Romans brought about a number of movements: the Batavi came to the area of the lower reaches of the Rhine, the Canninefates to the western coastal area of the mouth of the Rhine, the Marsaci to the islands of Zeeland, the Toxandri to the Campine (Kempenland), the Cugerni to the Xanten district, and the Tungri to part of the area originally inhabited by the Eburones.

The Roman conquest of Gaul, which was completed by Caesar in 59–52 BC, stopped short at the Rhine. The emperor Augustus' attempt to extend Roman military power over the Elbe failed, and the area occupied by the Frisians, north of the Rhine, was therefore never under Roman rule. In the Rhine delta and to the south and west of the Rhine, the Romans set up the same administrative organizations as those found in other parts of Gaul. The Low Countries formed part of the provinces of Belgica and Germania Inferior (later Belgica Secunda and Germania Secunda), which themselves were subdivided into *civitates:* in Belgica, those of the Morini, Menapii, Treveri, Tungri, and possibly the Toxandri; in Germania Inferior, those of the Batavi, Canninefates, and Cugerni. Because of the later adoption by the church of the division into *civitates,* a number of centres of the *civitates* have become the seats of bishoprics; among these are Thérouanne, Tournai, Tongeren (Tongres), and Trier (Trèves).

From the mid-1st to the mid-3rd century AD, the Gallo-Roman culture penetrated the northern provinces of the empire. The famous road network was constructed, and important garrisons were concentrated along the Rhine and also on the Waal at present-day Nijmegen. This affected a whole region: a more inland city such as Tongres became an important market for grain to be brought to Cologne. Along the great Cologne-Tongres-Bavai-Boulogne axis, relatively rich *villae* were located at regular distances. One of these, the city of Maastricht, profited from the river trade on the Meuse and had baths as early as the 1st century, while graves in the vicinity contained sarcophagi with bas-relief ornamentation, as well as splendid glass and sculptures of Mediterranean origin. The Gallo-Roman elite were concentrated along the main roads and especially on the richest lime soils. Some large industrial settlements producing iron works and clay tiles were located near the Schelde close to crossings of secondary roads to the north.

Decline of Roman power

In the mid-3rd century Roman power in the Low Countries began to weaken, and the forts were abandoned. This was the result not only of a resurgence of the Germanic tribes but also probably of the encroachment of the sea, which in all likelihood brought about a drastic change in the area's economy. A temporary recovery began at the end of the 3rd century. In particular, Julian, Caesar of Gaul, waged several wars in the Low Countries between 355 and 360 and was able to put new strength, for a time, into the Rhine border. A great invasion by Germanic tribes in 406–407, however, ended the Roman occupation of the Low Countries. The Romans had already tolerated the Germanic penetration of their territory and had given some tribes the task of protecting the borders of the empire. The Franks, who had settled in Toxandria, in Brabant, were given the job of defending the border areas, which they did until the mid-5th century.

Frankish rule. The Franks were probably influenced considerably by Roman culture, becoming familiar with the Roman world and way of life, although the expansion of their own race and their growing self-confidence were barriers to complete Romanization. About 450 they moved southward, founding a new Frankish kingdom in a region that was centred on the road from Tongres to Boulogne. The Gallo-Roman population had left the less-populated sandy areas in the north and withdrawn south of that road. The first king of the Merovingian Franks, Childeric I (d. 481/482), ruled the region around Tournai, while his son Clovis I (ruled 481/482–511) extended the kingdom, eliminating other Frankish leaders and becoming ruler of much of Gaul. During the 6th century, Salian Franks had settled in the region between the Loire River

in present-day France and the Coal Forest in the south of present-day Belgium. From the late 6th century, Ripuarian Franks pushed from the Rhineland westward to the Schelde. Their immigration strengthened the Germanic faction in that region, which had been almost completely evacuated by the Gallo-Romans. The Salian Franks, on the other hand, had penetrated a more densely Latinized area where they came under the strong influence of the dominant Roman culture.

Resistance to the Franks

The area occupied by the Frisians in the north was completely outside the Frankish sphere of influence, but the Rhine delta and even what is now Noord-Brabant also appear to have retained the virtually independent status they had possessed during the Roman era.

The Frisians were part of a North Sea culture that formed a distinct foil to Frankish power. The Frisians played an important role in trade, which sought routes along the Rhine and the Meuse and across the North Sea. Industrial products were imported from northern France, the Meuse plain, and the Rhineland, where Merovingian power was more firmly established and where centres of commerce (*e.g.,* Dinant, Namur, Huy, and Liège) developed. The more or less independent area on the North Sea coast, however, found itself threatened during the 7th century by the rise of the Frankish nobles. In particular, the family of the Pepins, who came from the centre of Austrasia (the Ardennes and upper Meuse), was able to secure land in Limburg. Moreover, encouraged by the Frankish king Dagobert (ruled 623–639), the Frankish church began an offensive that led to the foundation of the bishopric of Thérouanne (the *civitas* of the Morini).

This collaboration between church and nobles prepared the way for an expansion of political power to the north, which was carried out under the leadership of the Pepins, who as "mayors of the palace" in Austrasia had virtually taken over power from the weakened Merovingian kings. Charles Martel, a bastard son of Pepin II, who managed after several years' fighting (714–719) to grasp supreme power over the whole Frankish empire, succeeded in 734 in forcing his way through to the northern centres of the Frisians and gaining a victory near the Boorne River. His victory was later consolidated by Pepin III and his son Charlemagne (ruled 768–814). The whole area of the Low Countries thus effectively formed part of the Frankish empire, which was then ruled by the Pepin, or Carolingian, dynasty.

Life under the Franks

The Low Countries under the Carolingians. *Government.* The administrative organization of the Low Countries during this period was basically the same as that of the rest of the Frankish empire. Supreme authority was held by the king, who, aided by servants of the palace, toured the country incessantly. The Carolingian kings naturally made several visits to the Low Countries, where they had old palaces or built new ones (Herstal, Meerssen, Nijmegen, Aix-la-Chapelle) and where they also possessed extensive crown estates. Their authority (*bannus*) was delegated to counts who had control of counties, or *gauen* (*pagi*), some of which corresponded to Roman *civitates.* Among these counties in the Low Countries were the *pagus* Taruanensis (centred on Thérouanne), *pagus* Mempiscus, *pagus* Flandrensis (around Brugge), *pagus* Turnacensis (around Tournai), *pagus* Gandensis (Ghent), *pagus* Bracbatensis (between the Schelde and the Dijle rivers), *pagus* Toxandrie (modern Noord-Brabant), and, north of the great rivers, Marssum, Lake et Isla, Teisterbant, Circa oras Rheni, Kinnem, Westflinge, Texla, Salon, Hamaland, and Twente. In the north, however, it is frequently not possible to determine with certainty whether the word *gau* in fact denoted a region controlled by a count who exercised the king's authority or indicated simply a region of land without reference to its government. Smaller administrative units were the *centenae,* or hundreds, and districts called *ambachten.* These last were mainly in what are now the provinces of Vlaanderen, Zeeland, and Holland.

Religion. The conversion to Christianity of the southern Low Countries, which took place largely during the 7th century, led to the foundation of further bishoprics at Arras, Tournai, and Cambrai, which were part of the ecclesiastical province of Rheims (the former Roman province of Belgica Secunda). Germania Secunda contained the ecclesiastical province of Cologne, in which the *civitas* of Tongres seems to have had an uninterrupted existence as a bishopric since Roman times; the centre of this bishopric was moved for a time to Maastricht (6th and 7th centuries) until, about 720, Liège became the seat of the bishopric. Christianity was brought to the north of the Low Countries mainly by Anglo-Saxon preachers, by Frisians influenced by them, and by Franks. This Anglo-Saxon Christianity was particularly important in the missionary bishopric of Utrecht, which at first, because of its missionary character, had no precisely defined borders. True, the city of Utrecht had been named as the see of the bishopric, but, as in England, the monasteries played an important part in the missionary work; among these was the monastery of Echternach in Luxembourg and the two important Benedictine abbeys in and near Ghent, founded by St. Amand in the early 7th century. The country between the Meuse and the Waal rivers and the area around Nijmegen belonged to the bishopric of Cologne, while certain districts in the north and east were part of the bishopric of Münster (founded by Charlemagne).

Social classes. The social structure of the Low Countries in the Frankish era included a number of classes. At the top was an elite that probably already operated on a hereditary system and of which the members were bound to the king as vassals and rewarded by fiefs (*beneficia*). Next were the freemen (*liberi, ingenui*), bound to the king by an oath of allegiance and traditionally under an obligation to serve in the army and in the law courts. A freeman's *Wergeld*—the sum that had to be paid to his family if he was killed—was in principle 200 shillings (*solidi*); but the *ingenui Franci,* or *homines Franci* (found in the region of the great rivers; probably descended from native nobles who had early placed themselves in the service of the Franks in their policy of conquest), had a much higher *Wergeld.* At the bottom of the ladder were the bondsmen, who were closely dependent on a lord (often an important landowner), in whose service they stood, in most cases working on his estates. It may be supposed that the position of the bondsmen was relatively favourable in the coastal areas of Holland and Friesland, where there were no large estates and, moreover, where the struggle against the sea required as much manpower as the community was able to offer.

Economy. Economically, the structure of the Low Countries in the Frankish period was principally agrarian. Particularly in the south and east, it was common practice to exploit the land from a central farmhouse (*villa,* or *curtis*), using the services of dependent subjects (bondsmen), who were duty-bound to work on the domain of the lord and to this end received small farms from him. The nature of the land in the west and north, however, probably to a large extent precluded this classical type of exploitation of the domains; there was scattered, even fragmentary, ownership of land, and the *curtis* was no more than a gathering place to which the bondsmen had to take a part of their produce. In Holland and Friesland, fishing and the raising and selling of cattle were of importance. This Frisian trade, of which Dorestad was a centre, was greatly stimulated by absorption into the Frankish empire, and it reached its zenith under Charlemagne and Louis I the Pious (ruled 814–840). Moreover, by virtue of its becoming part of the Frankish empire, Friesland obtained an important hinterland in the southern regions of the Meuse and Rhine and was thus in a position to develop export and through trade to Denmark, Norway, and the Baltic countries. The importance of Frisian trade may be seen in the Carolingian coins found in Dorestad, where there was a toll and a royal mint. This trade was supplied by the southern Low Countries. Thus the cloths that were sold as Frisian cloths were produced in the area of the Schelde (later called Flanders). Quentovic, at the mouth of the Canche, was another trading centre; it too had a toll and a mint. Smaller trade settlements (*portus,* or *vicus*) emerged at Tournai, Ghent, Brugge, Antwerp, Dinant, Namur, Huy, Liège, and Maastricht—a clear indication of the commercial importance of the Schelde and the Meuse.

Decline of the Frankish empire. The great Carolingian

Partition of the empire

dynasty passed into a decline as early as the reign of Louis the Pious, and the process was accelerated after his death in 840. Repeated wars broke out under his sons, leading eventually to the partition of the empire. The dissolution of Carolingian power was further helped by Viking, Magyar, and Saracen attacks—the Viking attacks being of greatest import for the Low Countries. The attacks had begun immediately after the death of Charlemagne (814) in the form of plundering raids, the magnitude and danger of which soon increased. (Dorestad, for example, was destroyed four times between 834 and 837.) Churches and monasteries, with their rich treasures, were the principal targets for the Vikings, who soon took to spending the winter in the Low Countries. In order to ward off the danger, attempts were made to throw up walls around towns and monasteries or even to drive off the Vikings by fierce counterattacks—a procedure that enjoyed some success—so that the counts of Flanders, for example, were able to lay a firm foundation for their own power. Another method of defense was to admit the Vikings on the condition that they defend the areas given them against other Vikings. The danger diminished after 900.

THE DEVELOPMENT OF THE TERRITORIAL PRINCIPALITIES AND THE RISE OF THE TOWNS (925–c. 1350)

Politically speaking, the period between 925 and about 1350 is characterized by the emergence, growth, and eventual independence of secular and ecclesiastical territorial principalities. The rulers of these principalities—both secular and spiritual—had a feudal relationship with the German king (the Holy Roman emperor), with the exception of the count of Flanders, who held his land principally as the vassal of the French king, with only the eastern part of his county, Imperial Flanders, being held in fealty to the German king. While the secular principalities came into being as a result of individual initiative on the part of local rulers and of their taking the law into their own hands, to the detriment of the king's authority, the development of the spiritual princes' authority was systematically furthered and supported from above by the king himself. The secular principalities that arose in the Low Countries and whose borders were more or less fixed at the end of the 13th century were the counties of Flanders and Hainaut, the duchies of Brabant and Limburg (after 1288 joined in personal union), the county of Namur, the county of Loon (which was, however, to a large degree dependent on the bishopric of Liège and incorporated in it from 1366), the county of Holland and Zeeland, and the county (after 1339, duchy) of Guelders. The Frisian areas (approximately corresponding to the modern provinces of Friesland and Groningen, but excluding the city of Groningen) had no sovereign authority. The spiritual principalities were Liège, Utrecht, Tournai, and Cambrai. The secular authority of the bishop of Utrecht was exercised over two separate areas: the Nederstícht (now the province of Utrecht) and the Oversticht (now the provinces of Overijssel and Drenthe and the city of Groningen).

The spiritual principalities

It must be noted that, although these principalities displayed common characteristics in their economies, social structures, and cultures, it was the intrusion of the Burgundian dynasty that brought about a certain degree of political unity, which in turn furthered economic, social, and cultural unity and even led to the beginnings of a common national feeling (which was nevertheless too weak to prevent partition in the late 16th century).

The secular principalities. The secular princes consolidated their power in a number of ways. The count still exercised the rights that had for centuries been attached to the Carolingian office of count, denoted by the term *comitatus*. They included the administration of justice, various military powers, and the right to levy fines and tolls. To these rights fiefs were attached, which during the passage of time were expanded by the counts, who eventually owned such large estates that they were by far the greatest landowners in their territories. Soon the term *comitatus* covered not only the office, or duty, but also the whole area over which that office was exercised; thus it could be said that the count held his county in fief of the king. An important element of the count's authority was supervision over the county's religious foundations, especially the monasteries. In the 10th century, the counts sometimes even assumed the function of abbot (lay abbot); but they later contented themselves with the control of appointments to ecclesiastical offices, through which they often had great influence over the monasteries and profited from the income from monastic land. Thus, monasteries such as St. Vaast (near Arras), St. Amand (on the Scarpe), St. Bertin (near St. Omer), and St. Bavon and St. Peter (in Ghent) became centres of the power and authority of the counts of Flanders; Nivelles and Gembloux, of the dukes of Brabant; and Egmond and Rijnsburg, of the counts of Holland.

Expansion of counts' power

At the end of the 9th and in the 10th century, during the Viking attacks and while connections with the empire were loosening, the local counts built up their power by joining a number of *pagi* together and building forts to ensure their safety. The counts of Flanders amalgamated the *pagi* Flandrensis, Rodanensis, Gandensis, Curtracensis, Iserae, and Mempiscus, the whole being thenceforth called Flanders; they fortified this area of their power with new or surviving Roman citadels. In the northern coastal regions, the Viking Gerulf was granted in about 885 the rights over a number of counties between the Meuse and the Vlie (Masalant, Kinnem, Texla, Westflinge, and a district known as Circa oras Rheni, which was, as the name implies, on both sides of the Rhine); his descendants consolidated their power there as counts of west Frisia and, after 1100, took the title of counts of Holland. In Brabant and Guelders, the amalgamation of fragmentary and dispersed estates took place later than in Flanders and Holland.

During the 10th and 11th centuries, the German kings of the Saxon and Salian dynasties attempted to impose their authority on the increasingly powerful secular principalities by the appointment of dukes. In Lorraine, during the reign of Otto I (936–973), the king appointed his brother, Bruno, the archbishop of Cologne, to the position of duke. Bruno soon split Lorraine into two dukedoms—Upper and Lower Lorraine. In Lower Lorraine, the title of duke was given to the counts of Louvain and the counts of Limburg—the former at first called themselves dukes of Lorraine but soon assumed the title of dukes of Brabant; the latter were known as the dukes of Limburg.

Rise of bishops and abbots

The spiritual principalities. That the German kings failed to integrate Lorraine into the Holy Roman Empire as a duchy ruled by a viceroy may be attributed to the fact that the kings soon developed another way to strengthen their power, not only in Lorraine but throughout the empire, by systematically investing bishops and abbots with secular powers and making them pillars of authority. This procedure, developed by Otto I and reaching its summit under Henry III, was carried out in phases and led eventually to the establishment of the Imperial Church (Reichskirche), in which the spiritual and secular principalities played an important part. The most important ecclesiastical principalities in the Low Countries were the bishoprics of Liège, Utrecht, and, to a lesser degree, Cambrai, which, though within the Holy Roman Empire, belonged to the French church province of Rheims. The secular powers enjoyed by these bishops were based on the right of immunity that their churches exercised over their properties, and that meant that, within the areas of their properties, the counts and their subordinates had little or no opportunity to carry out their functions. The bishops' power was consolidated when the kings decided to transfer to the bishops the powers of counts in certain areas that were not covered by immunity.

Certain bishops, such as those of Liège and Utrecht, were able to combine their rights of immunity, certain jurisdictional powers, regalia, and ban-immunities into a unified secular authority, thus forming a secular principality called a *Sticht* (as distinct from the diocese) or—where the power structure was very large and complex, as in the case of the bishop of Liège—a prince-bishopric. As princes, the bishops were vassals of the king, having to fulfill military and advisory duties in the same way as their secular colleagues. The advantage of this system to the kings lay in the fact that the bishops could not start a

dynasty that might begin to work for its own ends, and its smooth running stood and fell with the authority of the kings to nominate their own bishops.

Thus the spiritual-territorial principalities of the bishops of Liège and Utrecht emerged—the prince-bishopric of Liège and the *Sticht* of Utrecht. In Liège this development was completed in 972–1008 under the guidance of Bishop Notger, appointed by Otto I. As early as 985 he was granted the rights of the count of Huy, and the German kings made use of the bishopric of Liège to try to strengthen their positions in Lorraine. Utrecht, which lay more on the periphery of the empire, developed somewhat later. It was principally the kings Henry II, Conrad II, and Henry III who strengthened the secular power of the bishops through privileges and gifts of land.

Struggle for independence. Thus, the Low Countries during the 10th and 11th centuries saw the development of the pattern of a number of more or less independent feudal states, both secular and ecclesiastical, each of which was struggling for more freedom from the king's authority, the enlargement of its sphere of influence, and the strengthening of its internal power. Flanders led the way. In the 10th and 11th centuries it needed to pay only scant attention to the weak French kings of the Capetian dynasty and was thus soon able to exercise its power farther south—in Artois—and was even able to play an important part in a political power struggle around the French crown. In 1066 the count of Flanders lent his support to the expedition to England of his son-in-law, William, duke of Normandy. The counts of Flanders built up a strong administrative apparatus—the *curia comitis,* based on central officials and on local rulers called burgraves, or castellans (*castellani*), who were in charge of districts known as castellanies, where they had extensive military and administrative powers. The reclamation of land from the sea and from marsh and wasteland in the coastal area, which began in the 11th century, enlarged the estates and the income of the counts and brought about the need for a rational administrative system. The nobles were a power to be reckoned with, but Count Robert I (ruled 1071–93) and his successors were able to find support and a balancing force in such developing towns as Brugge, Ghent, Ypres, Courtrai, and Cassel. The murder of the powerful and highly respected Count Charles the Good (ruled 1119–27), who was childless, plunged Flanders into a crisis that involved not only the nobles and the towns but also, for the first time, the French king.

Leadership of Flanders

About 1100 such other territories as Brabant, Hainaut, Namur, and Holland began to expand and form principalities, helped by the weakening of the German crown during the Investiture Contest (a struggle between civil and church rulers over the right to invest bishops and abbots). The Concordat of Worms (1122) ruled that bishops were to be chosen by the chapter of canons of the cathedral; thus, the German king was obliged to transfer the secular powers to an *electus,* who was then usually ordained bishop by the metropolitan. Although the king still exercised some influence over the elections, the local counts were able to make their voices heard the loudest in the chapter, so that Utrecht, for example, soon had bishops from the families of the counts of Holland and Guelders. This was the end of the strong influence that German imperial power exercised through the bishops in the Low Countries. Thenceforth, the spiritual and secular princes stood together, although the death of a bishop still tended to plunge the principality into a crisis.

End of German imperial power

French and English influence. As their power declined, the Holy Roman emperors could do little more than involve themselves almost incidentally in the affairs and many conflicts of the Low Countries. The German decline went hand in hand with the increasing influence of the French and English kings, particularly after 1200; this applied especially to French power in Flanders. A struggle for the throne that broke out in Germany at the death of Henry VI (1197) found the two powerful factions—the Ghibellines and Guelfs—on opposite sides; in the Low Countries, a game of political chance developed, in which the duke of Brabant (Henry I) played an important role, alternatively supporting both parties. The French king, Philip Augustus, and his opponent, King John of England, both interfered in the conflict, which polarized into Anglo-Guelf and Franco-Ghibelline coalitions, each looking for allies in the Low Countries. A victory won by the French king at the Battle of Bouvines, east of Lille (1214), put the count of Flanders at his mercy. The southern parts of the county were split off and incorporated into the county of Artois.

Throughout the 13th century, the French kings increased their influence in Flanders, which was joined to Hainaut by personal union. The power of the counts diminished during the reign of two countesses from 1205 to 1278 because of the increasing pressure of the kingdom and the growing power of the cities. The counts' efforts to control the urban elites (the patriciate) by controlling the cities' finances and the appointment of the magistrates (aldermen, or *schepenen*) failed because the French king supported the patricians. King Philip IV, who was successful in his territorial expansion in Champagne and Gascony, also tried to incorporate the county of Flanders by a military invasion, in which he was supported by his patrician partisans. By 1300 the annexation of Flanders was almost complete. Resistance by Count Guy, which was supported by the crafts in the towns, culminated in a resounding victory by the Flemish army (which consisted largely of citizens of the towns fighting on foot) over the French knights at Courtrai (the Battle of the Golden Spurs, 1302) and prevented total annexation.

French influence remained strong during the 14th century, however, as the counts saw themselves repeatedly opposed by a mighty coalition of subjects in revolt. An early case was the peasant revolt in the western part of the county, supported by Brugge and lasting from 1323 to 1328; it was provoked by heavy taxation as a consequence of the French-imposed peace conditions of 1305. Only the massive help of a French army enabled the count to impose his heavy repression. Then the outbreak of the Hundred Years' War about 1337 tempted the Flemish to take sides with the English, whose wool imports they needed for their large-scale textile industry. From 1338 until his death in 1346, Count Louis I of Nevers sought the protection of the French king, to whom he fled, leaving his county virtually in the hands of the three major cities of Ghent, Brugge, and Ypres, which had developed as city-states. Again in 1379–85 a new revolt of the major cities against the count's son, Louis II of Male, provoked French military intervention, which, however, did not resolve the situation. Louis of Male also fled to France, and peace with the Flemings could only be negotiated favourably for the cities by their new prince, Philip, duke of Burgundy, youngest son of the French king, John II.

Social and economic structure. To obtain some insight into the social structure of the Low Countries between 900 and 1350, it is important to realize that, although the territorial princes wielded supreme power, the people were in fact directly dependent on an elite that, by virtue of owning land and possessing certain powers of jurisdiction and administration, had formed seigneuries, in which they held considerable effective power. These lords could control their dependents by demanding agricultural services, exercising certain rights over dependents' inheritances, levying monies in return for granting permission to marry, and forcing them to make use of the lords' mills, ovens, breweries, and stud animals. In the main, the owners of these seigneuries were treated as nobles and were often, though not always, bound to the territorial prince by feudal ties. A separate class was formed by the knights, who in the 12th century were usually *ministeriales* (servants who had originally been bondsmen) and were used by their lords for cavalry service or for higher administrative duties, for which they received a fief. It was not until the 13th century and, in many places, even later that the feudal nobility and ministerial knights became unified in a single aristocracy. Apart from these nobles, there were also freemen who owned their own land (*allodium*), but little is known about them; they were present, however, in large numbers in the cattle-breeding regions of Flanders, Zeeland, Holland, and Friesland, where the numerous rivers and streams must have split up the land into many

Social classes

small farms. The descendants of noble families who were no longer able to live as richly as the nobles and who were known as *hommes de lignage* (in Brabant), *hommes de loi* (Namur), or *welgeborenen* (Holland), must have been very close in status to the freemen. In the agricultural areas of Hainaut, Brabant, Guelders, and the Oversticht were dependents whose legal status is difficult to determine, though they may be classed as bondsmen because of their being liable for various services and payments.

A factor of great, if not decisive, importance for social and economic relations, not only in the Low Countries but in all of western Europe, was the growth of the population. There is no direct statistical information but only a certain amount of indirect knowledge—after about 1050, it can be seen in the internal colonization (in the form of reclamation of such waste ground as woods and bogs), in the building of dikes and polders, in the expansion of agricultural land, and in the growth of the villages (new parishes) and towns.

Expansion of the land

The opening up of extensive areas of wood and heathland led to the foundation of new settlements (known in the French-speaking areas as *villes neuves*), to which colonists were attracted by offers of advantageous conditions—which were also intended to benefit the original estates. Many of these colonists were younger sons who had no share in the inheritance of their fathers' farms. The Cistercian and Premonstratensian monks, whose rules prescribed that they must work the land themselves, played an important part in this exploitation of new land. In the coastal regions of Flanders, Zeeland, and Friesland, they were very active in the struggle against the sea, building dikes both inland and on the coast itself. At first these dikes were purely defensive, but later they took on an offensive character and wrested considerable areas of land from the sea.

Especially important was the reclamation of marshland in the peat-bog areas of Holland and Utrecht and in the coastal regions of Flanders and Friesland. The Frisians had specialized in this work as early as the 11th century; Flemings and Hollanders soon adopted their methods, even applying them in the Elbe plain in Germany. The system, which consisted of digging drainage ditches, lowered the water table, leaving the ground dry enough for cattle grazing and, later, even for arable farming. The colonists, who were freemen, were given the right to cut drainage ditches as far back from the common watercourse as they wished. Certain restrictions were later imposed by the lords, however, who regarded themselves as the owners of these waste areas and demanded tribute money as compensation. Reclamation work was organized by a contractor (*locator*), who was responsible to the count and often carried out the function of local judge.

Thus, in the 12th and 13th centuries, a large area of land in the Holland-Utrecht peat-bog plain was made available for agriculture, facilitating the rise of nonagricultural communities (*i.e.,* the towns). In Flanders, Zeeland, Holland, and Utrecht this struggle against the sea and the inland water was particularly noteworthy in that it led to the foundation of water boards, which in the 13th and 14th centuries were amalgamated to form higher water authorities (the *hoogheemraadschappen*). Mastery over the water had to be carried out on a large scale and in an organized fashion; the building of dikes required a higher authority and coordinated labour. Thus, various organizations emerged, acting independently in the field of canal and dike building and maintenance and responsible only to the government itself. These were *communitates,* with their own servants and their own managements (dike reeves and *heemraden*) and empowered to take necessary measures to maintain the waterworks, administer justice, and issue proclamations. This included the levy of taxes for this purpose, under the exclusive control of the landholders, who had to contribute proportionally to the area they possessed. The need of absolute solidarity, imposed by geography, thus created a system of communal organization based on full participation and equality exceptional in European terms. In the core of Holland, three large *hoogheemraadschappen* controlled the whole territory. They were headed by dike reeves who also were the count's bailiffs and thus functioned as high judges and administrators. They were assisted by *heemraden* elected by the landholders.

Formation of water authorities

The increase in the population and the reclamation of land from the sea and marshes, as well as the fight to keep the sea out, all helped change the social and economic structures of the Low Countries. For centuries, the southern and eastern areas had been agricultural, often making use of the domain system. In the coastal areas, however, reduced labour requirements of cattle raising could be combined with fishing, weaving, and overseas trading. Dorestad, the centre of the Frisian trade, fell into decay not so much as a result of Viking raids (it was rebuilt after each one) as of a change in the course of the river upon whose banks the town was situated. Dorestad's leading position in trade was then taken over by Tiel, Deventer, Zaltbommel, Heerewaarden, and the city of Utrecht. Wheat was imported from the Rhine plain, salt from Friesland, and iron ore from Saxony, and, before long, wine, textiles, and metal goods were brought along the Meuse and Rhine from the south. The IJssel in Guelders also began to carry trading traffic through Deventer, Zutphen, and Kampen and, on the coast of the Zuiderzee (now IJsselmeer), through Harderwijk, Elburg, and Stavoren.

Growth of Flanders

In the south, commercial developments were concentrated in two areas: one was the Artois-Flanders region, which profited from the shipping facilities of a river system providing access to the sea and to the wide Schelde plains; the other was the Meuse corridor. For centuries, sheep farming on chalky soils and coastal marshlands had produced the wool needed in the cloth industry; but to meet an increased demand wool was imported from England, for which purpose merchants from various Flemish towns joined together in the Flemish Hanse, a trade association, in London. Flemish cloth produced in fast-growing cities such as Arras, Saint-Omer, Douai, Lille, Tournai, Ypres, Ghent, and Brugge found its buyers throughout Europe. Notary's registers in Genoa and Milan, preserved since about 1200, mention many transactions of different varieties of Flemish cloth and indicate the presence of Flemish and Artesian (from Artois) merchants. The fairs (markets) in the Champagne region linked northern Italy with northwestern Europe; in Flanders a series of similar fairs was set up to facilitate contacts and credit operations among merchants of different nationalities.

Flemish cloth market

To a large extent, the Flemish economy became dependent on the import of English wool, while its exports of finished cloth were directed mainly to the Rhineland, northern Italy, the French west coast, the northern Low Countries, and the Baltic. Flanders' early dominant position was possible owing to a favourable combination of geographic and economic factors. Because Flanders had the first large export industry in northern Europe, its production centres attained the highest levels of quality through specialization and diversification.

For the cloth industry itself, Ghent and Ypres were among the most important towns. In Ghent the production process was run by drapers (*drapiers*), who bought the raw material, had it treated by spinners, weavers, fullers, and dyers, and eventually sold the final product. A drop in wool imports from England could therefore cause immediate social and political upheavals in the city.

The area of the Meuse also carried on considerable trade and industry; merchants from Liège, Huy, Namur, and Dinant are named in 11th-century toll tariffs from London and Koblenz. This trade was supplied mainly by the textile industry of Maastricht, Huy, and Nivelles and by the metal industry of Liège and Dinant. Trade in Brabant, actively supported by the dukes, used the road, or system of tracks (medieval road systems were not advanced), that ran from Cologne through Aix-la-Chapelle, Maastricht, Tongres, Louvain, and Brussels to Ghent and Brugge. Four major trade routes thus developed before 1300 in the Low Countries, favouring the growth or even the emergence of cities; these were between the Rhine and the Zuiderzee, along the Meuse, along the land route from Cologne through Brabant to the sea, and through Flanders. Only the latter displayed a spectacular growth

during this period, taking advantage of its proximity to the sea to build up a massive export industry of labour-intensive, high-quality consumer products.

Since prehistoric times, fishing, particularly for herring, had been important in the coastal regions of Zeeland and Flanders. Since the 5th century BC, archaeological evidence shows that the people produced salt, important in fish preservation, by boiling seawater. In later centuries, a more sophisticated technique was devised by burning peat, from which salt could be refined. This industry was located along the coast and near Biervliet and Dordrecht on the major rivers. It evidently was established to support the fisheries. The fishing industry was given added stimulus by the shift of the herring shoals from the coast of Schonen (Sweden) to the North Sea. The ships, however, were increasingly placed at the disposal of general trade and, in particular, of the wool trade with England. The German merchants also turned their attention to Holland, where Dordrecht became the most important centre. Because of its central position in the rivers area, this town offered the counts the chance to raise tolls on all traffic in the neighbourhood; moreover, all cargoes had to be unloaded and offered for sale—wine, coal, millstones, metal products, fruit, spices, fish, salt, grain, and wood.

Importance of Dordrecht

The towns. The towns gave the Low Countries a special character of their own. Apart from some towns that had existed even in Roman times, such as Maastricht and Nijmegen, most towns arose in the 9th century; in the 11th and 12th centuries, they expanded and developed considerably. The emergence of the towns went hand in hand with the population increase and the extension of cultivable land, which made possible higher production. The population centres that emerged were not primarily agrarian but specialized in industry and trade.

The oldest towns were in the regions of the Schelde and Meuse. Near existing counts' castles or walled monasteries, merchants formed settlements (*portus,* or *vicus*). In some cases, like that of Ghent, for instance, the commercial *portus* was older than the count's castle and grew purely because of its advantageous location. The *portus* gradually merged with the original settlements to form units that both economically and in their constitutions took on their own characters with respect to the surrounding country—characters that were later manifested by defensive ramparts and walls. The cities in the Meuse valley (Dinant, Namur, Huy, Liège, and Maastricht) had already developed in the 10th century, owing to the heritage of this region as the core of the Carolingian empire. Maastricht in particular played a prominent role as one of the main seats of the German imperial church. In the Schelde valley a dense urban network had also developed. A later group (though not much later) was formed by the northern towns of Deventer and Tiel, while Utrecht had long been a town in the sense of a commercial centre. Zutphen, Zwolle, Kampen, Harderwijk, Elburg, and Stavoren are other examples of early towns. Much younger (13th-century) are the towns of Holland—Dordrecht, Leiden, Haarlem, Alkmaar, and Delft.

All the towns formed a new, nonfeudal element in the existing social structure, and from the beginning merchants played an important role. The merchants often formed guilds, organizations that grew out of merchant groups and banded together for mutual protection while traveling during this violent period, when attacks on merchant caravans were common. From a manuscript dated about 1020, it appears that the merchants of Tiel met regularly for a drinking bout, had a common treasury, and could clear themselves of a charge by the simple expedient of swearing an oath of innocence (a privilege they claimed to have been granted by the emperor). Thus, there and elsewhere, the merchants constituted a horizontal community formed by an oath of cooperation and with the maintenance of law and order as its goal.

Formation of guilds

In contrast, therefore, to the vertical bonds in the feudal world and within the manors, horizontal bonds emerged between individuals who were naturally aiming at independence and autonomy. The extent to which autonomy was achieved varied greatly and depended on the power exercised by the territorial prince. Autonomy often developed spontaneously, and its evolution might have been accepted either tacitly or orally by the prince, so that no documentary evidence of it remains. Sometimes, however, certain freedoms were granted in writing, such as that granted by the bishop of Liège to Huy as early as 1066. Such town charters often included the record of a ruling that had been the subject of demands or conflicts; they frequently dealt with a special form of criminal or contract law, the satisfactory regulation of which was of utmost importance to the town involved. Indeed, the first step a town took on the road to autonomy was to receive its own law and judicial system, dissociated from that of the surrounding countryside; a natural consequence of this was that the town then had its own governing authority and judiciary in the form of a board, whose members were called *schepenen* (*échevins*), headed by a *schout* (*écoutète*), or bailiff. As the towns grew, functionaries appeared who had to look after the town's finances and its fortifications. They were often called burgomasters (*burgemeesters*).

The development of a town's autonomy sometimes advanced somewhat spasmodically as a result of violent conflicts with the prince. The citizens then united, forming *conjurationes* (sometimes called communes)—fighting groups bound together by an oath—as happened during a Flemish crisis in 1127–28 in Ghent and Brugge and in Utrecht in 1159. The counts of Flanders from the house of Alsace (Thierry, ruled 1128–68, and Philip, 1168–91) kept careful watch, supporting and aiding the towns in their economic development but otherwise keeping the process in check.

Town opposition to the prince

In their struggle for autonomy, the towns had to fight for financial freedom, such as for the lessening or abolition of the taxes and tolls they had to pay to the prince but also and principally for the right to impose their own taxes, usually in the form of indirect taxation (*e.g.,* excise duties), in order to raise money for necessary public works. Especially important to them was the right to frame their own laws; this legislative right (the *keurrecht*) was in most towns originally restricted to the control of prices and standards in the markets and shops but was gradually extended to cover civil and criminal law. The extent of a man's obligation to serve in the prince's armed forces was often fixed or limited or both (sometimes by the provision for payment in lieu, sometimes by a legal definition of the number of foot soldiers or manned ships to be made available).

Thus, the town in the Low Countries became a *communitas* (sometimes called *corporatio* or *universitas*)—a community that was legally a corporate body, could enter into alliances and ratify them with its own seal, could sometimes even make commercial or military contracts with other towns, and could negotiate directly with the prince. Land within the town's boundaries usually became its property or its burghers' by redemption, and the town's inhabitants were usually exempt from any dependent relationship with outsiders.

A town's population usually had a distinct social structure. The merchants, the oldest and leading group, soon emerged as a separate class (the patriciate); they generally managed to gain control of the offices of *schepen* and burgomaster and thus controlled the town's finances. Sometimes the *homines novi,* a new class of up-and-coming merchants, tried to become part of the patriciate, as in Dordrecht and Utrecht. Beneath the patriciate a lower class formed, called the *gemeen* ("common," in the strict sense of the word), which embraced the artisans and organized into crafts such tradesmen as butchers, bakers, tailors, carpenters, masons, weavers, fullers, shearers, and coppersmiths. These crafts originally developed out of charitable organizations of people in the same profession and had to adhere to regulations laid down by the authorities. Gradually, however, they tried to obtain their independence, exercise influence in politics, cut themselves off from outsiders by means of compulsory membership, and introduce their own regulations regarding prices, working hours, quality of products, apprentices, journeymen, and masters. During the second half of the 13th century, class antagonism rose in the main industrial cities in Flanders. The political conflict between the count of Flanders, the

Class antagonism in Flanders

king of France, and the partriciate opened the way for the craftsmen to score a military victory in 1302. This led to the constitutional recognition of the crafts as autonomous organs with the right of considerable participation in the cities' administration. The achievements of the Flemish artisans inspired their colleagues in Brabant and Liège to revolt and raise similar demands; Flemish military incursions provoked the same reaction in Dordrecht and Utrecht. In Brabant, the concessions were only short-lived, but their effects were more durable in the other places, although never undisputed by the old elites.

In Flanders and in the bishopric of Liège, the towns rapidly attained such power that they constituted a threat to the territorial prince, a situation that often resulted in violent conflicts. In contrast to this, relations between the prince and the towns of Brabant were more harmonious; the political interests of the prince and the economic interests of the towns coincided for the most part during the 13th century, while John I, Duke of Brabant, sought expansion toward the Rhine valley, which offered protection for the growing trade that moved from Cologne overland through Brabant. Duke John II, however, left such formidable debts that Brabant merchants were arrested abroad, which made them claim control over the duke's finances during Duke John III's minority (1312–20). The fact that from 1248 to 1430 only two dynastic successions involved a direct adult male heir gave the cities (which had incurred massive debts) recurrent opportunities to intervene in the government and to impose their conditions on the successors in the form of public testaments called *joyeuse entrée* acts, which were delivered at all successions from 1312 until 1794. The acts, which also applied to Limburg, contained dozens of ad hoc regulations besides a few more general and abstract notions, such as the indivisibility of the territory, a nationality requirement for the officials, approval of the cities before embarking on a war, and the subjects' right of resistance in case of violation of any stipulation of the acts. In Holland the towns did not really develop until as late as the 13th century, when they were helped by the counts.

During this period, when foundations were being laid for the dominant role the towns would later play in the Low Countries, a decisive change also took place in the authority of the territorial prince. Originally he regarded his powers mainly as a means of increasing his income and of extending the area over which he could exercise power. He felt little duty toward his subjects or desire to further the welfare of the community as a whole. At best there were religious as well as material motives in his dealings with the churches and monasteries. There were no direct relations between the prince and all his subjects, for he was primarily lord of his vassals. The political, social, and economic developments discussed above, however, brought a change in this situation. In the first place, the prince's increasing independence meant that he himself began to behave like a king or sovereign lord. His authority was then referred to as *potestas publica* ("public authority"), and it was believed to be granted by God (*a Deo tradita*). The area over which he ruled was described as his *regnum* or *patria*. This implied not only the duty of a lord toward his vassals but also that of a prince (*princeps*) toward his subjects. This duty included as its first priority the maintenance of law and order (*defensio pacis*) by means of laws and their administration. He had further to protect the church (*defensio* or *advocatio ecclesiae*), while his involvement in land reclamation and in the building of dikes and with the development of the towns brought him into direct contact with the nonfeudal elements of the population, with whom his relations were no longer those of a lord toward his vassals but took on a more modern aspect—that of a sovereign toward his trusted subjects. He became, according to the 14th-century lawyer Philip of Leiden, the *procurator rei publicae* ("he who looks after the matters of the people"). Contact with his subjects was through the representatives of the *communitates* of the water boards and *heemraadschappen* and through the towns and nonurban communities, which were legally corporate bodies in dealings not only with outsiders but also with the prince. Sometimes the towns expressly placed themselves under the protection of the prince and declared themselves committed to loyalty to him. Such a town was Dordrecht, which, in a document dated 1266, expressed its loyalty and at the same time described the count of Holland as *dominus terrae* ("lord of the land"). These new notions point to a more modern conception of a state, to a growing awareness of territoriality, and to new possibilities of collaboration between prince and subjects.

Change in the prince's authority

CONSOLIDATION OF TERRITORIAL STATES (1384–1567)

Among the many territorial principalities of the Low Countries, Flanders, Brabant, Hainaut-Holland, and Gelderland (Guelders) in the mid-14th century had a dominating military and diplomatic position. Flanders had already arrested the course of French domination, and its feeling of territoriality was strengthened by this and by many minor wars between the principalities as well as by three major revolts of large segments of the population against the principality's count. This antagonism displayed some early expressions of Flemish nationalism against the count and the nobility, who were backed by France and were French-speaking. In Brabant, national feelings were similarly fostered by fears of foreign invasions in the 1330s. In many respects, Flanders was the real territorial leader during the late Middle Ages. Its population was by far the largest of the principalities, its economic development the strongest, and its institutions the most elaborate. The extraordinary size of the largest cities made it impossible to rule the county without their collaboration. Thus during the 13th century, the *scabini Flandriae*, uniting delegations from the governments of the main cities, intervened in various political matters of the principality, especially concerning economic policy. During the 14th century, the three largest cities, Brugge, Ghent, and Ypres, formed a nearly permanent consultation committee called the three members of Flanders on which was bestowed decisive powers in most political matters, including taxation, legislation, and justice; it wielded as well a strong influence in international relations. During the repeated periods of revolt or absence of the count, the three members automatically extended their functions to the overall exercise of power. This experience explains why in Flanders, in contrast to Brabant and Hainaut, a system of representation by three estates (clergy, nobility, and the burghers) did not develop spontaneously. The power of the cities proved so overwhelming that they did not have to share control with the clergy and the nobility. It was the duke of Burgundy who introduced assemblies of three estates from 1385 onward, as a means to contain the cities, just as he imposed the addition of a fourth member to the consultation committee, which provided rural representation. These moves, however, did not profoundly alter the balance of power, which remained intact until the prince expanded his territory during the 15th century.

The three members of Flanders

In the county of Holland, power relations were balanced between the count, the nobility, and the burghers; the clergy played almost no role, since there were few important abbeys. The cities were much smaller than those of Flanders; a group of the six largest cities (Dondrecht, Leiden, Haarlem, Amsterdam, Gouda, and Delft) wielded the greatest influence and power. From 1349 onward a deep cleavage among the Dutch nobility over the succession to the throne led to the formation of two parties, the Kabeljauwen (Cods) and the Hoeken (Hooks); most cities were also divided along these party lines. Feuds on a local basis took the shape of the party antagonisms, which during certain periods of crisis spread over the whole county and over neighbouring Zeeland and Utrecht as well. During the years after 1392, the periods from 1419 to 1427, 1440 to 1445, and again in the 1470s and '80s, there was a high degree of discord in which the prince and his high officials saw their prerogatives seriously challenged. The relatively small size of the cities, close links between noble and patrician families, a weak administrative organization, and dynastic rivalries for the throne contributed to the ongoing party strife until the end of the 15th century.

Gelderland was later in its development, partly because the powerful Duke William (ruled 1379–1402) of that principality had his own financial resources as a result of his

military activities in the service of the English and, later, French kings; under William's successors, however, the knights and the towns became more powerful and finally gained permanent representation as estates. In Utrecht, too, there was cooperation between the prince (the bishop) and the estates; and the clergy, particularly the collegiate churches of the town of Utrecht, played an important part: the Land Charter of Bishop Arnold in 1375 was inspired by the Joyeuse Entrée of Brabant. In the prince-bishopric of Liège, cooperation between prince and estates had to be won by violent conflicts between the towns and the bishop and, within the towns, between the patriciate and the crafts. It was mainly to these territorial estates that the princes had to turn for financial help, which was often voted to them only on limiting conditions.

Beginning of Burgundian infiltration

The Burgundians. In the second half of the 14th century, the dukes of Burgundy (princes of the French royal house of Valois) began to penetrate these territorial principalities in the Low Countries, whose feelings of territoriality made them regard the dukes of Burgundy with suspicion. The marriage in 1369 of Philip II the Bold of Burgundy to the heiress of the count of Flanders (Margaret) signified the beginning of this Burgundian infiltration, which was repeatedly furthered by marriages, wars, and such tricks of fate as inheritances.

Through his marriage Philip gained possession, after the death of his father-in-law in 1384, of the counties of Flanders, Artois, Rethel, Nevers, and the free county of Burgundy (Franche-Comté), the latter being within the Holy Roman Empire. He thus not only gained a large and powerful part of the Low Countries but was also able to extend his Burgundian property. Though it seemed at first that French power might again become the dominant force in the Low Countries, it soon became clear that the Burgundian dukes, while happy to continue taking part in French politics, were extremely independent and more interested in forging a single powerful empire out of the Low Countries and Burgundy. Duke John the Fearless succeeded to all his father's lands in 1404, while his younger brother Anthony was given Brabant, where the childless Duchess Joanna had named him as her successor, which was accepted by the estates. Anthony's branch of the Burgundians died out as early as 1430, so that Brabant fell to the other branch under Philip III the Good (ruled 1419–67), who also gained possession—through war, family relations, and purchase—of Hainaut-Holland, Namur, and Luxembourg. This Burgundian power structure was not a state but was founded on a personal union among the various principalities, each of which jealously guarded its own freedom and institutions. The Burgundian dukes did, however, attempt to set up central organizations to bridge the differences among the principalities and to keep the various regions under stricter control by appointing governors (stadtholders).

Regional courts and exchequers increasingly enforced the central government's control in administrative, political, and judicial fields. Some principalities, such as Brabant and Hainaut, claimed that their privileges disallowed any foreign interference in their territories; in Flanders and Holland, however, the dukes introduced officials from their Burgundian homeland. In the long term, this policy of bringing in foreign administrators raised serious resistance against the central government, especially because it tended to make French the only administrative language, while the majority of the population in the Low Countries was Dutch-speaking. To further central control, Duke Philip extended his court in order to incorporate regional nobilities, and in 1430 he created The Order of the Golden Fleece, to which he brought the highest nobles from his principalities. In addition, the judicial tasks of his Great Council were entrusted from 1435 to a special group of councillors who steadily increased the weight of the central jurisdiction over local and regional customs and privileges. The ambitions of the Burgundian dukes finally ran aground on the forced and overly hasty centralization and expansion of power carried out by Charles the Bold (ruled 1467–77), who was able, nevertheless, to annex Gelderland. Charles imposed increasingly high financial demands, which were put before the States-General—an assembly that united the delegates from the various states at meetings called by the duke and held at regular intervals; he tried to constitute a kingdom in the Low Countries with himself as regent, an endeavour that failed in 1473. Charles did manage, however, to elevate the central law court to the rank of the royal Parliament of Paris—an obvious defiance of the king of France's prerogatives. After his defeat and death in battle to French-supported forces, a movement for regional and local rights arose and won a series of privileges from his daughter Mary (ruled 1477–82) that halted the previous centralization movement. Moreover, the duchy of Burgundy itself was taken over by the French crown, so that the Burgundian union, as it was reformed by the States-General from 1477, became a union without Burgundy. The pressure of French incursions brought the members of the States-General into closer collaboration. While ensuring their loyalty to the Burgundian dynasty and organizing a defense against France, they obtained the first written constitution for the whole of the principalities in the Low Countries. It recognized extensive rights to the States-General, such as control over the waging of war, currency, taxation, and tolls; furthermore, it prescribed the use of the legal language to be used in the courts. This text remained for centuries a point of reference for the rights of the subjects, granting to individuals the right of resistance in cases where tenets of the document were seen to be violated.

Resistance to foreign administration

The Habsburgs. After Mary's position had become more firmly established by her marriage to Maximilian of Habsburg (the son and future successor to the Holy Roman emperor), the States-General, because of its internal particularism, proved unable to provide a lasting administration. Gradually, a restoration took place, at first under the regency of Maximilian after Mary's death in 1482. Maximilian, however, lacked the political skills to deal with the various social forces in the Low Countries. His political strategy was aimed simply at a thorough recovery of the territorial and institutional losses since 1477, but his policy of high taxation, debasement, warfare, and violation of privileges, during a period of deep general economic crisis, provoked opposition and revolt, first in Flanders but also later in Holland, Brabant, and Utrecht. His answer was, as it had been in the past, the brutal use of military force, which plunged these regions into 10 years of devastating internal war. When his and Mary's son Philip I the Handsome (ruled 1493–1506) took over the government, he smoothly resumed the centralization process by refounding the central law court (then known as the Great Council of Malines) and set up within the duke's council permanent commissions to discuss important political and financial questions.

Centralization

The fate of the Low Countries was already closely bound up with that of Austria by virtue of the Habsburg marriage; in 1504, this situation was intensified when Philip and his wife, Joan, inherited the Spanish crown. From then on, the Low Countries were merely a part of a greater whole, and their fate was principally decided by the struggle of this Spanish-Austrian empire for European hegemony. They repeatedly had to make sacrifices for the many wars waged against France, particularly under Emperor Charles V, who in 1519 had added the German imperial crown to his many possessions. The emperor, who was almost always out of the country, placed the Low Countries under the rule of governors-general—first his aunt Margaret and later his sister Mary, who retained control and worked toward further centralization even when he was in the country.

The States-General could do little more than offer passive resistance, principally through financial manipulations. As a meeting place for the regional deputies, the States-General did have a certain influence and, by its opposition, strengthened a sort of negative feeling of unity. That the emperor himself also saw the Low Countries as a unit can be seen in his incorporation of the territories in the north and east, including Groningen and Friesland (1522–28). A remarkable step was the imposition of temporal power over the bishop of Utrecht (1528); full power was also acquired over the duchy of Gelderland in 1543. Consequently, Charles took measures to separate his so-called

Seventeen Provinces of the Low Countries from the empire as "Burgundian Kreis" (1548) and in the Pragmatic Sanction (1549), which stated that succession would be regulated in identical fashion in all the regions of the Low Countries that he had included in his empire. The Low Countries were thus prevented from being split up.

The collateral councils

In the meantime, the process of centralization had reached a decisive phase with the foundation of the collateral councils (1531), which were separate from the Great Council. They were the Council of Finance, which had in effect already existed for some time; the Council of State, in which members of the high nobility could advise the governess; and the Secret Council, in which permanent officials dealt with everyday administration and composed ordinances without having to wait for advice. All the government organs, except for the central law court in Malines, were in Brussels, which from that time became the capital of the Low Countries. The States-General and territorial states were still a stumbling block in the acquisition of financial resources, so that Charles V was never able to provide himself with a standing army.

Under Charles's son Philip II, who in 1555–56 succeeded as king of Spain and prince of the Netherlands, the policy of centralization was continued. It culminated in the introduction of a new ecclesiastical hierarchy. The Low Countries, which formerly had been, ecclesiastically speaking, merely an extension of the archbishoprics of Cologne and Reims, became by virtue of a papal bull of 1559 a directly governed region of the church under three archbishops and 15 bishops. There was fierce resistance to this by the high nobles, who saw the high positions in the church slip from their grasp; by the abbots, who feared the incorporation of their monasteries for the maintenance of new bishoprics; and by a number of territories, which were afraid of greater inquisitorial activities under new bishops. The high nobles, who were often excluded from the activities of the Secret Council, led the resistance under the capable Prince William of Orange (1533–84) and the popular Count van Egmond. Resistance increased when the Burgundian Antoine Perrenot de Granvelle (bishop of Arras and virtually prime minister under the Netherlands' governor Margaret of Parma) was appointed archbishop of Malines and then cardinal of Malines and primate of the Netherlands. The government gave way, and Granvelle was forced to leave the country; yet the high nobles themselves hardly knew how to run affairs. The initiative was thus transferred to the low nobility, who in 1565 united by bond of oath in the so-called Compromise and in 1566 presented to the governor a petition requesting the relaxation of edicts and ordinances against the Calvinists and other Protestants. At the same time, they adopted the name Geuzen (*gueux*, "beggars"), originally a term of abuse.

As the resistance grew stronger, the Protestants became more confident, and fanatics started a violent campaign against churches—the "breaking of the images" (August 1566)—against which the governor took powerful measures but only in the first few months of 1567 managed to restore peace. King Philip II, however, whose information concerning these events was somewhat out of date because of slow communications and who was uneasy because of the "breaking of the images," decided to take stern measures. He sent his trusted general, Fernando Álvarez de Toledo, Duke de Alba, to the Netherlands. Alba's strict regime precipitated a revolt that eventually led to the partition of the Netherlands.

Economic structure. The economic structure of the Low Countries underwent far-reaching changes in the 14th–16th centuries. The growth in population, which in western Europe had begun in the 10th century, ceased with relative suddenness after 1300. The European famine of 1315–17 had dramatic effects in the cities; in Ypres 10 percent of the population that died and had to be picked up off the streets were buried by public means. Social tensions, insurrections, and internal wars also cost numerous lives during the 14th century, especially in the rebellious cities of Flanders and Liège. Many Flemish weavers and fullers fled to England, helping there to build up an English cloth industry, which came to compete with that of the Low Countries. The effects of recurrent plagues from 1349 onward, raging once in each decade until the early 15th century, must have been devastating as well. The global population was seriously diminished, but in the cities, where overpopulation had been developing since the late 13th century, the losses were replaced by rural surpluses, leaving somewhat easier living conditions in the cities for the survivors. Generally, the standard of living in the Low Countries improved in the second half of the 14th century.

The famine of 1315–17

In the 14th and 15th centuries, Brugge became the main international market of northwestern Europe. Colonies of foreign merchants installed their offices: Italians, Catalans and other Iberians, French and English, and above all the German Hanse, for whom Brugge was the most important *Kontor* (office). Southern and northern Europe met at Brugge, and their exchange networks were linked there. An intensive movement of bills of exchange converged there and helped to balance the region's export deficit with the Mediterranean states. The densely populated Low Countries evidently formed an important market for imported goods such as wine, Mediterranean fruits, and Eastern spices and silk; grain was also an important import. The relatively affluent population could afford expensive goods, but it also produced labour-intensive, high-quality objects, including fashionable clothing and various works of art and applied art, such as paintings, jewelry, woodcuts, and pottery. The trade network helped to spread these works throughout Europe.

On the other hand, the loss of some one-third of the European population, mostly to plague, had severely reduced the export markets, causing competition to intensify. The Brabantine cities had developed their own textile industry, competing internationally. Since the crafts held a firm grasp on wages and regulations from 1302 onward in Flanders, they raised the production costs higher than those in Brabant and much higher than those in England and Holland. The Flemish had to become reoriented toward ever more sophisticated methods and higher-quality products in that state's large, old cities. Improvements in linen and tapestry weaving exemplified new innovations. Entrepreneurs now shifted their production toward villages, unrestricted by craft regulations, where wages were lower and quality controls weaker. These rural manufacturers used cheaper wools from local areas and (from the 15th century) Spain, and they produced lighter, less refined cloth, which found a wide middle-class market.

Shift to rural cloth production

Holland became the site of marked economic change during the second half of the 14th century. The drainage of the peat bogs had made them gradually less suitable for the cultivation of bread grains, and cattle raising had become the major means of subsistence. That occupation's minimal labour requirements drove a large proportion of the rural population into the cities, where some found jobs in crafts and seafaring. Dairy products continued to be exported to the larger cities in Flanders and Brabant, but grain now had to be imported, largely from Artois and, increasingly from the 15th century, the Baltic region. The Dutch also learned the technique of preserving herring common to that region; the shift of the herring shoals to the North Sea had helped the Dutch take the lead in this trade. In addition, they developed a shipbuilding industry for which they again needed the import of wood, iron, tar, and pitch from the Flemish Hanse area. They succeeded in building a competitive fleet that could offer transportation at a lower cost than that of the Hanse. The Dutch then were able to penetrate the Baltic Sea region, not only to buy sorely needed raw materials but increasingly also to sell and transport. None of the Dutch products were exclusive to them, the goods being often of even lesser quality than those offered by their competitors; their price, however, was always more advantageous, thanks to their excellent cargo facilities. Apart from the herring industry, the Dutch competed in cloth and, even more effectively, in beer: their quality of barley, clear water, and hops enabled them to brew a product of distinctive character for which demand grew. The cities of Delft, Gouda, and Haarlem became major beer-exporting centres, shipping to the southern Netherlands and to the Baltic regions as

well. The Dutch also exported some bulk salt. The production of salt derived from peat having proved to be of insufficient quantity and quality for salting fish, the Dutch imported raw maritime salt from the French Atlantic coasts and refined it in their peat-fueled ovens. This was suitable for the fish industry and could also be exported to the Baltic area, the traditional production from Lüneburg, Ger., having slowed down.

While Holland thus laid the basis for its remarkable 17th-century prosperity, the southern Netherlands showed a shift of commercial leadership from Brugge to Antwerp.

Commercial ascendancy of Antwerp

During the 15th century, Antwerp developed strongly thanks to its free entrepreneurial climate and its two annual fairs, which were combined with two more in the nearby Schelde harbour city of Bergen-op-Zoom. At that time, the fairs still functioned as a corollary to the Brugge market, but they nevertheless attracted merchants from central and southern Germany. While Brugge lived through a deep political crisis in the 1480s, Antwerp attracted the new colonial trade, especially that of the Portuguese, and the important Augsburg, Frankfurt, and Nürnberg merchant and banking houses. They imported new textiles in return for copper, silver, and other metal products. The Italians soon left Brugge for Antwerp, belatedly followed by the increasingly regressing German Hanse. The fast expansion of the Antwerp market was supported by excellent relations with the monarchy which, in turn, could finance its hegemonistic policy through loans from Antwerp merchants. A special innovation was financial techniques developed at the Antwerp *beurs* (stock exchange), created in 1531. While Brugge remained a clearinghouse for international commercial debts, where exchange rates for bills were determined, the Antwerp exchange specialized in transferable, usually discounted, public debts.

Generally speaking, a commercial capitalism was developing that stimulated the entire economy of the Netherlands. Competition in the cloth industry was growing especially strong between urban and expanding rural manufacturers. The towns battled these rural clothmakers in vain, though in 1531 Holland issued an edict to restrict them throughout the county but with little success. Moreover, Holland itself had begun to play an increasingly important economic role; new industries were developing, but fishing, shipping, and trade remained its main means of support apart from arable farming and cattle breeding. Dordrecht, one of the major commercial centres of the Low Countries, was rivaled by Rotterdam and Gorinchem and, by the 16th century, was outstripped by Amsterdam, which cornered an increasing proportion of Baltic trade, as evidenced from the lists of the toll in the Sound (between Sweden and Denmark).

The regions along the Meuse and IJssel also maintained their commercial activity. In the bishopric of Liège there was even a metal industry with blast furnaces, paid for by capital raised by traders. Coal mining in the area between the Meuse and the Sambre was also organized according to modern capitalist methods.

The cultivation of commercially exploitable crops also developed in country areas—hemp for rope making, hops and barley for brewing, flax for the manufacture of linen.

Decline of grain farming

Yet all this was at the expense of wheat farming. Grain had to be imported in increasingly large quantities, and, whenever grain imports fell off, the people, particularly the lower classes, went hungry. The economic apparatus had become more versatile and brought greater prosperity, but at the same time, precisely because of this specialization, it had become more vulnerable. The distribution of prosperity was variable; the great mass of the people in the towns suffered the consequences and bore the main burden of the rise in prices occasioned by inflation.

Population growth. It is impossible to estimate the population of the Low Countries before about 1470, and even for that date complete data are not available. Figures are often not available for all areas at a given date in the Middle Ages. An acceptable figure for the Low Countries in the late 15th century might be about 2,400,000 inhabitants. Flanders was by far the most populated and most densely inhabited principality, with about 750,000 people and a density of 30 persons per square mile (77 per square kilometre). It was followed by Brabant with 413,000 people and about 15 persons per square mile (40 per square kilometre) and Holland with 268,000 people and 25 per square mile (66 per square kilometre), although the latter data are from the year 1514. The other principalities counted far fewer inhabitants—for example, 209,000 in Hainaut, 180,000 in Artois, and 140,000 in Gelderland, Liège, and Luxembourg.

After 1470 the population must have declined generally, owing to wars, bad harvests, and epidemics. From 1490 a new period of growth especially favoured Brabant and Holland. About 1570 the duchy of Brabant counted about 500,000 inhabitants, which was still less than the more densely populated Flanders. One-quarter of the Flemish peasants farmed plots of only 5 to 12 acres (2 to 5 hectares), and nearly half had even less than 5 acres. The level of urbanization was growing extremely fast in the Low Countries, especially in the largest principalities. In 1470, 36 percent of Flanders' population and 31 percent of Brabant's were city dwellers, while in Holland the proportion reached 45 percent in 1514. It should be noted, however, that the cities of Holland were still relatively small, the largest being Leiden with 14,000. In the southern Low Countries in the mid-14th century, Ghent and Brugge attained populations of 64,000 and 46,000, respectively, while Brussels counted 33,000 in 1482 and Malines (Mechelen) grew to 25,000 around 1540. Antwerp showed spectacular growth, from 15,000 in 1437 to nearly 40,000 around 1500, and more than 100,000 in 1560, its peak for this period.

Culture. The Low Countries played an important part in the artistic, scientific, and religious life of Europe. In the late Middle Ages, when prosperity was increasing and the princely houses, particularly that of the Burgundians, as well as the middle classes in the towns, were encouraging progress, the Low Countries began to make independent contributions to cultural life.

Artistic, scientific, and religious contributions

The most original of these were in the field of visual and applied arts. From the late 14th century the Low Countries produced sculptors like Claus Sluter, whose most famous works are the funerary monuments for the duke of Burgundy, Philip the Bold, and his wife at Dijon, Fr., and painters like Melchior Broederlam who also served the duke. In the 15th century, however, the cities in the southern Low Countries became the core of cultural activity, because the duke's court resided mostly in that region and because the local bourgeoisie, clergy, and noblemen profited from the Burgundian prosperity and could invest in works of art, which allowed them to share somewhat in the splendour of the court. The main centres were Ghent (Jan and Hubert van Eyck and Hugo van der Goes), Louvain (Dirck Bouts), Brussels (Rogier van der Weyden), and Brugge (Hans Memling, and Gerard David). Each of these masters stands for a school of followers. Miniature painting similarly was a most flourishing activity, reaching its first height in the northern Low Countries (Utrecht) about 1400, but rising also in the south through the 15th century. Tapestry weavers in Arras attained a unique quality, which was imitated in Tournai, Brussels, Oudenaarde, Brugge, Ghent, and elsewhere. Brabant was famous for its woodcut triptychs made in Louvain and Antwerp (then in Brabant). Brugge for its lace, jewelry, and fashionable clothing. All these extraordinary works were exported through Europe, where they won the appreciation of princes, aristocrats, and rich burghers.

In the southern Low Countries, mysticism reached its zenith in the 13th and 14th centuries in the poems of Sister Hadewych and the prose of the prior Joannes Ruusbroec (Jan van Ruysbroeck). Ruusbroec's writings were founded on a considerable knowledge of theology; it is not certain whether his work had a direct influence on the founding of the religious movement along the IJssel—the modern devotion (*devotio moderna*)—or whether mysticism merely created the intellectual climate in which the new school of thought could develop. The modern devotion was inspired by Geert Grote (Gerard Groote, 1340–84) of Deventer, who preached, as did many others, the ascetic and pious life and resistance to the secularization of the church. His

message was well received, and many lay people found in themselves a desire to live in communities devoted to the service of God; these were the Brethren and Sisters of the Common Life, who later organized themselves into the Windesheim monasteries and convents, which followed Augustinian rules. Their communities were extremely important for both education and religion; they were industrious copyists and brought a simple piety to the lower classes. Their work, like that of the mendicant orders, was a typical product of life in the towns. The movement reached its peak in Thomas à Kempis, from Zwolle, whose *Imitatio Christi* (*The Imitation of Christ*) became quite widely read, not least in Dutch versions.

Development of Dutch humanism

Within the modern devotion, where great importance was attached to good teaching, Dutch humanism was able to develop freely. Of importance was the foundation in 1425 of the University of Louvain; it received in 1517 the Collegium Trilingue where Latin, Greek, and Hebrew were taught. The greatest Dutch humanist was Erasmus (1469–1536), whose fame spread throughout the world and who had been taught in the schools of the Brethren of the Common Life. He drew his inspiration, as did many other humanists, from antiquity and was famed for his pure Latin. He was in touch with the greatest minds of his time, visited England (Cambridge) and Italy, and worked for some years in Basel and in Freiburg. Erasmus' greatest achievement was to turn the science of theology, which had degenerated into meaningless Neoscholastic disputes, back to the study of sources by philological criticism and by publishing a new edition of the Greek New Testament. Although he vociferously criticized the church and even the princes, he avoided out of conviction a break with the church and pleaded for religious tolerance.

The humanists were principally intellectuals, however, expressing themselves in literary and scientific treatises and having little impact on the broad masses of the people. Many of them, like Erasmus, desired no break with the church and did not accept that break when it became a fact by the appearance of Martin Luther. Instead, they wanted reformation within the church. It was otherwise for the reforming movements that brought turmoil to the Low Countries in the first half of the 16th century. Even Lutheranism had few followers, despite its early appearance (Luther's dogmas were condemned by the University of Louvain as early as 1520). There was a Lutheran community in Antwerp; but otherwise, support was limited to individual priests and intellectuals. It was precisely over the question of the Eucharist that the Sacramentarians differed with Luther; they denied the consubstantiation of Christ in the Eucharist, although their stance enjoyed little support from the people.

The Anabaptists

An uproar was caused by the Anabaptists (so called because they rejected the baptism of infants and therefore had themselves rebaptized as adults), who refused to swear the oath of allegiance to the prince or to serve in the armed forces or in government per se and who believed in a *lumen internum* ("inner light"). This baptist movement won great popularity in the Low Countries after 1530; from the very beginning there were two branches—the social revolutionaries and the "quiet baptists." The first of these was characterized by a lively enthusiasm and a willingness, once the external trappings of the church had been rejected, to organize itself into communities, which soon formed close ties with each other. Prophesies by the social-revolutionary branch of the imminent coming of Christ and of a New Jerusalem fascinated the masses, while their fanaticism and readiness to sacrifice themselves made a deep impression on a population suffering poverty and misery. In 1534 a section of the Anabaptists moved to Münster in Westphalia, where they supposed that the New Jerusalem would be built; and in 1535 an abortive attempt was made to take over the town hall in Amsterdam. After a long siege, the bishop of Münster succeeded in reconquering his town, and the Anabaptists suffered terrible vengeance. Only the "quiet baptists" were able to continue, under the leadership of the Frisian pastor Menno Simons (these Mennonites are even today strongly represented in the provinces of Groningen, Friesland, and Noord-Holland).

The future of the movement for reformation in the Netherlands was assured, however, not by the biblical humanists nor by the Anabaptists but by a movement less intellectual than the first and more realistic than the second—Calvinism.

The theology of John Calvin (1509–64) was radical, strict, logical, and consistent. Its central theme was the absolute might and greatness of God, which made man a sinful creature of no significance who hoped merely to win God's grace by honouring him in daily hard work. Calvinism found its way to the Netherlands by way of France, though there may have been some direct influence from Geneva, Calvin's town. Calvinist writings were known in Antwerp as early as 1545, while the first translation into Dutch of his *Christianae religionis institutio* is dated 1560, which was also the year in which support for him spread in the Netherlands, largely because the Calvinists preached their creed in public and held open-air services.

Calvinist teaching appealed not only to the lower classes but also to the intellectual and middle classes because of its glorification of work, its discipline, its organization into communities, and its communal singing of the psalms. The government saw the movement as a threat to its plans of unity and centralization, which were supported by the Roman Catholic church, and it took stern measures against Calvinism. Calvinists forcibly removed their coreligionists from prisons and occasionally even attacked monasteries. This group's rejection of icons, paintings, statues, and valuables in churches sometimes led them to remove them and hand them over to the town magistrates. But this idealism became corrupted, and the leaders were unable to retain control of the movement.

It should be noted that Calvinism and other forms of protestantism had spread rapidly among the urban middle classes after 1550 in defiance of rule by Roman Catholic Spain. From 1551 to 1565 the number of persons persecuted in the county of Flanders for heresy rose from 187 to 1322. In Antwerp, the largest city of the Low Countries, with some 100,000 inhabitants around 1565, one-third of the population openly declared for Calvinist, Lutheran, or other Protestant denominations; another third declared itself to be Roman Catholic, while the last third was undeclared. Similar proportions are assumed to have existed in the other main cities, while the rural textile area in southwest Flanders counted large numbers of Anabaptists and Calvinists. It was among these Calvinists that an iconoclast movement to desecrate churches and destroy church images began in August 1566, spreading within a week to more than 150 villages and towns in the southern principalities.

Persecution for heresy

The movement was weakened, however, when it lost the support of the nobility, and especially the lower nobility, which had been sympathetic to Calvinism. The government now besieged and captured the Calvinist centre, Valenciennes, by defeating a Calvinist army at Oosterweel, near Antwerp. The result was a great exodus of Calvinists. Nevertheless, Calvin's ideas had penetrated deeply, and his supporters, who had emigrated to England, East Friesland, and the Pfalz of Germany, were able to maintain their unity and support their coreligionists in the Low Countries. The Calvinists were to become the driving force behind the revolt against Spanish rule.

THE REVOLT AND THE FORMATION OF THE REPUBLIC (1567–79)

The forcible measures taken by the central government against the "breaking of the images" were followed by a brief period of peace. The Duke de Alba (who became governor after the departure of Margaret of Parma on the last day of 1567), introduced stern measures at the express command of the king. These provoked a resistance to the government (often referred to as the "revolt") that triggered the Eighty Years' War (1568–1648). The iconoclast movement itself, which had raged across the country like a storm, had already shown a deep-rooted resistance that had many causes and was brought to a head by Alba's measures.

Causes of the revolt. It is impossible to label any of the causes of the revolt as the decisive factor. An important

one, however, was a religious motive. Criticism of the structure of the church and the riches and worldly way of life of its prelates and the accompanying desire for reform had always been strong in the Low Countries; and Protestantism, through the teaching of Luther, the Sacramentarians, the Anabaptists, and, above all, the Calvinists, had gained a firm foothold. The measures taken against the resistance—harsh edicts, prison sentences, torture, and death sentences, carried out with great cruelty—fanned the flames all the more and among all classes. Social and economic causes, however, also lay behind the resistance, especially among the lower classes—the wars with France, the epidemics, poor harvests, hard winters, floods, and a frightening inflation and consequent rise in prices all combined to cause despair and misery among the masses and made them susceptible to radical ideas. At the same time, in the upper classes of the nobility and the urban patriciate, there was a sharply felt reaction against the absolutist policy of the king, who lived far away in Spain and yet whose wish was law in the Low Countries. Towns felt their privileges being threatened, and the nobles found their independent status being undermined by the ever-increasing activities of the secret council. The mercenaries, who were often stationed in a town as a garrison and acted as occupying forces, also aroused hostility. The fact that the resistance did not present a united front may be ascribed to the particularism among the territories—Holland, with its commercial interests, could hardly be expected to be enthusiastic on behalf of typically agrarian feudal provinces such as Hainaut or Artois.

Harsh reaction to the resistance

The main cleavage in the opposition groups, however, was social as well as religious: the high nobility and richest merchants mostly remained Roman Catholic, as did the peasants and the urban poor living on the church's alms. The lower nobility, the urban middle classes, and the rural textile workers massively opted for one or the other form of religious, political, and social protest against the prevailing order. This fundamentally explains the earlier accommodation of the rural provinces of Artois, Hainaut, Namur, and Luxembourg under Spanish rule, while opposition was fierce in the urbanized provinces of Flanders, Brabant, Holland, and Zeeland. The rural northeast also remained predominantly Roman Catholic until well into the 17th century.

It is clear, however, that the terror organized by Alba burst like a bombshell in this political, social, economic, and religious climate. William, the prince of Orange, with sharp political insight, had decided not to wait for Alba's arrival; he had managed to escape in time to his birthplace in Nassau-Dillenburg, leaving behind all his possessions, which were promptly confiscated. His son, Philip William, was taken prisoner to Spain. Alba sent his troops to the principal towns and set up the Council of Troubles (or Council of Blood), which imposed severe penalties, often including the death sentence or confiscation of property, sparing nothing and nobody, not even the most powerful—the counts of Egmond and Hoorne were publicly beheaded in Brussels in June 1568.

Alba also rushed through installation of the new ecclesiastical hierarchy, which had not been completed. Furthermore, he attempted to make the central government independent of the provincial states by means of new taxes on property, on the sale of land or building, and on the sale of goods. This met with violent resistance because the taxes were to be general and permanent, so that the separate states would no longer have the means to make conditions for the furnishing of taxes (although they themselves already levied taxes on the sale of goods) and, more important, because a permanent tax system would make the king independent of his subjects. The taxes were the final link in the policy of absolutism and centralization, which would lead to a unified state controlled by a prince with unlimited power.

New taxes

The severity with which Alba ruled was not able to prevent the immediate appearance of resistance. The Geuzen (guerrilla forces) conducted pillaging raids in the country and piracy at sea, for which they had "authority" in the form of letters of marque issued by William of Orange in his capacity as sovereign of the principality of Orange. Attacks took place as early as 1568. A small force led by Louis of Nassau, William's brother, enjoyed a modest victory over the Spaniards at Heiligerlee (in the province of Groningen), considered the beginning of the Eighty Years' War; but shortly afterward Louis was defeated near Jengum in East Friesland. A greater setback, however, was the complete failure, due to lack of funds, of a campaign led by William himself in Brabant. During the sombre years of 1568–72 the "Wilhelmus" was written—a song of faith, hope, and trust that was to become the Dutch national anthem. Other songs written by the Geuzen lifted the spirits of the people during this period and in later years.

During these years, William negotiated for help from Germany, England, and, above all, the French Huguenots. A large-scale attack was planned for the summer of 1572. Before William could carry it out, the Geuzen seized the port of Brielle (April 1, 1572), west of Rotterdam. This was a move of considerable strategic importance because the port controlled the mouth of both the Meuse and the Waal, and the prince immediately supported the movement. The Geuzen then took Flushing, Veere, and Enkhuizen, so that William had useful bases in Holland and Zeeland. The help that the Geuzen received from the Calvinists in these towns was striking—the Calvinists, a radical minority, were again and again able to force the more conservative town magistrates to either cooperate or resign. Oudewater, Gouda, Dordrecht, Leiden, Hoorn, and Haarlem followed, only Amsterdam keeping the Geuzen out. The purposeful activities of the Calvinists also led to their gaining churches, often the principal church of a town, for their services; they closed monasteries, and Roman Catholic services were soon forbidden.

The revolt was at first successful only in Holland because of its unique position. As a commercially oriented province, it had been more inclined to look after its own interests than to cooperate with other provinces. Trade had been seriously threatened by the Geuzen but was now free again. Moreover, the province lay in a strategically favourable position—difficult to reach from the central government in Brussels and almost inaccessible to the Spanish armies by virtue of its many rivers, lakes, drains, and bogs.

To give the revolt a legal basis, the fiction was invented that it had been a revolt not against the king but against his evil advisers, particularly the governor. By their own authority, in July 1572 the states of Holland gathered in Dordrecht, where William of Orange was proclaimed stadtholder of Holland and Zeeland. The prince himself went to Holland and, realizing that the Calvinists had been the driving force behind the revolt, became a member of the Calvinist church. But he repeatedly expressly avowed his ideal of the United Netherlands, in which there would be room for Catholics and Calvinists alike.

Legal basis of the revolt

Alba, disappointed by his failure to push through the tax reforms and about to return to Spain, learned of the fall of Brielle and decided to stay and start a counteroffensive. The south was immediately brought under control with the occupation and plundering of Malines; then Zutphen and Naarden in the north were taken and likewise plundered. This provoked stronger resistance, and Haarlem was retaken only after a long siege, which not only demoralized and decimated Alba's troops but also strengthened the other towns in their decision to offer resistance (1573). Thus, the Spaniards were unable to take Alkmaar, their fleet suffered a heavy defeat in the Zuiderzee, and a long siege of Leiden was relieved by flooding the surrounding country (1574). (As a reward, the town later was given a university, where Calvinistic theology was to be a principal subject for study.) Spanish troops never again forced their way into Holland—a heavy blow for the most powerful monarchy in the world.

Unification after Alba. Alba left on Dec. 18, 1573, and his successor, Don Luis de Requesens, was unable to prevent further secessions in the north. Even the south, which had been loyal to Spain until then but where active Calvinist movements existed (especially in Ghent), became amenable to William's ambition for a united resistance to the Spanish regime. Problems involved were consider-

able, with one of the most contentious points being the question of religion—the more radical north demanded the total abolition of Roman Catholicism in Holland and Zeeland and the acceptance of Calvinism by the southern provinces. William, however, was diplomatic enough not to make this demand. It was finally agreed that the States-General would deal with the question later, and until such time the Calvinists would be masters only of Holland and Zeeland. A new governor (Requesens died in March 1576) was to be accepted only if he approved the pacification and sent away the foreign troops, who, because they had received no pay, were beginning to mutiny and plunder and were becoming an increasing nuisance. Another condition of his acceptance was that he govern with native officials and in close consultation with the states. On this basis, delegates from all the provinces came to an agreement, and on Nov. 8, 1576, they signed the Pacification of Ghent. Their sense of unity was further strengthened by the news that on November 4 Antwerp had been invaded by mutinying Spanish troops, who had slaughtered 7,000 citizens in a massacre that came to be known as the "Spanish Fury."

The Pacification of Ghent

William's idealism, his desire for unity, and his tolerant ideas had apparently triumphed. Unity of thought, however, did not last long; and within three years signs of a split appeared between the urbanized and rural provinces (which later became a permanent split). It was immediately obvious that within the United Netherlands there were opposing powers of radicalism and reaction. For various reasons, they could not maintain equilibrium; the reactionaries tried to force their ideas on the country with the help of the new governor, Don Juan de Austria, a half-brother of the king, and the Calvinists continued their radical program to make theirs the official and only religion. In Ghent, Malines, and Brussels, radical Calvinists took over the city governments, while in Antwerp, the magistrate displayed a conspicuous tolerance toward the Protestants.

Many intractable factors underlay these conflicts—deep-running religious differences between regions; a deeply rooted particularism that hindered cooperation; and structural and economic differences between Holland and Zeeland on the one hand (commerce and industry) and Hainaut and Artois on the other (agrarian economy and feudal possession of land). It is impossible to point to any one factor that was of paramount importance. William did his utmost to save the pacification, and he found support for his ideas of tolerance among the rich burghers; yet he was unable to bridge the differences between rich and poor, Roman Catholics and Calvinists. Moreover, Don Juan died in 1578 and was succeeded by Alessandro Farnese (duke of Parma and son of the earlier governess Margaret), who was conspicuous for his military and diplomatic gifts, which made him a worthy opponent for William and who may be credited with removing Calvinist control in the south and with the return of loyalty to the king in the southern provinces.

Notable, too, was the appearance in the north and south of movements toward "closer unions," which within the whole of the United Netherlands were to bring about greater community of interests between certain provinces.

The Union of Arras

On Jan. 6, 1579, the Union of Arras (Artois) was formed in the south among Artois, Hainaut, and the town of Douay, based on the Pacification of Ghent but retaining the Roman Catholic religion, loyalty to the king, and the privileges of the estates. As a reaction to the accommodation of Artois and Hainaut, the Union of Utrecht was declared, at first including northern principalities but later drawing signees from the south. This unity was eventually broken by military force. (C.v.d.K./W.B.)

History of The Netherlands (1579 to the present)

The early history of the Low Countries, including the area now occupied by the Kingdom of The Netherlands, has been treated in the preceding section. Treated in the following section is the history of the modern state of The Netherlands, beginning with its establishment in 1579.

THE UNION OF UTRECHT

On Jan. 23, 1579, the agreement at Utrecht was concluded, forming a "closer union" within the larger union of the Low Countries led by the States-General sitting in Brussels. Included in the Union were the provinces and cities committed to carrying on resistance to Spanish rule: Holland, Zeeland, Utrecht, Gelderland (Guelders), and Zutphen (a part of Overijssel) as the first signatories, followed in the next year by the whole of Overijssel, most of Friesland, and Groningen, all in the north; and in the south by the cities of Antwerp and Breda in Brabant, and Ghent, Brugge, and Ypres in Flanders. Designed to establish a league for conduct of the war of independence and ultimately to strengthen the central government in Brussels, the Union of Utrecht became in fact the foundation of a separate state and a distinct nation in the northern Netherlands. The new state was named the United Provinces of the Netherlands, or, more briefly, the "Dutch Republic," and was known in the international community as the "States-General." The people of the northern Netherlands began to be distinguished from the inhabitants of the south (to whom the name of Flemings continued to cling) by the appellation Hollanders (French: Hollandais; Italian: Olandese; German: Holländer; and so forth), after their principal province. The English, however, came to apply exclusively to the Hollanders the term Dutch, which previously they had applied to all German speakers (from German Deutsch, Dutch Duits). The name Netherlanders, which remained in use in the Low Countries for the inhabitants of the United Provinces specifically and for all those, north or south, who spoke Dutch (Nederlands), passed out of currency in most foreign countries or came to be restricted to the northerners. The transformation had a price: the erosion of the bond of historical identity between northerners and southerners, Dutchmen and Belgians as they would be called in the 19th and 20th centuries.

The "Dutch Republic"

The treaty that formed the basis of the new northern union established a military league to resist the Spaniards but on a "perpetual" basis, and it provided for closer political arrangements among the provinces than those of "allies" in the ordinary sense. The provinces united "for all time as if they were a single province"; each remained sovereign in its internal affairs, but all acted as a body in foreign policy. Decisions on war and peace and on taxation could be made only unanimously. The union did not throw off the formal sovereignty of the king of Spain, but it confirmed the effective powers of the provincial stadtholders (formally the "lieutenants," or governors, of the king) as their political leaders (there was no "stadtholder of the United Provinces," as foreigners often assumed). The union moved away from the religious settlement embodied in the Pacification of Ghent of two years before (see above) and toward a predominance of the Calvinists and their monopoly of public practice of religion in the key provinces of Holland and Zeeland.

The immediate political significance of the union was that it dovetailed with the Union of Arras, concluded earlier in the month, which began the reconciliation of the southerners with King Philip II of Spain. The two "unions," parallel but opposite, thus undermined the policy of Prince William of Orange of collaboration between Roman Catholics and Calvinists throughout the Low Countries in resistance to the Spanish domination, which required mutual toleration among the religions. But it took some time before the "general union," with its base in the States-General at Brussels, fell apart irrevocably. For another half decade the prince struggled to keep intact the broader union and at the same time to assure its military and political support from abroad. Although Archduke Matthias of Habsburg, named governor-general by the States-General in 1577 after the deposition of Don Juan, remained the formal head of state until 1581, the prince continued to exercise his leadership. That the prince was the head and heart of the rebellion was recognized by Philip II in 1580 when he put him under the ban of outlawry. William's *Apology* in defense of his conduct was followed in 1581 by the Act of Abjuration (Akte van Afzwering) by which the States-General declared that

Declaration of independence

Philip had forfeited his sovereignty over the provinces by his persistent tyranny. This was a declaration of independence for the whole of the Low Countries, but the military and political events of the next decade limited its permanent effect to the northern provinces under the "closer union" of Utrecht.

FOREIGN INTERVENTION

Yet independence did not become William's objective even after the proclamation of the Act of Abjuration. Archduke Matthias returned home in 1581 after William turned to the duke d'Anjou, who agreed to take over the "lordship" of the Low Countries in 1580. The prince hoped for assistance from the duke's brother, King Henry III of France, and considered the "lordship" of Anjou as only a kind of limited, constitutional "sovereignty" like that which the rebels had hoped to impose on Philip II at the beginning of their rising. Anjou, however, saw the lordship as a means to total dominion over the Netherlands. Irritated by restraints upon his authority, he even attempted the seizure of power by military force, resulting in the so-called French Fury of Jan. 17, 1583, when his troops tried to capture Antwerp. The coup misfired, but William managed to keep Anjou (who returned to France) in his post despite the outraged feelings of the Netherlanders. Holland and Zeeland were on the verge of offering the title of count to William when he was assassinated on July 10, 1584, at Delft, by Balthasar Gérard, a fanatical young Roman Catholic from Franche-Comté, spurred by the promises of the ban of Philip II. William's death did not end the rebellion, as Philip had hoped, but it did result in the almost unnoticed disappearance of the central government in Brussels. The States-General, which now met at The Hague in Holland, represented only the provinces in the Union of Utrecht.

Leicester as governor-general

With the Spaniards steadily overrunning Flanders and Brabant, the Dutch in their plight did not immediately abandon William's policy of seeking foreign assistance. But after Henry III of France and Elizabeth I of England both refused sovereignty over the country, the States-General in 1586 named as governor-general Robert Dudley, earl of Leicester, whom Elizabeth had sent to command Dutch and English auxiliary forces against the Spaniards after the fall of Antwerp. Leicester, like Anjou before him, endeavoured to make himself absolute master of the country, relying on the support of popular Calvinism and of the outlying provinces that were jealous of Holland to create a strong centralized government under his authority. Holland thwarted Leicester's efforts, which culminated in an attempted invasion of Holland from Utrecht in 1587. With Leicester's departure, the United Provinces put aside all efforts to obtain a foreign protectorate and stood forth as an independent state.

THE FORMATION OF A NEW GOVERNMENT

Although derived from historical institutions, the government of the United Provinces was in practice largely a new set of institutions, not created, but confirmed, by the Union of Utrecht. Their primary force lay in the provinces, seven in number (Holland, Zeeland, Utrecht, Gelderland, Overijssel, Friesland, and Groningen), which were ruled by assemblies of provincial States representing the towns and the landed nobility. Although the stadtholders (who after a few years came to be drawn exclusively from the house of Orange) were elected by the States of the provinces, they at the same time possessed important prerogatives in the selection of members of the town governments from which the provincial assemblies ultimately derived their authority, and they were the acknowledged military leaders of the republic. Central government passed from the Council of State to the States-General, which was more explicitly subordinated to provincial authority. Although it conducted the military and diplomatic work of the republic, the States-General failed to obtain effective rights of direct taxation (except for import and export duties assigned to the admiralties), and its major decisions were taken under the rule of unanimity. In practice the province of Holland, by far the wealthiest province in the union and the contributor of more than half of the revenues of the central government, became the preponderant political force in the country, along with the stadtholders of the house of Orange. The relationship between Holland and the house of Orange governed the republic's politics for the two centuries of its existence. As collaborators, Holland and the princes of Orange could make the clumsy governmental system work with surprising effectiveness; as rivals, they imperiled its potency as a state, at least until one or the other emerged a temporary victor: but neither force was able to rule permanently without the other.

The decades immediately after 1587 were marked by close collaboration between Johan van Oldenbarnevelt, "advocate" of Holland (the legal and executive secretary of the provincial States), and Maurice of Nassau, William I the Silent's second son (the first, Philip William, became prince of Orange and remained loyal to Spain), who was named stadtholder of Holland and Zeeland and became the commander of the republic's armies. The result was a series of military triumphs over the Spanish forces under Parma. Maurice recaptured the Dutch territories north of the great rivers and extended them southward into much of Brabant and enough of Flanders to cut off Antwerp from the sea. These victories are recorded in the historical memory of the Dutch as "the closing of the garden," the territory that became the republic of the United Provinces and then (with a few additions) the modern Kingdom of The Netherlands. These victories were accompanied by the emergence of the States-General diplomatically recognized by England and France as an independent state.

ASCENDANCY OF THE DUTCH ECONOMY

Commercial domination of Amsterdam

The military prowess of the fledgling republic rested upon the wealth of Holland—which managed in wartime to maintain and extend its trade to all Europe and, after the turn of the century, even to East Asia. Amsterdam replaced Antwerp, the great port on the Schelde River, as the principal warehouse and trading centre for all Europe, even while Holland maintained the leadership in shipping it had already garnered during the 16th century. The foundation of Dutch economic prosperity lay in the fishing and shipping industries. Even during the period of Antwerp's ascendancy, ships from Holland and Zeeland had carried a large portion of the goods that passed through the Schelde, and now that Amsterdam had taken over from Antwerp, Dutch shipping only expanded its predominance. Dutch fishermen had harvested the North Sea for centuries, and the salted cargoes were sold widely through western and central Europe. Dutch trade benefited, as had that of Flanders, from the location of the country at the nexuses of the great north-south and east-west trade routes of Europe. To these were added the route to the East Indies early in the 17th century. Amsterdam and the lesser ports of Holland and Zeeland became the principal European suppliers of grain and naval stores from the Baltic, to which they shipped manufactured goods and wines from the south. Germany's principal exports were now shipped down the Rhine, as Dutch ports replaced the Hanseatic towns of northern Germany. The bulk of French exports were carried in Dutch ships, and even Spain and Portugal depended on the Dutch for grain and naval stores (thereby enabling the Dutch to finance their war of independence). During the 17th century the Dutch assumed a major role in supplying grain and other northern commodities to the countries of the Mediterranean and also became the principal importer of spices and other luxury goods from the East. Even England relied to a great extent upon Dutch shipping. The Dutch advantages lay not only in their situation but also in the efficient design of their bulky flyboats (*fluiten*), manned by small crews at less cost than any of their competitors. Modern banking institutions developed to meet the needs of the vastly expanding trade. Amsterdam's "exchange bank" was instituted in 1609 to provide monetary exchange at established rates, but it soon became a deposit bank for the safe settling of accounts. Unlike the Bank of England, established almost a century later, it neither managed the national currency nor acted as a lending institution (except to the government in emergencies). Private bankers met the need for credit, as well as acting as brokers in financial transactions. The need

Banking in Amsterdam

for commercial exports, as well as a growing population at home, spurred industry in many towns. Although the shipbuilders on the Zaan, northwest of Amsterdam, and the sugar refiners in particular developed large-scale operations, sometimes including machinery, Dutch industry generally remained at the level of handicraft production. Dutch agriculture also responded to the new needs. Grain production was encouraged in the inland provinces, while the polders of the delta islands and along the coast were drained and diked, providing pastureland for a flourishing dairy industry.

THE TWELVE YEARS' TRUCE

The Twelve Years' Truce that began in 1609 arose out of political controversies that were to dominate the republic for the next two centuries. The collaboration between the house of Orange and the leaders of the province of Holland, which had thwarted Spain in its reconquest of the Netherlands north of the great rivers, was replaced by an intermittent, but often fierce, rivalry between them, in which the other tensions of Dutch political life were reflected and incorporated: the jealousy among the lesser provinces of a Holland that they considered too wealthy, too mighty, and too arrogant but which they knew they needed for their own defense; the misunderstanding between maritime and landward provinces; the annoyance of landed nobles that they were dependent upon the goodwill of burghers in Holland (they preferred the prince of Orange, whom they saw as one of themselves); the resentment of the popular classes, men of small property and of none, toward the town regents (members of government) from whom they looked to the princes of Orange to protect them; and the antipathy of the Reformed clergy toward the regents, who obstructed their desire to make the state serve the church. The debate over whether or not to conclude a peace with Spain mingled these various interests with that of the house of Orange, partly because Maurice opposed peace, partly because it involved making some compromise with Spain, and partly because it would mean a reduction of his influence in the state; but the province of Holland in particular, under Oldenbarnevelt's leadership, felt that the independence and security of the United Provinces had been sufficiently assured to permit a reduction of the immense expenditures for the war. When Spain reduced its immediate proposal to a truce rather than permanent peace, agreed to treat the United Provinces as independent and sovereign, which was just short of outright recognition, and put aside efforts to win guarantees for Dutch Catholics, the pressure for conclusion of a truce could not be withstood.

The Twelve Years' Truce did not, however, end internal controversy within the republic. If anything, it only sharpened Maurice of Nassau's opposition to Holland and Oldenbarnevelt. The staunch Calvinists endeavoured to hold the Reformed church to the strict orthodoxy expounded by Franciscus Gomarus, a Leiden professor of theology, against the broader, less rigorous tenets upheld by his colleague Jacobus Arminius. The Gomarists demanded that the government uphold their principles because the Reformed church was the only true church, but they reserved for themselves the right to declare what the correct doctrines were; and they vigorously asserted that other religious groups, Catholic, Protestant, and Jewish alike, should be suppressed or at least penalized and restricted. On the other hand, the Arminians had the support of the leaders of Holland and a majority of its towns, who felt that what was in effect the state church had to be under the authority of the government. Both out of principle and out of a desire not to hamper trade with men of all religions, they favoured a broadly inclusive Reformed church and toleration for those outside its ranks.

Gomarists versus Arminians

The efforts of Gomarists to seize churches for their own use in defiance of town authorities led to incipient civil war. Maurice broke openly with the dominant party in Holland when it attempted to set up little provincial armies in Holland and Utrecht. In 1618 he acted under the authority of the States-General, in which the majority of provinces favoured the Gomarists (now called the Contra-Remonstrants because they had opposed an Arminian petition) over the Remonstrants (Arminians) to crush the resistance of Oldenbarnevelt's party. Oldenbarnevelt, together with two of his chief supporters in Holland (including the great jurist Hugo Grotius) and an ally in Utrecht, was arrested and tried for treason by a special court instituted by the States-General. The defendants affirmed that they were subject only to the authority of the sovereign province that they served. The sentence, which to foes of the house of Orange over the centuries became an act of judicial murder, sent Oldenbarnevelt, then 71 years old, with almost four decades of service as Holland's leader, to his death by beheading in May 1619. Grotius and another defendant (the third had committed suicide) were sentenced to life imprisonment, although Grotius escaped, sensationally, a few years later.

During these fateful months, the Reformed church held a national synod at Dordrecht. Dominated by the Contra-Remonstrants, the synod expelled the Remonstrants, reaffirmed the doctrines of the church along Gomarian lines, and ordered the preparation of a new translation of the Bible (the famous States Bible that consolidated the Dutch language much as the contemporary King James Version consolidated English). The triumph of Maurice and the Contra-Remonstrants meant that war with Spain would be a virtual certainty upon the expiration of the Twelve Years' Truce in 1621—all the more because the Spanish authorities in the southern Netherlands insisted upon including rights for Dutch Catholics in a permanent treaty and even sought an acknowledgment by the States-General of the nominal overlordship of the king of Spain. Maurice did not use his new uncontested power to reform the complicated incoherence of the Dutch constitution; the structure of government and the distribution of formal power remained the same. Maurice was not a politically minded ruler and was satisfied as long as he had his way in military matters. The United Provinces remained essentially republican in character.

WAR WITH SPAIN (1621–48)

The war resumed in 1621 under Maurice's leadership. But his touch of victory was gone, and the republic appeared in danger when the great fortress of Breda on the southern frontier fell to the Spaniards in 1625. Only a few weeks before, Maurice had died. The danger was all the greater because the Austrian Habsburgs, in alliance with their Spanish cousins, were waging a successful struggle against their Protestant foes in Germany in the first stages of the Thirty Years' War. But Maurice's half-brother, Frederick Henry, who succeeded him as prince of Orange, stadtholder, and commander in chief, resumed the course of victory. He completed the recapture of towns recently gained by the Spaniards and extended the territory under the States-General to the key fortress of Maastricht on the Maas (Meuse) well to the south. At the same time, the Dutch navy won a series of victories over the Spaniards, including Piet Heyn's celebrated capture of their silver fleet off the coast of Cuba (1628) and the destruction of a Spanish fleet in the Downs, off the English coast, by Maarten Tromp in 1639.

Victories under Frederick Henry

Frederick Henry turned out to be a more subtle and purposeful politician than Maurice. On the one hand, he ended the suppression of the Remonstrants, with whose religious views he sympathized, without exasperating the Contra-Remonstrants beyond repair. On the other hand, he established a firm grip over the policies of the republic, notably by establishing a close alliance with France aimed at the joint conquest of the Spanish Netherlands. Frederick Henry's political predominance within the republic was based upon his control of the lesser provinces, which had a majority in the States-General and which could outweigh the influence of Holland. Gradually Holland turned against him, especially after he arranged the marriage of his young son William to Princess Mary Stuart, daughter of Charles I of England, on the eve of the English Civil War (1642–51). This fateful dynastic bond tied the interests of the house of Orange to the royal families of England, first to the Stuarts and later to the Hanoverians. The position of the house of Orange, however, was elevated by the connection: the French monarchy granted

Frederick Henry the honorary address of "His Highness," normally restricted to royalty; and the debate over the function of the princes of Orange in Dutch politics began to be conducted as a controversy over monarchy. A quasi-royal court rose up around Frederick Henry, and this in turn only clarified and strengthened the republicanism of his opponents, especially in Holland, who feared that the political leadership of the princes of Orange would be turned into an explicit monarchy.

During the 1640s, however, Frederick Henry lost his physical and intellectual powers and was unable to prevent Holland from reasserting its predominance over the republic's policies. The States-General entered into peace negotiations with Spain at Münster in Westphalia. Frederick Henry died in 1647 before the conclusion of the talks, but his son, William II, could not prevent the signing and ratification of the treaty in January 1648. Spain now formally acknowledged the independence of the Dutch, and indeed even urged its friendship upon the United Provinces, warning of the threat to both the Dutch and the Spanish from the rising power of France.

Peace of Westphalia

Prince William was not ready to accept a permanent peace, and he negotiated secretly with the French for a resumption of the war, not only against Spain but also against republican England, which had executed his father-in-law, King Charles I, in January 1649. Needing a powerful army to wage the anticipated war, William bitterly fought the efforts of Holland to reduce the standing army and thereby to permit more rapid payment of the huge debt accumulated over the eighty years' struggle for independence. Efforts at compromise broke down during the spring of 1650, as the Hollanders and William each sought to compel the other to concede political inferiority. William decided to make use of his preponderance in the States-General, and he led a delegation from that body to the towns of Holland to seek a change of their vote in the States of Holland; such a delegation was a direct violation of what Holland saw as its provincial sovereignty. Rebuffed by a number of town governments, most importantly by those of Amsterdam and Dordrecht, William decided to cut through the resistance by force. At The Hague, on July 30, 1650, he arrested six of the States' deputies from the recalcitrant towns and sent them to the castle of Loevestein (where Grotius had been imprisoned) on charges of having resisted lawful orders of the States-General. At the same time he sent an army to seize Amsterdam, but it was thwarted by delays on its march and by the determined resistance of the municipal authorities, supported by the common people. Amsterdam, however, faced a siege that might gravely imperil its trade, while the besiegers themselves ran the danger of being drowned should Amsterdam open the dikes. A compromise was soon worked out whereby William's opponents were released but were required to withdraw from government. William had cleared the way for his policies but at the price of arousing deep fears among the Dutch people—most of all in the powerful province of Holland—of military dictatorship, monarchical rule, and renewed involvement of the nation in war. But before he could carry out his plans, William II died of smallpox in early November. A posthumous son, William III, was born a week later.

Death of William II

THE FIRST STADTHOLDERLESS PERIOD

Fate thus intervened to give Holland's leaders, now intensely distrustful of Orangist influence, a chance to take over the country from the leaderless party of their antagonists. They governed the country for a little more than two decades, during what is known as the "first stadtholderless period" (1650–72) because the five leading provinces did not appoint a successor to William II. (William II's cousin, William Frederick, of the junior branch of Orange-Nassau, continued to govern Friesland as well as Groningen, which also elected him as stadtholder.) During the early months of 1651, a "Great Assembly" of the States-General, with expanded delegations from all the provinces, met at The Hague to consider the new situation. Holland was satisfied to consolidate the leadership it had so unexpectedly regained and conciliated the lesser provinces by leaving undisturbed the religious settlement of 1619 and by granting amnesty to those who had supported William II in 1650. But Holland's fears of the increased powers of the central government had been so stiffened that it depended upon its own preponderance, rather than upon constitutional reforms, to achieve effective government.

Yet efficiency of rule, so difficult to obtain when the powers to make and apply policy were so widely scattered, became all the more necessary when the republic became embroiled in war with the English Commonwealth in 1652. That conflict arose out of a medley of causes: first, the English republicans, after their successes against the royalists, took up the cause of defending English commercial interests against the Dutch and passed the Navigation Act of 1651 forbidding Dutch shippers from acting as middlemen in English trade both in Europe and overseas; second, the English sought to bring the Dutch into a political union directed primarily against the Stuarts and their cousins of the house of Orange. But the Dutch, whatever resentment the Hollanders bore against the Orange dynasty, were unwilling either to court civil war or to abandon their dearly won independence in a union that would make them junior partners to the English. An accidental clash between the Dutch and English fleets led to full-scale war in which a greatly improved English navy won the upper hand. By 1654 the Dutch were compelled to accept peace on English terms, including a secret promise by Holland ("Act of Seclusion") to exclude forever the prince of Orange from the stadtholderate and the supreme command.

The decision to accept a humiliating peace as the only way to terminate a disastrous war had been taken at the insistence of the young Johan de Witt, who had taken office in 1653 as councillor pensionary of Holland (the same office once held by Oldenbarnevelt). With the return of peace, de Witt became the brilliant leader of the republic's foreign and domestic policy. He rebuilt the Dutch navy, reduced indebtedness, improved the financial condition of both the States-General and the States of Holland, and restored the republic's prestige in Europe. Carefully averting any renewal of strife with England, he was able not only to compel France to back down in a naval dispute but also to send a powerful Dutch fleet to save Denmark from Swedish conquest in the First Northern War (1657–60).

Leadership of de Witt

When the exiled English king, Charles II, was restored to his throne in 1660, de Witt continued his policy of staying on good terms with England no matter who ruled there; this policy, however, foundered on the same two issues—commercial rivalry and the status of the house of Orange—that had brought about the war of 1652–54. Charles not only accepted the renewal of the Navigation Act of 1651 but intensified the rivalry with the Dutch by demanding forcefully that they acknowledge his sovereignty over the adjacent seas, pay tribute for the right to fish in the North Sea, and open the Dutch East Indies to English traders. When naval warfare resumed in 1664 off Africa, followed by war in Europe the next year, Charles took up the cause of the young prince of Orange. By persuading the Orangists that his price for peace was restoration of William III to the offices of his forefathers, the English monarch built up a friendly party in the United Provinces that urged acceptance of his terms and even fostered a conspiracy to overthrow the government of de Witt and his friends. But de Witt managed to meet the new threat. An Orangist plot in Holland was uncovered and put down in 1666.

When Charles had demanded too high a price for Dutch friendship in 1660–62, de Witt had negotiated an alliance with the French, who feared that the restoration of the prince of Orange would create a hostile Anglo-Dutch coalition. Furthermore, the fighting at sea increasingly went to the newly rebuilt Dutch navy. In 1667 the Dutch fleet sailed up the Thames and the Medway to Chatham, destroying the English shipyards and burning the fleet at its moorings. In that same year, however, the French, under Louis XIV, who had only belatedly sent naval and land forces to aid the Dutch, began an invasion of the Spanish (southern) Netherlands in the War of Devolution. As French conquest of the southern Low Countries constituted a threat to both the Dutch Republic and Britain, those states came to terms in the stand-off Peace of Breda

(July 31, 1667), followed in January by an Anglo-Dutch alliance compelling France to make peace with Spain.

The Triple Alliance

This Triple Alliance (so called because Sweden became a third partner) proved to be de Witt's undoing, although he had no effective diplomatic strategy to put in its place. Louis XIV, balked in his aim of conquest, considered that the Dutch had betrayed their alliance and turned to Charles II with proposals for a joint war against the United Provinces. Charles, bitterly resentful over his humiliating defeat at Chatham, accepted the French offer of a richly subsidized alliance. Even as the threat from France emerged more clearly, the Orangists imagined that the Dutch could still win over Charles by the restoration of William III, but they were able to obtain only the prince's appointment as commander in chief early in 1672. Charles joined the French in open war in the spring of 1672, counting upon William to accept rule of a rump Dutch Republic after France and Britain had taken away important territories for themselves. But William, who was given full power, including the stadtholdership, during a storm of riots and near rebellion that swept the country in June and July after the French invasion penetrated to its heart, took over the leadership of the Dutch defense from de Witt, who was lynched by a mob in The Hague in August. With William's support, the States-General rejected the Anglo-French terms.

WILLIAM III

The tide of war now turned against the aggressors. The Dutch navy under Admiral Michiel Adriaanszoon de Ruyter repeatedly defeated the allied fleets off the coast of the republic, while the Dutch armies held on behind the flooded polders of the "water line." When other powers—Spain, at first as an auxiliary, then as a full participant, the German emperor, and Brandenburg—joined the Dutch side, the French armies withdrew from the republic. During six years of bitter war, William III was able to bring about the withdrawal of England (1674) and the defeat of all French war aims against the Dutch; yet his Grand Alliance was unable to bring Louis XIV to his knees, although Spain paid the price of a peace negotiated at Nijmegen in 1678. But during these years in which his political control of the republic, while strong, was not absolute, William was no more interested in constitutional reform than de Witt, his predecessor in the leadership of the country, had been. He was satisfied to expel adversaries from office and dominate the decisions taken by men who represented the same groups and the same social principles as those whom they replaced; but Holland, whose wealth ultimately was the basis for all Dutch power, political and military, slipped from under his thumb and asserted its autonomy of judgment and decision. The transformation of the republic, which had been from its origins an aristocracy dominated by mercantile wealth, into an oligarchy of inherited power, continued unimpeded by William: he had used the violence of the urban citizenry during the crisis of 1672 to unseat his opponents, including de Witt, but he was no more sympathetic than they had been to the vague democratic aspirations that were expressed here and there.

During the decade after the conclusion of the Peace of Nijmegen, the tension between William and Holland (particularly Amsterdam) worsened because the prince was fixed upon a policy of renewed resistance to Louis XIV, while the Hollanders preferred peace at any reasonable price. But the upsurge of the threat from France in the late 1680s—the French incursions into western Germany and the threat of French domination of England under James II, a stalwart Roman Catholic and a pensioner of Louis XIV—brought William and Holland into agreement upon the need to support the prince's expedition to England in 1688, which resulted in his acceptance of the English throne, jointly with his wife Mary Stuart, early the next year. William, as king-stadtholder, had to give primacy to English interests because England was the more powerful partner in the alliance. He therefore approved the arrangement whereby England concentrated her efforts against France on the sea, while the Dutch did so on land; the result was neglect of the Dutch navy. Ironically, the final triumph of the English over the Dutch in their commercial rivalry was a consequence of their alliance, not their enmity.

William accepts the English throne

The war begun in 1689 ended with a stalemate peace in 1697, followed by two treaties between the maritime powers and France for partition of the Spanish monarchy. In 1700, however, Louis XIV accepted the bequest of the Spanish throne for his grandson, Philippe d'Anjou (Philip V of Spain), and war was resumed the next year.

William died, childless, in 1702. When Holland again took the initiative for government without a stadtholder, it was followed by the other provinces with much greater alacrity than had been true in 1650–51. Resentment had built up against the harshness with which the prince had governed the country for three decades, and the absence of an adult heir meant that there was no effective opposition to the new course. Leadership of the Dutch state for the next 45 years came from the councillor pensionaries of Holland, who were often able men but either unwilling or unable to do more than conduct current business without attempting the delicate and explosive task of restructuring the government. On the contrary, constitutional rigidity became the credo not only of Dutch republicans but also of the Orangist party, with the only point in contention between them being whether or not the prince of Orange-Nassau, who was stadtholder of Friesland, should be elected to the same office in the other provinces. William IV, who followed his father in Friesland in 1711, was chosen stadtholder in Groningen in 1718 and in Gelderland (and the district of Drenthe) in 1722. Even without a stadtholder in the principal provinces, Dutch subordination to English interests remained intact during the War of the Spanish Succession (1701–13) and the succeeding years of peace.

DUTCH CIVILIZATION IN THE GOLDEN AGE (1609–1713)

The "Golden Age"

The century from the conclusion of the Twelve Years' Truce in 1609 until either the death of Prince William III in 1702 or the conclusion of the Peace of Utrecht in 1713 is known in Dutch history as the "Golden Age." It was a unique era of political, economic, and cultural greatness during which the little nation on the North Sea ranked among the most powerful and influential in Europe and the world.

The economy. It was a grandeur that rested upon the economic expansion that continued with scarcely an interruption until 1648, at the end of the Thirty Years' War. The half century that followed was marked by consolidation rather than continued expansion, under the impact of the revived competition from the other nations, notably England and France, whose policies of mercantilism were in large degree directed against the near monopoly of the Dutch over the trade and shipping of Europe. Although the Dutch tenaciously resisted the new competition, the long-distance trading system of Europe was transformed from one largely conducted through the Netherlands, with the Dutch as universal buyer-seller and shipper, to one of multiple routes and fierce competitiveness. Nonetheless, the wealth earned during a long century of prosperity made the United Provinces a land of great riches, with more capital by far than could find outlet in investment. Yet the economic burden of repeated wars caused the Dutch to become one of the most heavily taxed peoples in Europe. Because the role of agriculture was secondary, taxes were to some extent imposed on the transit trade in and out of the country. But as mercantile competition became stiffer, the rate of such taxation could not be safely increased, and the burden therefore fell increasingly on the consumer. Excise and other indirect taxes made the Dutch cost of living one of the highest in Europe.

Dutch prosperity was built not only upon the "mother trades"—to the Baltic and to France and the Iberian lands—but also upon the overseas trades with Africa, Asia, and America. The attempt of the Spanish monarchs (who also ruled Portugal and its possessions from 1580 to 1640) to exclude Dutch merchants and shippers from the lucrative colonial commerce with East Asia led the Dutch to trade directly with the East Indies. Individual companies were organized for each venture, but the companies were

The Dutch East India Company

united by command of the States-General in 1602 in order to reduce the costs and increase the security of such perilous and complex undertakings; the resulting United East India Company established bases throughout the Indian Ocean, notably in Ceylon (Sri Lanka), mainland India, and the Indonesian archipelago. The Dutch East India Company, like its rival English counterpart, was a trading company granted quasi-sovereign powers in the lands under its dominion. Although the East India fleets that returned annually with cargoes of spices and other valuables provided huge profits for the shareholders, the East India trade of the 17th and 18th centuries never provided more than a modest fraction of Dutch earnings from European trade. The West India Company, established in 1621, was built upon shakier economic foundations; trade in commodities was less important than the trade in slaves, in which the Dutch were preeminent in the 17th century, and privateering, which operated primarily out of Zeeland ports and preyed upon Spanish (and other) shipping. The West India Company had to be reorganized several times during its precarious existence, while the East India Company survived until the end of the 18th century.

Society. The social structure that evolved with the economic transformation of Dutch life was complex and marked by the predominance of the business classes that later centuries called the bourgeoisie, although with some significant differences. It was an unabashedly "aristocratic" country, socially and politically. The social "betters" of Dutch aristocracy were only to a limited extent landed nobles, most of whom lived in the economically less advanced inland provinces. Most of the Dutch elite were wealthy townsmen whose fortunes were made as merchants and financiers, but they frequently shifted their activities to government, becoming what the Dutch called regents, members of the ruling bodies of town and province, and drawing most of their incomes from these posts and from investments in government bonds and real estate. The common people comprised both a numerous class of artisans and small businessmen whose prosperity provided the base for the generally high Dutch standard of living and a very large class of sailors, shipbuilders, fishermen, and other workers. Dutch workers were in general well paid, but they were also burdened by unusually high taxes. The farmers, producing chiefly cash crops, prospered in a country that needed large amounts of food and raw materials for its urban (and seagoing) population. The quality of life was marked by less disparity between classes than prevailed elsewhere, although the difference between a great merchant's home on the Herengracht in Amsterdam and a dockworker's hovel was all too obvious. What was striking was the comparative simplicity even of the wealthy classes and the sense of status and dignity among the ordinary people, although the exuberance that had earlier marked the society was toned down or even eliminated by the strict Calvinist morality preached and to some extent enforced by the official church. There was, too, a good deal of mingling between the burgher regents who possessed great wealth and political power and the landed gentry and lesser nobility who formed the traditional elite.

Religious "pillars"

Religion. One of the characteristic aspects of modern Dutch society began to evolve in this period—the vertical separation of society into "pillars" (*zuilen*) identified with the different Dutch religions. Calvinist Protestantism became the officially recognized religion of the country, politically favoured and economically supported by government. But the Reformed preachers were thwarted in their efforts to oppress or drive out other religions, to which a far-reaching toleration was extended. Mass conversion to Calvinism had been confined mainly to the earlier decades of the Eighty Years' War, when Roman Catholics still frequently bore the burden of their preference for the rule of the Catholic monarchs in the southern Netherlands. Sizable islands of Roman Catholicism remained in most of the United Provinces except Zeeland, while Gelderland and the northern parts of Brabant and Flanders conquered by the States-General were overwhelmingly Roman Catholic, as they remain today. Although public practice of Catholicism was forbidden, interference with private worship was rare, even if Catholics sometimes bought their security with bribes to local Protestant authorities. Catholics lost the traditional form of church government by bishops, whose place was taken by a papal vicar directly dependent upon Rome and supervising what was in effect a mission; the political authorities were generally tolerant of secular priests but not of Jesuits, who were vigorous proselytizers and linked to Spanish interests. Protestants included, along with the predominant Calvinists of the Reformed church, both Lutherans in small numbers and Mennonites (Anabaptists), who were politically passive but often prospered in business. In addition, the Remonstrants, who were driven out of the Reformed church after the Synod of Dort (Dordrecht; 1618–19), continued as a small sect with considerable influence among the regents.

There were also other sects emphasizing mystical experiences or rationalist theologies, notably the Collegiants among the latter. Jews settled in the Netherlands to escape persecution; the Sephardic Jews from Spain and Portugal were more influential in economic, social, and intellectual life, while the Ashkenazim from eastern Europe formed a stratum of impoverished workers, especially in Amsterdam. Despite unusually open contacts with the Christian society around them, Dutch Jews continued to live in their own communities under their own laws and rabbinic leadership. Successful though some Jews were in business, they were by no means the central force in the rise and expansion of Dutch capitalism. Indeed, no clear pattern can be detected of religious affiliation affecting the growth of the Dutch business community; if anything, it was the official Dutch Reformed Church that fulminated most angrily against capitalist attitudes and practices, while the merely tolerated faiths often saw their adherents, to whom economic but not political careers were open, prospering and even amassing fortunes.

Culture. The economic prosperity of the Dutch Republic in this "golden century" was matched by an extraordinary flowering of cultural achievement, which drew from the nation's prosperity not only the direct resources of financial nourishment but also a driving and sustaining sense of purpose and vigour. This was reflected in the first instance by a notable series of historical works: the contemporary chronicles of the revolt by Pieter Bor and Emanuel van Meteren; the highly polished account by Pieter Corneliszoon Hooft, a masterpiece of narration and judgment in the spirit of Tacitus; the heavily factual chronicle of Lieuwe van Aitzema, with its interspersed commentary of skeptical wisdom; Abraham de Wicquefort's history of the republic (principally under the first stadtholderless administration); and the histories and biographies by Geeraert Brandt. These were works in which a proud new nation took account of its birth pangs and its growth to greatness. Only in the latter part of the century did Dutch historians begin to express a sense that political grandeur might be transient.

Flowering of historical works

Political theorists shared the same concerns, although the effort to fit new experience and ideas into the traditional categories derived from Aristotle and Roman law created an air of unreality about their work, perhaps even more than was true of political thinkers elsewhere in Europe. Theorists such as the Gouda official Vrancken in the days of the foundation of the republic and Grotius in the early 17th century portrayed the republic as essentially unchanged since the early Middle Ages or even since antiquity—a country where sovereignty resided in provincial and town assemblies, which had partly lost their control to counts and kings before regaining it in the revolt against Philip II. The next surge of political debate came after mid-century, when for a little more than two decades the country was governed without a prince of Orange as stadtholder.

The controversy over whether the young Prince William had any right by birth to the offices of his forefathers probed the fundamental character of the republic, for even a quasi-hereditary stadtholdership created an incipient monarchy within the traditional structure of aristocratic republicanism. The debate involved the issue not so much of centralization versus provincialism as where the leadership of the republic properly lay, whether in the house

of Orange or in the province of Holland and notably its greatest city, Amsterdam. Only the celebrated philosopher Benedict de Spinoza, an outsider by origin and character (a Jew by birth and upbringing), elevated these political questions to the level of universality.

Another great philosopher of the 17th century who resided in the Dutch Republic was the Frenchman René Descartes. Though an outsider, Descartes found in the Netherlands a freedom from intellectual inquisitions and personal involvements. He lived there for two decades while engaged in the studies that helped transform modern thought.

Scientific achievements

Scientific activity in the United Provinces also reached a high level. The physicist Christiaan Huygens approached Newton himself in power of mind and importance of scientific contribution. The engineer and mathematician Simon Stevin and the microscopists Antonie van Leeuwenhoek and Jan Swammerdam rank in the front of their fields.

Dutch literature, which knew great creativity during the "golden age," remained the possession of the relatively small number of those who spoke and read Dutch. Figures like the historian P.C. Hooft or the poets Constantijn Huygens and Joost van den Vondel, who was also a distinguished playwright, wrote with a power and a purity worthy of the best that France and England produced at that time. Music was hampered by the Calvinists' antipathy to what they saw as frivolity. Organ music was barred from services in Reformed churches, although town authorities frequently continued its performance at other times. The great organist-composer J.P. Sweelinck was more influential in encouraging the creative wave in Germany than among his own countrymen. The art whose achievements rank at the very top was painting, which rested upon the broad patronage of a prosperous population. Group portraits of regents and other influential citizens adorned town halls and charitable establishments, while still lifes and anecdotal paintings of popular life hung in profusion in private homes. Some of the greatest work, from the brushes of such painters as Frans Hals, Jan Steen, and Jan Vermeer, were painted for these markets, but the greatest of Dutch painters, Rembrandt, broke through the boundaries of the group portrait to create works with his own extraordinary mood and inward meaning. The landscape painters, notably Jacob van Ruisdael, captured the distinctive Dutch flat land, broad skies with massed clouds, and muted light. Architecture remained at a lesser level, merging with some success the native traditions of brick buildings and gable roofs and fashionable Renaissance styles. Sculpture remained a largely foreign art.

THE 18TH CENTURY

Economic and political stagnation. Once the Dutch fleet had declined, Dutch mercantile interests became heavily dependent on English goodwill; yet the rulers of the country were more concerned with reducing the monumental debt that weighed heavily upon the country. During the 18th century Dutch trade and shipping were able to maintain the level of activity reached at the end of the 17th century, but they did not match the dramatic expansion of French and especially English competitors. The Dutch near-monopoly was now only a memory. Holland remained rich in accumulated capital, although much of it could find no outlet for investment in business. Some went into the purchase of landed estates, but a great deal was used to buy bonds of foreign governments; the bankers of Amsterdam were among the most important in Europe, rivaling those of London and Geneva. Dutch culture failed to hold its eminence; a medical scientist like Hermann Boerhaave or a jurist like Cornelis van Bynkershoek was highly respected, but they were not the shapers and shakers of European thought. Dutch artists were no longer of the first order, and literature largely followed English or French models without matching their achievements. The quality of life changed: instead of the seething activity of the 17th century, the 18th century was one of calm and easeful pleasantness, at least for men of property. The middling classes in town and countryside also knew continuing prosperity; conditions for the labouring classes continued to be hard, although foreign visitors thought the workers lived better than elsewhere. The poor as such were not labourers but a residual class of unemployed who subsisted on the charity of town governments and private foundations. Religious life was more relaxed, particularly among Protestants. Roman Catholics, still without political rights but facing milder restrictions, fell into a quarrel between adherents of Jansenism, which denied free will, and supporters of Rome; the former split off to form the Old Catholic Church, a small denomination that still exists. The educated classes widely accepted the principles and attitudes of the Enlightenment although without the sharp hostility to religion that characterized the French philosophes.

Decline of Dutch commerce and culture

During the second stadtholderless period of Dutch government (1702–47), the republican system became an immobile oligarchy. The "liberty" defended by the regents as soundly republican was in practice the rule of hereditary patricians, responsible to neither the citizenry below nor a stadtholder above. Although William IV yearned for restoration to the offices held by the princes of Orange before him in the provinces to the south, he accepted, with no less admiration and commitment than the regents, the perfection and immutability of the Dutch constitutional system, with the single difference that he envisioned it including the stadtholderate for all the provinces. It was not until the War of the Austrian Succession (1740–48) that the power of the regents began to crumble. As in 1672, disaster on the battlefield proved the Achilles' heel of a regime that had not built up a broad popular political base. The regents had not been able to overcome the traditional commitment of the people to the house of Orange as their natural leader and saviour. French and Prussian armies swarmed over the Austrian (formerly Spanish) Netherlands and were poised for invasion of the United Provinces, which were linked by alliance with England, although they had remained formally neutral. When the French forces crossed into Dutch territory, rioting reminiscent of 1672, although less widespread and violent, led to the fall of the second purely republican government and the election of William IV as hereditary stadtholder of all the provinces. Otherwise there was little change; some regents were compelled to step down from their posts, and leadership in the hands of the prince of Orange was uncontested. William rebuffed the efforts of burghers in Amsterdam and other towns who had supported his restoration in order to achieve democratic reforms, in which participation in government would be extended to men of modest property who had been completely disfranchised (although not to wageworkers or to paupers).

Reaction to French incursion

The Patriot movement. During the next decades, in the face of the rigid conservatism of the princes of Orange (William V succeeded his father in 1751 and assumed personal government in 1759) and under the influence of the French Enlightenment, an essentially new political force began to take shape. Known as the Patriot movement after an old party term used by both republicans and Orangists, it applied fundamental criticism to the established government. Although the Patriot movement was representative of the new democratic and Enlightenment ideals, it had strong roots in native Dutch traditions. From the beginning, the United Provinces had rejected specifically democratic institutions in favour of frankly aristocratic government (in the Aristotelian sense), but the notion that the regents had a duty to serve not their own private interests but those of the country and the people had persisted in theory and in mood. When the aristocracy ceased to recruit new members from below and thus became an enclosed caste, the discrepancy between its claim of service to the general welfare and the reality of its practice became evident. The Patriot movement took in a wide range of supporters: discontented noblemen like the Gelderland baron Joan van der Capellen tot den Pol; wealthy bankers and businessmen without a voice in government; artisans and shopkeepers, traditionally Orangist in sympathy, who were dismayed to find their claims to an effective role in the politics of their towns rebuffed by the princes; and intellectuals committed to the new Enlightenment rejection of arbitrary power. The Patriots included in their ranks many Protestant dissenters and

Roman Catholics, but the Jews continued to look to the prince of Orange as their protector. Some regents, holding firm to the republicanism of their ancestors and resenting the return of the stadtholderate, found a new base for their ideas in the Patriot movement. Most regents, however, saw more peril in the new movement for broader popular government than in the stolid conservatism of the princes of Orange; a reconciliation between the camps of the patrician republicans and the Orangists began to take shape under the impact of a common threat from below.

Causes of Dutch-British hostility

Again the events of war imperiled the established regime. Although the diplomacy of William V was firmly based upon the alliance with England, London became exasperated with the Dutch during the American War of Independence (1775–83), when they attempted to continue and expand their profitable trade with the new American nation as well as with France. Dutch flirtations with the Russian-sponsored League of Armed Neutrality, resisting British searches of neutral vessels, and indications of Dutch negotiations for an alliance with the Americans only worsened relations. Finally open hostilities erupted in the fourth Anglo-Dutch War (1780–84). The Dutch navy, sorely neglected for more than a half century, was utterly unprepared to battle the powerful British fleet, and the Dutch fleet's attempts to convoy their merchantmen brought only disaster.

The onus of defeat fell upon the stadtholder. He was unable to stand firm against the increased agitation of the Patriots, who forced their way into governments of town after town in Holland and other provinces. Holland began organizing its own army, distinct from that under the prince's command, and civil war seemed in the offing. William V fled to Gelderland with his wife, Wilhelmina, the sister of the Prussian King Frederick II. Holland declared him deposed.

It was the strong-willed Wilhelmina, rather than her hesitant and rather docile husband, who took the lead in the restoration of the stadtholderate. Dutch politics had now become a concern of the great powers. France sided with the Patriots, not out of sympathy with their principles but because they opposed the stadtholder, who had fallen back into dependence upon English and Prussian support. As long as Frederick II ruled in Prussia, Wilhelmina's pleas for armed intervention fell on deaf ears, but when the throne passed to his nephew Frederick William II in 1786, the way opened for action. The Patriots counted upon the support of the French, but the government at Versailles, then entering the final financial and political crisis of the monarchy that erupted in the Revolution of 1789, could give no more than verbal encouragement. Wilhelmina, working closely with the English ambassador, arranged to create a crisis by seeking to return to Holland; her detention at the provincial border was taken by Prussia as justification to send an army into the United Provinces. The Prussians quickly swept away the makeshift militias of Holland and Utrecht and restored the stadtholder, William V, to his offices. A period of repression of Patriots followed; many went into exile, first in the Austrian Netherlands and then in France. The outbreak of the French Revolution in 1789 gave new hope to the exiles and their friends at home. They looked now for more effective French assistance and at the same time found in the French revolutionary experience practical ideas for the reorganization of the government at home, notably the principle of a single, indivisible republic. The Patriots' hopes rose when the armies of the French Revolution swept over the Austrian Netherlands (which had had a brief interlude of independence in 1789–90) in 1792, but the French forces retreated the next year. It was not until 1794 that they returned to Belgium (as it now became customary to call the southern Netherlands), driving up to and then across the frontier of the United Provinces. The moment for which the Dutch Patriots had long been waiting was at hand: French power would more than overweigh the English and Prussian strength upon which the stadtholder relied (Prussia made a separate peace with France in 1795), and a democratic revolution, thwarted in 1787, would be possible. The freezing of the great rivers during the winter permitted the French forces to cross into the Dutch heartland, but even before they arrived the Patriots seized the reins of state from helpless William V, who abandoned office and fled to England.

Impact of the French Revolution

THE PERIOD OF FRENCH RULE (1795–1813)

The old republic was replaced by the Batavian Republic, and the political modernization of the Netherlands began—a process that would take more than half a century and pass through many vicissitudes; yet it was one marked by an extraordinary lack of violence. For all its flaws and inconsistencies, the old regime of the United Provinces had enjoyed many of the institutions and practices that other countries had to create in the fire of revolution: the sovereignty of parliamentary assemblies; wide-ranging political and religious toleration; equality of all citizens before the law; and an unusually broad distribution of the benefits of economic prosperity, however far the social system was from equality. Even the sense of nationhood had put down deep roots, although the awareness of differences of religion remained powerful. In a word, the Dutch had already achieved a large measure of the "liberty, equality, and fraternity" that had become the slogan of the French Revolution. The task that confronted the Batavian and the successor regimes was to adapt old institutions and create new ones that could meet the needs of a new era. But the Dutch statesmen had to operate within the confines of a small power shorn of most of its military and naval strength and yet more dependent than most other countries upon its trading and shipping.

The Batavian Republic (1795–1806). The Batavian Republic lasted 11 years, during which it proclaimed the sovereignty of the people but was in fact a protectorate of France. The organization of government had to be approved not only by the Dutch people but also by whatever government happened to be in control in France. The constitutions therefore reflected not only Dutch conditions and ideas but also the arrangements in effect in Paris; nonetheless, they did create a political system of the new type, a new regime, in the Netherlands. After much debate, the ancient historic provinces—so unequal in wealth, population, and influence—were replaced by a unitary republic divided into departments and electoral constituencies that were roughly equal in population, if not in wealth. The representatives elected to the National Assembly (which replaced the historic States-General) were not delegates of provincial assemblies by whose decisions they were bound but deputies with full independence of judgment. The ancient system of government, with its medley of assemblies and boards with imperfectly differentiated functions, was replaced by a modern system of separate and explicitly defined legislative, executive, and judicial branches; functionally organized ministries directed the work of foreign affairs, internal affairs, war, and navy. The full legal equality of all citizens in all parts of the country was proclaimed; the residents of North Brabant, Zeeland-Flanders, Limburg, and Drenthe gained the same rights as all other citizens of the republic, just as their districts, once excluded from the States-General, now participated in the national government equally with all others. The Reformed church lost its standing as the sole official, protected church, supported out of state revenues; equal status was accorded to all religious denominations, including Roman Catholics and Jews. Yet full separation of church and state was not proclaimed, and their relationship was to continue as one of the central factors in Dutch politics for more than a century. The historic privileges of class and locality were abolished; the liberty of each and all under the law and before the courts replaced the diverse "liberties" of town and province, noble and regent. Where, before, town governments had co-opted their members, deputies to the National Assembly were now elected; but the franchise was limited to property holders, and these did not choose their representatives directly but through electors named by primary assemblies. Most of these institutional changes were permanent, though the republican form of government was replaced by a kingdom in 1806 and never reestablished.

Reorganization of the provinces

While these momentous changes were being debated and adopted, the ordinary work of state and nation had to con-

tinue amid conditions of almost unprecedented difficulty. England reacted to the French occupation of the Netherlands and the flight and overthrow of the stadtholder by a declaration of war and a blockade. Dutch overseas trade and fishing, the country's most essential occupations, were brought to a near standstill, while most of the Dutch colonies were seized by the English on behalf of William V. The French, however, remained relentless in their own exploitation of the occupied "fraternal republic." The Dutch government, which took over the whole accumulated burden of national and provincial indebtedness, had also to bear the costs of the French occupying forces and to pay immense sums in tribute to the Paris government; indeed, the forced circulation of vastly inflated French assignats (paper currency) at face value was a scarcely disguised and very effective form of French taxation directly upon the Dutch people. Nor did the successive French governments—republican, consular, or imperial—grant the Dutch any greater freedom of trade with France or other countries under its control in compensation for the lost overseas business.

Shift toward agriculture

As trade declined and industry languished, the Netherlands began to change in economic character toward a primarily agricultural country. The venturesome spirit for which Dutch businessmen had been so famed a century or two before seemed to be lost, replaced by what the Dutch themselves called a "jansalie" (stick-in-the-mud) attitude; once-bustling cities dwindled to mere market towns; even Amsterdam lost much of its population. As a result, it became difficult to consolidate the new government. A multiple executive modeled on the French Directory and lacking a firm base in established political institutions and practices reflected the intrigues of individuals rather than the programs of clearly delineated parties. The victors quarreled among themselves and looked to Paris to decide among them, or at least passively accepted its dictum, given by coups d'état organized or approved by the French army command. In 1805, Napoleon gave quasi-dictatorial powers to R.J. Schimmelpenninck. Schimmelpenninck, called councillor pensionary after the fashion of the old provincial leaders, was actually an uncrowned and nearly absolute monarch (although, ultimately, power continued in Napoleon's hands); he nonetheless carried into practice many of the reforms that had been proposed but not adopted. Napoleon, however, decided the next year to incorporate the Dutch state directly into his "Grand Empire" of vassal states.

The Kingdom of Holland and the French Empire (1806–13). Renamed the Kingdom of Holland, the Netherlands received as its monarch Napoleon's younger brother Louis. The four years of his kingship were one of the strangest episodes in Dutch history. Louis Bonaparte was a stranger in the land, yet he took its interests to heart, evading his brother's commands and winning the respect, if not quite the affection, of his subjects. The reconciliation of former Orangists, republicans, and Patriots began under his rule, for, in the face of the apparent permanence of the Napoleonic empire, they entered his government and worked together. Nonetheless, the brute fact remained that, for Napoleon, Holland was the kingpin of the "continental system," which he hoped would bring England to its knees by cutting off its continental exports. French officials enforced the vigorous suppression of the smuggling of English and colonial goods to the Continent through Holland that had sprung up over the past decade with London's connivance. King Louis's resistance to his brother's efforts and his refusal to put French interests ahead of Dutch led to the emperor's decision to oust his brother from his throne in 1810 and to incorporate Holland into the French Empire.

Ouster of King Louis

Little changed, however; the same officials—some Dutch, some French—continued to do the work of government in the country, which remained outside the French tariff system. As long as the Napoleonic empire seemed firmly based and permanent, Dutchmen served the new sovereign as they had King Louis, all the more readily because the exiled prince of Orange gave permission for such collaboration. Dutch soldiers continued to fight in Napoleon's campaigns, losing heavily in the Russian invasion of 1812. But as it became increasingly obvious, after the failure of the Russian and Spanish campaigns, that the Napoleonic empire was collapsing, influential Dutchmen began to prepare for the creation of a new and independent regime; it was taken for granted that its head would be the prince of Orange—the son of William V, who had died in 1806—and that it was desirable that it be established by the Dutch people rather than imposed by the eventual allied victors. The movement for restoration was led by a remarkable figure, Gijsbert Karel van Hogendorp, a man of firm political principle who had refused to serve any of the governments that ruled in Holland after 1795, yet accepted the necessity for a reestablished prince of Orange to govern the country as a limited constitutional sovereign.

During the autumn of 1813, Hogendorp secretly planned a takeover of government from the French, which became possible without bloodshed during November as French troops withdrew to their homeland. On November 30, the hereditary stadtholder, at the invitation of Hogendorp's provisional authority, returned from England to proclaim his reign as hereditary prince. In 1814, he granted a charter establishing a constitutional monarchy, with restricted powers for a Parliament elected by a narrow property suffrage. At the insistence of the victorious powers meeting at the Congress of Vienna, he took the title of king of The Netherlands and was given sovereignty over the southern Netherlands, which included both Belgium and Luxembourg. During the campaign against Napoleon after his return from Elba in 1815, Dutch troops played a major role in his defeat at Waterloo.

THE KINGDOM OF THE NETHERLANDS (1814–1918)

King William I. The reign of King William I, as the restored prince of Orange was now called, was one of the most critical periods in the history of The Netherlands. During this quarter-century the adaptation of the country to the conditions and requirements of modernity moved in a complex and even contradictory way, guided by a monarch who in his economic policy was far more forward-looking than most of his countrymen but who in politics resisted the expansion of Parliament and the introduction of liberal principles. He was a 19th-century version of the "enlightened despot," a man intent upon power, although not so much for its own sake as in order to serve the welfare of his country as he saw it. The role of the States-General—which continued to represent a general electorate of tax-paying citizenry—was strictly limited to the enactment of laws proposed by the government and to approval of a long-term budget; it was in no sense the representative of a sovereign people. The ministers of state were the agents of the king and responsible to him, not to the States-General. Yet the basic structure of modern government had been created in The Netherlands; constitutional debate would be concerned with redistributing powers and responsibilities among existing institutions.

Role as the "enlightened despot"

William I was at his best in confronting the problem of reviving the economic life of the country after the shattering impact of the long French occupation. He put the support of both the government and his own private fortune behind encouragement of commerce and, to a lesser extent, of industry. He sponsored the formation of The Netherlands Trading Society, a nominally private firm that undertook the important but costly and risky enterprise of reorganizing Dutch long-distance trade and shipping, particularly to the Netherlands East Indies, which were returned to Dutch sovereignty by England as part of the peace settlement. With the reopening of trade between the European continent and the wider world, the advantages of the Dutch position at the mouth of the great rivers favoured the revival of the traditional branches of Dutch enterprise; but competition from the ports of other countries, notably from Hamburg and Bremen, as well as from Britain, remained strong. Only in the Netherlands East Indies did the Dutch have a clear advantage over their rivals, despite the abandonment of the monopoly formerly maintained under the East India Company.

The most difficult problem faced by the new regime in The Netherlands was the relations between Holland (which now became the everyday name for all the north-

ern Netherlands, in Dutch as well as foreign usage) and Belgium. The king was passionately devoted to the preservation of a single state encompassing all the Low Countries, a unity lost in the revolt against Spain more than two centuries before; but the sense of common nationhood, cultural and political, was quite weak among the people. The Belgians resented assuming a share of the burden of debt inherited by Holland; they were oriented toward industry, Hollanders toward trade. French was the language of the leading classes in the south, and the use of Dutch as the official language was bitterly opposed even by Flemings, who resented the Dutch version of the common Dutch-Flemish language. Most Flemings, as devout Roman Catholics, were hostile to the predominantly Protestant Hollanders. William's efforts to assume the control that Napoleon had possessed over the Belgian Catholic church met fierce resistance. At the same time the authoritarian character of William's government, particularly the sharp censorship of the press in Belgium, aroused the antipathy of liberals to the regime. The result was the outbreak of the Belgian Revolution of 1830 and the proclamation of Belgian independence. William, supported by a majority of Dutchmen, who were angered by what they saw as Belgian ingratitude, was able to defeat the hastily organized Belgian army; but the European powers intervened to secure Belgian independence, although it was not until 1839 that a final settlement was reached and the last Dutch troops withdrew from Belgian soil. William, deeply despondent, abdicated the next year, leaving to his son, King William II, the task of coming to terms with the new situation.

The Belgian Revolution of 1830

William II and William III. The new king was not a man of clear ideas or strong will, but he was able to do what his father dared not even envisage—to oversee the transformation of The Netherlands into a parliamentary, liberal state. When the crisis of the 1848 revolutions broke, first in France and then in central Europe, William II turned to the leading liberal thinker, J.R. Thorbecke, to guide the change. A new constitution was written, largely modeled on the British (and Belgian) pattern, which gave effective supremacy to the States-General and made the monarch a servant and not the master of government. The king died the next year, and the work of transformation continued under his son, William III (1849–90), who named Thorbecke prime minister. The constitutional monarchy was consolidated, even though Thorbecke stepped down in 1853 because of Protestant rioting against the reestablishment of a Roman Catholic archbishop at Utrecht. Gradually, over the next century, the scope of Dutch democracy was extended to include ever broader sections of the Dutch population in the franchise; universal male suffrage was achieved during World War I, and suffrage was extended to women after World War II. During this period, political parties of the modern type took shape, organized along religious and ideological lines; to the original Liberal, Protestant, and Catholic parties were eventually added Socialist, Conservative-Protestant, Communist, and minor parties. As no single party was able to emerge with a majority, coalition politics became inevitable. The central issue of political controversy became the "school conflict" (*schoolstrijd*), which pitted the liberal (and later socialist) advocates of public schools against the combined Protestant and Catholic parties, which demanded that the state support private ("special") schools equally with the public schools. For several decades, the liberals remained generally in control and made few concessions on the school issue. But when the Protestant leader Abraham Kuyper formed a coalition with the Catholics in 1888, the religious parties were able to gain power and to favour the special over the public schools. Their policy was assailed by the secular parties, the traditional liberals, the progressives, and the socialists. The liberals, however, were at odds with the other anticlerical parties on other issues, notably economic policies and the extension of the suffrage. The liberals tended to be the most conservative party on economic issues and favoured a restricted electorate; the progressives were vigorously democratic in outlook, as were the socialists, who also favoured universal suffrage, protection of the right to strike, labour legislation, and other welfare measures. The other major issue of the latter half of the 19th century was the role of the Dutch East Indies. The income received by the Dutch treasury from Indonesian taxes helped balance the national budget; yet the revelations of harsh conditions in the distant archipelago made it impossible to maintain the "culture system," which had been introduced to force the production of certain crops for export, while the long Achinese War drained the treasury.

Issue of the Dutch East Indies

Queen Wilhelmina and World War I. During the first half of the reign of Queen Wilhelmina (1890–1948), the political situation remained fundamentally unchanged. The major parties came to recognize that the school struggle interfered with the solution of other problems. An agreement in principle was reached on the eve of World War I, by which the secular parties accepted state support for religious schools on a basis of equal funds in exchange for enactment of universal male suffrage. When war broke out in 1914, Holland, which had declared its neutrality, put aside the proposed reforms in order to concentrate on the immediate problem of maintaining the country's livelihood in the face of blockades. The "Pacification," as the compromise was called, was adopted in 1917 and put into effect after the return of peace. The war years saw almost all political controversies set aside, while the government took unprecedented action in maintaining trade and guiding economic life. Although spared the horrors of combat, the Dutch had to maintain a large standing army, and mutinies broke out among the soldiers in 1918.

The century from the restoration of Dutch independence in 1813 until World War I saw fundamental transformations of Dutch life. The economic base was modernized; the role of agriculture fell off, with most Dutch farmers producing dairy and meat products for the market; trade and shipping were revived in the face of fiercely competitive conditions. But most important was the rise of industry—first textiles in the eastern provinces, then coal in the southeast in Limburg, and finally modern manufactures, notably the great Philips electrical products factories at Eindhoven. Rotterdam became one of the world's busiest ports and the centre of chemical and other industries. These changes were paralleled in society by the gradual extinction of pauperism, the domination of the middle-class business and professional men, and the improvement of the conditions of working people and farmers, especially after the mid-19th century.

Changes in Dutch society

Although religious freedom in the Netherlands was generally as great as anywhere in Europe, Protestant conservatives faced major difficulties, especially during the first half of the 20th century, when they protested the modernizing ideas of the Reformed (Hervormde) church; their efforts to create independent religious communities met with sharp resistance from the government, which, it should be noted, did not interfere in non-Protestant religions. Some of the Gereformeerden (the older name for "Reformed" used by the conservatives) emigrated, many of them to the United States; but, by the latter half of the century, persecution ceased.

The cultural life of Holland remained very largely confined within national boundaries; Dutch thinkers, writers, and artists responded strongly to influences from Germany, France, and England but themselves had little impact abroad. Dutch scientists maintained a respected position for their country; Hugo de Vries was one of the principal founders of the science of genetics, while the physicist Hendrik Antoon Lorentz contributed greatly to Einstein's theories of relativity. Dutch artists were generally imitative, although the Hague school of Impressionists displayed great gifts; only van Gogh, who spent most of his active life in France, achieved world reputation. Dutch literature ran parallel to main currents abroad; the Réveil early in the century was a movement of intensely religious romanticism with strongly conservative ideas, while Eduard Douwes Dekker (pseudonym Multatuli) in mid-century expressed the moods of social criticism with great power; the movement of "Men of the 'Eighties" (Tachtigers) brought to the fore an emphasis on aesthetic values and spirituality; and early in the 20th century a literature of social protest reemerged.

THE NETHERLANDS SINCE 1918

The modernization of The Netherlands accelerated after 1918. Although the country became a member of the League of Nations, it reaffirmed its neutrality, which was symbolized by the presence of the International Court of Justice at The Hague. There were troubled relations with Belgium, which not only abandoned its neutrality for a close alliance with France but demanded territorial cessions from Holland. The Dutch government successfully resisted any amputation of its territory. The Dutch, for their part, refrained from giving any official support to the Flemish nationalist movement in Belgium, although a Great Netherlands movement, principally among intellectuals, emphasized the underlying unity of the Dutch and Flemings. Domestic politics followed the same course, with the Protestant political parties continuing to back generally conservative policies, especially after the onset of the world depression in the 1930s.

Dutch resistance to Belgian demands

World War II. At the outbreak of World War II in 1939, the Dutch sedulously maintained their neutrality, although their sympathies lay overwhelmingly with the Allied powers. Nonetheless, when Nazi Germany undertook the campaign against France in the spring of 1940, its forces attacked not only Belgium in order to outflank the French defenses but also Holland. The Dutch armies were overwhelmed in less than a week, and the government, accompanied by Queen Wilhelmina and the royal family, withdrew to England and formed a government in exile.

Under German occupation, public administration remained the responsibility of the Dutch bureaucracy, which made some effort to buffer German political repression, deportation of Jews, and forced employment of Dutch labour in Germany. A resistance movement sprang up, which, with the exception of a few Dutch Nazi collaborators, spanned all groups from the conservatives to the communists. The Germans retaliated by executing Dutch hostages for such measures of resistance as the strike of Amsterdam dockworkers against the seizure and deportation of Dutch Jews to extermination camps in Germany. Some Jews were able to go into hiding with the assistance of friends, but the large majority were taken away to their death. In the final phases of the war, the Dutch faced severe food shortages, and, during the last months before liberation (May 1945), they were near famine.

The postwar period. After World War II Dutch life changed dramatically. Wilhelmina and her government returned from exile to reestablish a government more strongly democratic than ever, with both universal suffrage and proportional representation in elections. Anticipating the difficulty of postwar reconstruction, the government, industry, and labour agreed on a plan for industrial and commercial expansion that avoided a rapid expansion of prices or wages. The plan worked effectively for more than two decades, so that the Dutch were able to avoid serious inflation until the breakdown of the consensus between industry and labour in the late 1960s.

Dutch industrialization moved forward with speed and depth, expanding to include the large-scale production of steel, electronics, and petrochemicals. Holland, putting aside the policy of neutrality as a failure, entered vigorously into the postwar Western alliances, including the Benelux economic union with Belgium and Luxembourg and the North Atlantic Treaty Organization (NATO). It also was one of the founding members of the European Economic Community (1957), now part of the European Union (EU), but, as a relatively small country, it has had limited influence. In Indonesia, after wartime occupation by Japanese forces, a nationalist rebellion forced the Dutch to grant the country full independence in 1948. The Netherlands Antilles remained part of the Dutch kingdom, although no longer under the authority of the government at The Hague; Surinam became independent in 1975 and was renamed the Republic of Suriname in 1978.

Abandonment of neutrality

Dutch political alignments since the mid-20th century have evolved slowly. The first postwar governments were dominated by an alliance of the Labour and Catholic parties, which continued until the Labour Party went into opposition in 1958. From 1958 until 1973, centre-right coalitions ruled the country, and from 1973 to 1977, a left coalition controlled the government. Since the 1970s, governing coalitions have included at least two of the three main parties (Christian Democrats, Liberals, and Labour) in various combinations. During the 1990s, support for the Christian Democrats declined, and most governments were Liberal-Labour coalitions.

During the 1960s the postwar social consensus broke down, and protests by youth and labour erupted into riots, especially in Amsterdam. The royal family was the subject of controversy, particularly after the marriage in 1966 of Queen Juliana (who had succeeded Wilhelmina in 1948) to a German diplomat. The queen's husband and consort, Prince Bernhard, was involved in a bribery scandal and resigned his public offices. Juliana abdicated in 1980 and was succeeded as queen by Beatrix. Meanwhile, The Netherlands faced a series of economic recessions during the 1970s and '80s, as well as a controversy during the 1980s over the siting of U.S. nuclear missiles in the country.

By the 1970s Dutch politics, like Dutch society in general, had largely ceased to practice what was called pillarization (*verzuiling*)—the organization of political parties, schools, labour unions, businessmen's organizations, social and sport clubs, and many professional groups on the basis of membership in a religious-ideological "pillar," either Roman Catholic, Protestant, or humanist (the latter including liberals and socialists). Pillarization had received official confirmation in the Pacification of 1917 and removed most of the tinder from Dutch politics, but it also kept ordinary Dutch people socially separated to a greater degree than in most other Western countries. Some 25 years after the end of World War II, the system began to disintegrate. New political parties were formed, most importantly the Christian Democratic Appeal (CDA), inclusive of all major Christian factions. The Labour Party (Partij van de Arbeid), keeping its distance from the more extreme leftist groups, joined with the CDA in forming a coalition government in 1989. In 1990 left-wing groups formed a new party called Green-Left. (H.Ro./Ed.)

Discontinued pillarization

During the 1990s, while the economy prospered, environmental concerns increased, not only because of the country's vulnerability to rising sea levels, river flooding, and the effects of pollution but also because Dutch industry and agriculture are themselves major sources of pollution.

By the turn of the 21st century, The Netherlands had developed a reputation for liberal policies, such as toleration of prostitution and of the limited use and sale of marijuana and hashish. Same-sex marriages and euthanasia were legalized, and penal sentences were relatively light. However, The Netherlands also was one of the most heavily planned and regulated Western societies: the state had a role in most matters, despite attempts to reduce its intervention in the 1980s and '90s. In general, the Dutch tradition of tolerance extended to its immigrant population, but anti-immigrant politician Pim Fortuyn was able to tap into increasing Dutch uneasiness in 2002. Just nine days before that year's election, Fortuyn was assassinated—the country's first modern political killing. Nevertheless, his party gained enough support to become part of a centre-right governing coalition. Because of disputes within Fortuyn's party, however, the government resigned after only three months in office. (M.J.W./Ed.)

For later developments in the history of The Netherlands, see the BRITANNICA BOOK OF THE YEAR.

For coverage of related topics in the *Macropædia* and *Micropædia,* see the *Propædia,* sections 921, 923, 961, 963, 969, and 972, and the *Index.*

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(M.W.H./H.Me./L.P.L.K./W.B./H.Ro.)

New Orleans

Unquestionably one of the most distinctive cities of the New World, New Orleans was established at great cost in an environment of conflict. Its strategic position, commanding the mouth of the great Mississippi–Missouri river system, which drains the rich interior of North America, made it a pawn in the struggles of Europeans for the control of North America. As a result, the peoples of New Orleans evolved a unique culture and society, while at the same time blending many heritages. Its citizens of African descent have provided a special contribution in making New Orleans the birthplace of jazz. New Orleans is a city of paradox and contrast: while it shares the urban problems afflicting other U.S. cities, it has nevertheless preserved the exuberant and uninhibited spirit exemplified by its carnival season, which culminates in the famous annual Mardi Gras, when more than 1,000,000 people throng the streets. The city also has a solid economic base: it is the largest city in Louisiana, the second port of the United States in tonnage handled, a major tourist resort, and a medical, industrial, and educational centre.

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Physical and human geography

THE LANDSCAPE

The city layout. The city of New Orleans and Orleans Parish (county) are coextensive, covering an area of 199 square miles (518 square kilometres). The boundaries are formed by the Mississippi River and Jefferson Parish to the west and Lake Pontchartrain to the north. Lake Pontchartrain is connected by the Rigolets Channel to Lake Borgne on the east, and the southern boundary of New Orleans is made up of St. Bernard Parish and, again, the Mississippi River. The city is divided by the Mississippi, with the principal settlement on the east bank. The west bank, known as Algiers, has grown rapidly. It is connected to eastern New Orleans by the Greater New Orleans Bridge. The bridge, completed in 1958, proved to be a bottleneck to the city's traffic; a second, adjacent bridge designed to alleviate the problem was completed in September 1988.

The early city was located on the east bank along a sharp bend in the Mississippi, from which its popular name, "Crescent City," is derived. The modern metropolis has spread far beyond this original location. Because its saucer-shaped terrain lies as low as five feet (1.5 metres) below sea level and has an average rainfall of 57 inches (1,425 millimetres), a levee, or embankment, system and proper drainage have always been of prime importance to the city.

Climate. New Orleans has a moderate climate; the average daily temperature from October through March is 60° F (16° C), and from April through September the daily average is 77° F (25° C). Freezing weather is rare, and the temperature rises above 95° F (35° C) only about six days a year.

THE PEOPLE

The population of New Orleans has been declining. Whites account for less than half of the total, whereas in 1960 they made up almost two-thirds. In contrast to the population decline in Orleans Parish, the adjacent parishes of St. Bernard, Jefferson, and St. Tammany—which, together with Orleans, compose one of the national Standard Metropolitan Statistical Areas (SMSA)—have shown steady increases. Since the black population in these three parishes is quite small, these figures indicate a white move to the suburbs, a trend common to major U.S. cities.

The shift in population to the suburbs has been motivated less by racial tension (although this may play a part) than by desires for better and more modern living facilities. The fact that a large segment of the black population resides in declining neighbourhoods (some segregated, some integrated) has spurred both black and interracial political, social, and religious organizations to work either independently or with city and federal agencies on projects to improve the quality of life for low-income citizens. The additional fact that New Orleans has an upper-class and a middle-class black population has been a significant factor in such projects.

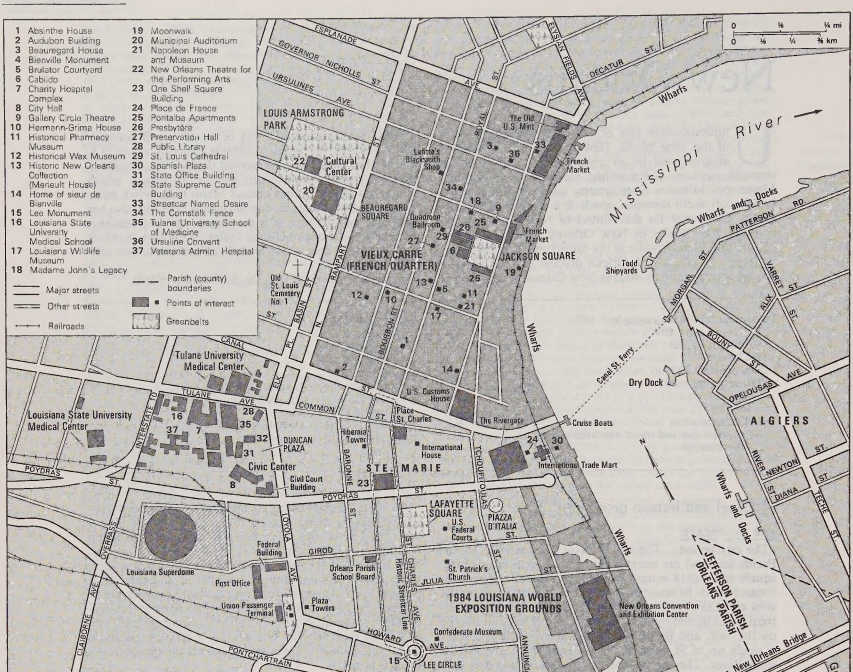
THE ECONOMY

The port. New Orleans has always been primarily a commercial centre, with manufacturing playing a secondary role in its economic life. The busy harbour, besides adding to the city's cosmopolitan atmosphere, is the foundation of the metropolitan economy, influencing many aspects of urban life.

The era of the modern Port of New Orleans began in 1879 with the construction of jetties in South Pass, one of three passes that flow from the river into the Gulf. Sandbars had formed at intervals in these passes and had hindered ships entering the river since the city's founding. The jetties narrowed South Pass, forcing the river to cut a deeper channel to a depth of 30 feet. Later, a second channel, Southwest Pass, was deepened to 40 feet by installing jetties; it is now the main pass used by seagoing vessels entering and leaving the river. The distance from New Orleans to the Gulf is about 110 miles (180 kilometres).

Another major step forward for the port was taken in 1896, when the state legislature removed wharf facilities from the control of private contractors and created the Board of Commissioners of the Port of New Orleans (the Dock Board), a body charged with administering the public wharves. In 1908 the Dock Board was authorized to issue negotiable bonds for the improvement of port facilities. The projects subsequently accomplished included the rebuilding and expansion of public wharves and the construction (in partnership with the Board of Levee Commissioners of the Orleans Levee District) of the five-and-a-half-mile Industrial Canal, which links the river to Lake Pontchartrain, the Intracoastal Waterway, and the Mississippi River–Gulf Outlet. In 1963 the Mississippi River–

Legislative control of the port



Central New Orleans.

Gulf Outlet, a ship channel shortening the passage to the Gulf by 40 miles, was opened to maritime traffic.

The Dock Board has formulated a plan called Centroport U.S.A., by which much of the port's activities will be switched from the Mississippi River to wharves and industrial complexes along the Gulf Outlet. The river frontage thus retired from maritime use will be diverted to such projects as high-rise apartments and public recreation areas. The Julia, Erato, and upper Poydras wharves were developed as the site of the 1984 Louisiana World Exposition. Permanent structures enhancing this area are the New Orleans Convention and Exhibition Center and the International Pavilion.

New Orleans is a major grain port both in the United States and worldwide; other exports include raw and processed agricultural products, fabricated metals, chemicals, textiles, oils, petroleum and petroleum products, tobacco, and paperboard. There has been substantial growth in bulk exports since the early 1980s, which has made New Orleans the lighter aboard ship (LASH) cargo and Seabee barge capital of the world. Grain, coal, and animal feed make up a major portion of LASH and Seabee trade. In international commerce about 5,000 oceangoing vessels dock at New Orleans annually, and more than 40 nations have consular offices in the city.

Industry. Greater New Orleans is a major industrial area. A concentration of petrochemical plants has sprung up along the Mississippi River above New Orleans. The National Aeronautics and Space Administration established the Michoud Assembly Facility in New Orleans in 1961 to produce the giant Saturn rocket boosters used in flights to the Moon. The major goods manufactured in the Greater New Orleans area are food products, clothing and related items, stone, clay and glass articles, primary metal and fabricated metal items, and transportation equipment. Tourism is a major industry.

Petrochemical industries along the Mississippi above New Orleans and offshore oil rigs in the Gulf have become serious polluters, however, through oil-rig fires and oil slicks and discharges of mercury, arsenic, and lead, threatening the city's drinking water, ruining the taste of river fish, and endangering the ecology of the Gulf. Despite federal actions against the offending industries, much remains to be done.

Transportation. The transportation facilities of New Orleans include three airports: New Orleans International Airport, to the west of the city; New Orleans Airport, on Lake Pontchartrain, devoted to private and corporate use; and the U.S. Naval Air Station, serving air reserve units of the various armed services. Several railroads operate out of New Orleans, and passenger bus, truck, and barge lines transport people and cargo to and from the city. Regular express sailings by steamship lines also offer passenger- and cargo-carrying service. The major access bridges serving

the Greater New Orleans area, in addition to the Greater New Orleans Bridge (also known as the Crescent City Connection), are the Huey P. Long Bridge, which crosses the river above the city, and the Lake Pontchartrain Causeway, a twin span that is among the world's longest bridges, stretching more than 23 miles.

ADMINISTRATIVE AND SOCIAL CONDITIONS

Government. Both the political life and the municipal government of New Orleans have been dominated by factions of the Democratic Party. The question of state interference in city affairs versus home rule is one of the major issues. In 1954 New Orleans finally received a strong home rule charter, which substituted a mayor–council form of government for the mayor–commission form that had existed since 1912.

Municipal management

In addition to the mayor and seven council members—five elected from districts and two at large—who serve four-year terms, the position of chief administrative officer to the mayor was created. The mayor is the top administrator over the 14 municipal departments and oversees the affairs of various commissions and boards. The chief administrative officer, appointed by the mayor, is charged with supervision of city departments, the preparation of the annual budgets, and the coordination of city relations with state and federal agencies. The council is strictly a legislative body.

Political issues have changed. Gone is the antagonism between city and state governments that spanned the era from governors Huey Long in the 1920s through Earl Long in the 1940s. Political corruption is no longer an issue in city politics, and blacks have become more politically articulate since they emerged as the majority of the city's population. There has been an increase in voter registration among blacks, and black political groups now play an effective role in municipal politics. The city's first African-American mayor, Ernest N. Morial, was elected in 1978 and reelected in 1982. His son, Marc H. Morial, was elected mayor in 1994 and 1998.

Although most city and parish government has been consolidated in New Orleans, Orleans Parish officials continue to play an important role. These officials include the district attorney, the board of assessors, and the Orleans Parish School Board, which supervises public education under the state department of education.

Municipal services. Expansion of new residential areas in New Orleans, combined with the spiraling cost of services, has caused the operating budget for municipal services to rise considerably. The municipal government has been hampered by a lack of funds necessary to carry out its work effectively and to provide an appropriate income for the employees of its various departments. One of the major problems is the low assessment of taxes on both residential and industrial property and the loss of taxpayers to the suburban parishes.

Drainage has always been the main problem among municipal services. The city is virtually surrounded by levees—25 feet high on the Mississippi River and nearly 20 feet high on Lake Pontchartrain—and has some two dozen major drainage pumping stations. The drainage machinery used at these stations is among the largest found in the world. Following the disaster of 1965, when Hurricane Betsy flooded the city's lower Ninth Ward, the Sewerage and Water Board operating the pumping stations drafted a plan to make these facilities hurricane-safe. Further improvements in drainage canals and pumping equipment in the older sections of the city were also made.

Drainage and flood-control systems

Flood control along the river, Lake Pontchartrain, and secondary waterways in the city is under the direction of the Board of Commissioners of the Orleans Levee District. In addition to its primary job of flood control, the board has, since the 1920s, reclaimed hundreds of acres of Lake Pontchartrain bottomland and developed it into one of the most scenic lakefront areas in the United States. A majority of the land is dedicated to public facilities, which include sandy beaches, a marina, a cement seawall from which fishing can be enjoyed, picnic grounds, parkways with flower beds, fountains, and shelter houses. The remainder of this reclaimed land has been turned into residential subdivisions, which are among the finest in the city.

In the fight against the steadily rising crime rate in the city, the police department has, since 1961, introduced a guard-dog corps, reorganized its patrol system to increase its effectiveness, created additional police districts, built new stations in older districts, more than doubled its automotive equipment, established a community relations division, and put into operation a communication van, which acts as a field command post in times of emergency.

Police and crime

Police programs designed to mobilize citizen groups have been greatly increased to include the Neighborhood Watch Programs and the New Orleans Neighborhood Police Anti-Crime Council. A police psychologist has been added to the force, and the narcotics squad has been increased.

Health. New Orleans has become a medical and educational centre. The Medical Center of Louisiana is the teaching hospital for two adjacent institutions, the Tulane and the Louisiana State University medical schools, with which the nearby Veterans Administration Hospital is also affiliated. In addition to serving local residents, specialists frequently treat patients from Latin America.

Education. Among New Orleans' institutions of higher learning are Tulane University, Loyola University New Orleans, the University of New Orleans, Delgado Community College, Our Lady of Holy Cross College, Dillard University, Xavier University of Louisiana, and Southern University at New Orleans. The city has many private, parochial, and business schools. The public school system began in 1841 with 83 pupils and four teachers and now has some 1,000 times as many students and teachers. In 1960 a public school crisis, attracting international attention, developed when an attempt was made at the token integration of two white schools. Within 20 years the school system was overwhelmingly black, both students and teachers.

CULTURAL LIFE

The cultural life of New Orleans is a synthesis of contributions by both whites and blacks. The white American heritage is reflected in the business and commercial life of the city, while the immigrant heritage—Irish societies, German Oktoberfest, Italian St. Joseph's Day altars—adds ethnic colour to urban conformity. The black heritage is particularly rich. In antebellum days, free persons of colour were musicians, poets, journalists, business entrepreneurs, and landlords. Both black freemen and slaves were renowned for their craftsmanship in such trades as bricklaying, iron grillwork, and carpentry. The contribution of black musicians to the birth of jazz out of black blues and "field hollers" and white dance tunes and hymns is well known.

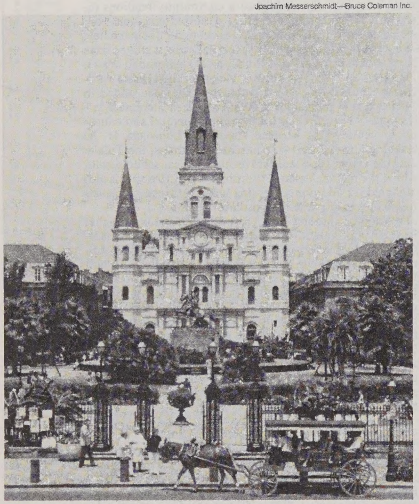
Facilities for recreation and relaxation in New Orleans are justly famous. New Orleans is often referred to as "the city that care forgot," and it has always been a town for those seeking a good time. Its residents love music, dancing, and a "Continental Sunday" spent in amusements. The three factors that have contributed to its popularity with tourists are the Old World charm of the Spanish–French architecture in its Vieux Carré (French: Old Square), the reckless abandon of its carnival and Mardi Gras, and its reputation as the birthplace, between the 1880s and World War I, of jazz.

The Vieux Carré, or French Quarter, is a sightseer's delight. Its Creole architecture, creating the atmosphere of a foreign city, combines native architectural ingenuity with adaptations of French colonial traditions of eastern Canada and West Indian Spanish colonial styles. Typical are one-story cottages opening directly on the sidewalks, with high-pitched roofs and windows reaching to the ground. Another style is the L-shaped two-story dwelling with a side entrance to an inner patio. Also built to the sidewalk, it has a roof that extends out over balconies on both the street and patio sides. Iron grillwork, designs for which were created locally and executed to a high perfection by slave craftsmen, decorates these balconies and also supports the roof. Such houses are built side by side with no openings between them, but the patios offer space for trees, flowers, and fountains and ensure privacy for the occupants.

The Vieux Carré: Creole architecture and ironwork

Central to the Vieux Carré is Jackson Square, facing the Cabildo and the Presbytère (former governmental centres, but now part of the Louisiana State Museum) and St. Louis Cathedral. All date from colonial times, but considerable stylistic changes have been made on these buildings since they were erected.

Joachim Messerschmidt—Bruce Coleman Inc.



St. Louis Cathedral in the Vieux Carré (French Quarter), in New Orleans.

On either side of this square are the Pontalba Buildings, apartments built in 1849–50, while nearby is the historic French Market. Curio and antique collectors throng the many shops on Royal Street. Side streets are lined with art galleries, perfume shops, sidewalk cafés, and tearooms. Bourbon Street is famous for its nightclubs, where a variety of music and risqué floor shows are a specialty. Devotees of jazz may visit Preservation Hall, where revivals of traditional styles may be heard. The New Orleans Jazz Club established a Jazz Museum and later donated the collection to the Louisiana State Museum system. The jazz collection is displayed in the Old U.S. Mint. Each spring the city puts on the New Orleans Jazz and Heritage Festival.

Every year during Spring Fiesta there are tours of private homes and patios in the Vieux Carré and also of the spacious Garden District uptown, the elite 19th-century neighbourhood. Boats tour the extensive harbour facilities and the magnificent scenery of nearby waterways. The observation point on the 31st floor of the World Trade Center at the foot of Canal Street offers a panoramic view of the river and city. The world-renowned Creole and spicy Cajun cuisine may be sampled in numerous restaurants, ranging from elegant dining rooms with French menus and waiters, to small cafés with checkered tablecloths, serving red beans and rice and crawfish, a local specialty.

The sporting life and the lively arts

Sports share an honoured position with jazz and carnival activities in New Orleans. The city is the home of the New Orleans Saints, a member of the National Football League, and the site of the Louisiana Superdome, one of the world's largest sports arenas. Horse racing is held at the local Fair Grounds Race Course. Boating and fishing are popular pastimes on the city's many waterways. The city's Southern Yacht Club, on Lake Pontchartrain, is the second oldest in the country. In addition to the lakefront, popular recreation areas include the city's two largest parks, City and Audubon, the latter of which has one of the nation's best zoos. The New Orleans Recreation Department operates more than 100 playgrounds and directs organized recreation activities for thousands of youngsters. In early January the Sugar Bowl football game between outstanding college teams is held at the Superdome; in conjunction with the game are competitions in other major sports.

Since World War II, New Orleans has become an art centre, with many artists and galleries offering original works to collectors. The New Orleans Museum of Art is a public museum displaying many treasures. Live theatre is represented by several community theatre groups. Musical events include operas staged annually by the New Orleans Opera Association, concerts given by the Louisiana Philharmonic Orchestra, performances by the New Orleans Ballet Association, and concerts presented by the New Orleans Jazz Club. Other attractions include the Aquarium of the Americas, one of the top aquariums in the country; the Historic Voodoo Museum; and the Contemporary Arts Center. Tours of the city's unique above-ground cemeteries are also popular.

Mardi Gras

The New Orleans carnival season begins January 6 and culminates in Mardi Gras, the "Fat Tuesday" before Ash Wednesday. The two weeks before Mardi Gras are filled with parades, both day and night, climaxing on Mardi Gras with the Rex parade. The first parading carnival group (called a "krewe") was the Mystick Krewe of Comus, which appeared in 1857, though celebrations by masked participants date back to the 1820s. The krewe of Rex came into existence in 1872. In 1992 the city council began requiring all krewes to be racially integrated; as a result, several krewes stopped parading and held only private balls. The Presbytère has an exhibit devoted to Mardi Gras.

In the latter half of the 19th century there were about a half-dozen leading newspapers, including one in French. Through a process of gradual consolidation, New Orleans now has only one major daily, the *Times-Picayune.* The city also has weekly newspapers, trade publications, college journals, and regional magazines of considerable circulation. Competitive journalism is kept alive among the city's television and radio stations.

History

FOUNDATION AND EARLY SETTLEMENT

The decision to found New Orleans, or Nouvelle-Orléans, was made in Paris in 1717 by John Law's Company of the West, which had taken control of Louisiana that year. The colony's new proprietors envisioned New Orleans (named for the French regent, the duc d'Orléans) as a "port of deposit," or transshipment centre, for future trade from upriver in the Mississippi Valley. Jean-Baptiste le Moyne, sieur de Bienville, the man who suggested the site, was entrusted with the actual foundation of the city. Clearing of underbrush for the new city probably began in March 1718. The engineers charged with this task met with problems arising from uncooperative convict labour, a shortage of supplies, two severe hurricanes (in 1721 and 1722), and the unpleasant physical conditions of mosquito-infested swamps as they set up the first crude dwellings covered with bark and reeds. An engineer, Adrien de Pauger, drafted the first plan for the town, encompassing what is now the Vieux Carré and consisting of 66 squares forming a parallelogram.

Hostility of the environment

The first residents were a colourful mixture of Canadian backwoodsmen, company craftsmen and troops, convicts, slaves, prostitutes, and indigents. In a census taken in November 1721, New Orleans had a population of 470 people: 277 whites and 172 black and 21 Indian slaves. In 1722 New Orleans was designated the capital of Louisiana, and in 1731 the city returned to the control of the French crown. More respectable colonists began to arrive, but growth continued to be precarious. The main economic staples grown in the vicinity of New Orleans were tobacco and indigo for export and rice and vegetables for local consumption. Naval stores were also exported. French ships, however, were reluctant to call at New Orleans to pick up such cargo because its value did not match its bulk.

In 1762 France, ready to part with its unprofitable port, secretly agreed to cede Louisiana to Spain, and by the Treaty of Paris (1763) Spain received New Orleans and the Louisiana Territory west of the Mississippi. After a brief rebellion—which was sternly suppressed—the inhabitants of New Orleans enjoyed peace and a growing prosperity under Spanish law, while trade arose with the British colonies in spite of Spanish restrictions. At the same time English-speaking colonists were moving west to settle along the tributaries of the Mississippi. In the decade of the American Revolution, these "Kaintucks," as they were called, began floating their cargoes downriver to New Orleans; several times Spanish officials suspended the right of deposit of American goods at New Orleans in response to the boisterous conduct of American frontiersmen along the city's upper levee.

In 1800 Louisiana was secretly returned to Napoleon's France, and by 1803 the French emperor had negotiated its sale to the United States. The ceremonies transferring Louisiana to France and later to the United States took place in New Orleans' Cabildo and main square, the Place d'Armes (now Jackson Square), in the winter of 1803.

The Louisiana Purchase

THE GROWTH OF THE CITY

The early 19th century. New Orleans' population in 1803 was approximately 8,000, consisting of 4,000 whites and 2,700 enslaved and about 1,300 free persons of colour. Its prosperity was reflected in its 1803 exports, which had a value approaching $2,000,000 and were bound mainly for American ports. In 1805, when it was incorporated as a municipality, New Orleans took on an identity separate from that of Louisiana's territorial government. As the city expanded out of its original limits, one of the first new tracts of land to be added was the Faubourg Ste. Marie, a suburb lying on the uptown side of the Vieux Carré and separated from it by a broad "commons" (now Canal Street, New Orleans' main street). It became the "American section" in the early 19th century and the hub of most business activities. Other *faubourgs* (outskirts, or suburbs) were laid out above and below the two nuclear settlements and across the river and were finally absorbed into the city by the 1870s.

During the War of 1812, New Orleans was threatened by a British invasion force, which approached the city from the Gulf of Mexico. Gen. Andrew Jackson, with an army of frontiersmen and local volunteers, won a smashing victory on January 8, 1815, saving the city, though, unknown to him, the war already had been concluded.

The era of cotton

The next 40 years constituted the golden age of New Orleans as a great cotton port. The first steamboat to reach the city, in 1812, was appropriately called the *New Orleans.* Mississippi River steamboats increased to 400 by 1840, and local commerce skyrocketed in value, reaching $54,000,000 by 1835. By 1840 the city was rated the fourth port in the world; after the 1840s canals and railroads diverted produce eastward to New York City.

German and Irish immigrants arrived in New Orleans in large numbers in the 1840s. By 1850 the city's total population had swelled to 116,375. New Orleans, however, had not learned to cope with the health hazards of its mushrooming growth: drinking water came from the river or cisterns; no sewerage system existed; drainage was deficient; and flooding was common after heavy rains. The results were sporadic outbreaks of cholera and yellow fever, the worst of which was the yellow fever epidemic of 1853, accounting for more than 8,000 deaths.

The Civil War and its aftermath. During the American Civil War, the strategic location of the city was inadequately appreciated by the Confederate military. The Union fleet of Adm. David Farragut was able to capture New Orleans in April 1862. The city was placed under the military command of Gen. Benjamin Butler, and city officials were removed from office. Although Butler was replaced as commander by Nathaniel Banks by the end of 1862, his brief régime became infamous in local history for his roughshod handling of the population.

During the period of Reconstruction, 1865–77, racial tensions ran high. "Scalawags" (white Southerners who cooperated with Republican forces) and "carpetbaggers" (Northerners accused of exploiting the situation for personal gain) cooperated to gain political control of the city and state, with the support of black voters. By 1872 amnesty had been granted to the ex-Confederates, and the municipal government returned to traditional white control, although the state government and the city police force remained under Radical Republican control until 1877.

In the 1880s the debt of $24,000,000, incurred under carpetbag regimes, increased steadily with each subsequent administration. This municipal debt had to be paid before the city could undertake any new bond issues for sorely needed municipal improvements. In the last 20 years of the 19th century, therefore, New Orleans made limited, though steady, progress. Between 1840 and 1900, it had dropped from third to 12th place in national rank, although its population had increased to 287,104.

Yellow fever was sharply curtailed after the Civil War and was finally eradicated by 1906. By the early 20th century the river steamboats, unable to compete with railroads, disappeared; the Port of New Orleans, attracting less railroad freight than Eastern ports, reached a low ebb shortly before World War I. With the development of towboats and barges large enough to hold almost an entire trainload of cargo, however, the port grew to be second in the nation after World War II. Substantial progress, at least in physical improvements, came to the city in the 1950s. During the administration of Mayor DeLesseps S. Morrison a vast railroad consolidation program was achieved, and a $15,000,000 railroad terminal constructed. Streets were widened, railroad ground crossings were spanned with overpasses, and a $20,000,000 civic centre, which includes the 11-story City Hall, was built.

20th-century growth

Also in the 1950s petrochemical industries began locating in New Orleans, followed by oil refineries in the 1970s. The 1984 Louisiana World Exposition revitalized the warehouse district but was a financial disaster. In the mid-1980s the local oil industry went bust, and the city's fortunes began to decline. Movement of middle-class citizens to the suburbs, which had begun in the '60s, continued in earnest. A high crime and murder rate and police corruption characterized the city into the mid-1990s; subsequently, however, the situation improved considerably, buoyed by a strong tourism-based economy.

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(J.J.J.)

New York City

New York City is the largest, most influential, and most international metropolis in the United States. Located in southeastern New York state where the Hudson and East rivers empty into one of the world's premier harbours, New York City is both the gateway to North America and its preferred exit to the oceans of the globe. With an area of 309 square miles (800 square kilometres), it encompasses Manhattan and Staten islands, the western sections of Long Island, and a small portion of the New York state mainland to the north of Manhattan. New York City is in reality a collection of many neighbourhoods scattered among the city's five boroughs—Manhattan, Brooklyn, the Bronx, Queens, and Staten Island—each exhibiting its own lifestyle. Moving from one city neighbourhood to the next may be like passing from one country to another. The urban area extends into adjoining parts of New York, New Jersey, and Connecticut.

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Physical and human geography

CHARACTER OF THE CITY

New York is the most ethnically diverse, religiously varied, commercially driven, famously congested, and, in the eyes of many, the most attractive urban centre in the country. No other city has contributed more images to the collective consciousness of Americans: Wall Street means finance, Broadway is synonymous with theatre, Fifth Avenue is automatically paired with shopping, Madison Avenue means the advertising industry, Greenwich Village connotes bohemian lifestyles, Seventh Avenue signifies fashion, Tammany Hall defines machine politics, and Harlem evokes images of the Jazz Age, African American aspirations, and slums. The word *tenement* brings to mind both the miseries of urban life and the upward mobility of striving immigrant masses. New York has more Jews than Tel Aviv, more Irish than Dublin, more Italians than Naples, and more Puerto Ricans than San Juan. Its symbol is the Statue of Liberty, but the metropolis is itself an icon, the arena in which Emma Lazarus's "tempest-tost" people of every nation are transformed into Americans—and if they remain in the city, they become New Yorkers.

Immigrant groups

For the past two centuries, New York has been the largest and wealthiest American city. More than half the people and goods that ever entered the United States came through its port, and that stream of commerce has made change a constant presence in city life. New York always meant possibility, for it was an urban centre on its way to something better, a metropolis too busy to be solicitous of those who stood in the way of progress. New York—while the most American of all the country's cities—thus also achieved a reputation as both foreign and fearsome, a place where turmoil, arrogance, incivility, and cruelty tested the stamina of everyone who entered it. The city was inhabited by strangers, but they were, as James Fenimore Cooper explained, "essentially national in interest, position, pursuits. No one thinks of the place as belonging to a particular state but to the United States." Once the capital of both its state and the country, New York surpassed such status to become a world city in both commerce and outlook. It also became a target for terrorism—most notably the destruction in 2001 of the World Trade Center, which for three decades had been the most prominent symbol of the city's global prowess. However, New York remains for its residents a conglomeration of local neighbourhoods which provide them with familiar cuisines, languages, and experiences.

THE LANDSCAPE

Geology

The city site. Sections of the granite bedrock of New York date to about 100 million years ago, but the topography of the present city is largely the product of the glacial recession that marked the end of the Wisconsin Glacial Stage about 10,000 years ago. Great erratic boulders in Manhattan's Central Park, deep kettle depressions in Brooklyn and Queens, and the glacial moraine that remains in parts of the metropolitan area provide silent testimony to the enormous power of the ice. Glacial retreat also carved out the waterways around the city. The Hudson and East rivers, Spuyten Duyvil Creek, and Arthur Kill are, in reality, estuaries of the Atlantic Ocean, and the Hudson is tidal as far north as Troy. The approximately 600 miles (1,000 kilometres) of New York shoreline are locked in constant combat with the ocean, as it erodes the land and adds new sediments elsewhere. Although the harbour is constantly dredged, ship channels are continually filled with river silt and are too shallow for more modern deep-sea vessels.

South of the rockbound terrain of Manhattan stretches a sheltered, deepwater anchorage offering easy access to the Atlantic Ocean. In 1524 the Italian navigator Giovanni da Verrazzano was the first European to enter the harbour, which he named Santa Margarita. Verrazzano's daring expedition was commemorated in 1964, when what was then the world's longest suspension bridge was dedicated to span the Narrows at the entrance to Upper New York Bay.

Only the third largest American port at the time of the U.S. War of Independence, New York gradually achieved trade domination and by the mid-1800s handled more than half of the country's oceangoing travelers and commercial trade. After 1900 New York was the world's busiest port, a distinction it held until the 1950s. Cargo containerization, the obsolescence of its waterfront piers, and soaring labour costs shifted business to the New Jersey side of the river after the 1960s, but at the end of the 20th century the Port Authority of New York and New Jersey still dominated the water trade of the northeastern United States.



Brooklyn Bridge, one of the icons of New York City, with the Lower Manhattan skyline (background) as it existed prior to the destruction of the World Trade Center in 2001.
© Joseph Sohm; ChromoSohm, Inc./Corbis

Climate and plant and animal life. The average temperature in January is about 31° F (0° C) and in June about 72° F (22° C), but recorded temperature extremes range from −15° to 106° F (−26° to 41° C). Because of New York's moderate climate, the harbour rarely freezes. The annual precipitation is 44 inches (1,120 millimetres).

The city's flora and fauna are testimony to the rapid changes in the ecosystem imposed by urban settlement. In areas that once were hunting and fishing paradises for several bands of Native Americans, the most prevalent animals today are the cockroach and the Norway rat, both introduced to the city via trade with Europe. A wide variety of animal species are still found within the city, including 80 species of fish, scores of birds from the peregrine falcon to the pigeon, and such mammals as the raccoon and the occasional coyote. Wildlife refuges at Jamaica Bay and in Clove Lakes (Staten Island) and Alley Pond (Queens) parks provide sanctuaries for many species, allowing them to survive even within an unfavourable city environment. Vegetation has enough precipitation but has been reduced and destroyed with the advance of urban sprawl. The main characteristics of contemporary city plants are their ability to thrive despite acid rain and air that contains large components of ozone, vehicle emissions, and industrial by-products. However, the city's two botanical gardens, one in the Bronx and the other in Brooklyn, are highly regarded throughout the country, and zoos in every borough enchant visitors of all ages.

Skyscrapers

The city layout. The city's ancient bedrock provides the immovable foundation for hundreds of modern skyscrapers. New York has more of these awesome structures than any other world city. Architects may argue about the origin of the modern skyscraper, but most agree that Manhattan was where structures with steel skeletons were combined with the elevator to create a genre of buildings where great height could be reached practicably.

The earliest pathways for moving around Manhattan Island followed animal and Native American trails across difficult terrain; Broadway still follows one of these routes, which extended northward through the island. City planning was foreign to burghers in the 17th century, and roads were haphazardly authorized; only a few important ones to outlying agricultural communities were maintained, and it was not until 1798 that the city appointed a commissioner of streets. Colonial nonchalance is still visible in the meandering streets of Lower Manhattan. The optimistic spirit of the town is apparent in the street plan adopted in 1811, a grid of blocks, avenues, streets, and lots extending to the northern reaches of the island. City Hall, located now as then in Manhattan, was at that time so far removed from the centre of activity that its northern facade was left unfinished, since few could imagine it would ever be seen. Although often modified in specific cases, the rectilinear patterns imposed upon Manhattan in its infancy have determined its developmental patterns, and other boroughs adopted the system after the creation of Greater New York in 1898. The building of Central Park interrupted the grid, and road construction there pioneered concepts of limited-access and transverse-running roadways. In the 20th century, parkways were incorporated into the traffic patterns of all boroughs, as Eastern and Ocean parkways in Brooklyn, Riverside Drive (Manhattan), the Grand Concourse (the Bronx), and Queens Boulevard attest. Regardless of all its efforts, the modern city is infamous for the volume of traffic that clogs its well-laid-out street system.

The boroughs. The administrative structure of New York was shaped by the consolidation of the greater city in January 1898. Following the 19th-century pattern of urban imperialism, and spurred by the challenge that Chicago posed to its primacy, modern New York was formed when the independent city of Brooklyn, the portion of Westchester county called the Bronx, Staten Island, and large parts of Queens county were added to Manhattan following a referendum. Although the population of the city expanded from about 2 million to 3.4 million, much of the new territory was still rural, and only two-fifths of all roads in the expanded city were paved. The five boroughs, which were all soon designated counties of New York state, became the basic municipal administrative units. The office of borough president was created, its duties from 1901 to 1990 including service on the Board of Estimate, a central financial agency. Borough presidents now also serve as conduits of neighbourhood concern to the mayor, the city's chief administrator, and are responsible for appointing members of community boards, the City Planning Commission, and the Board of Education. These officials carry much of the burden in the continuous battle between strong mayors seeking central authority and local leaders aspiring to independent action.



New York City metropolitan area.

The subway system

In the early 20th century, when the population of Greater New York more than doubled, a major concern of city administrators was interlacing communication and transportation systems to create coherence within the metropolitan area. The first segment of the subway system opened in 1904, and soon all the boroughs were linked except Staten Island; the world's most extensive subway system soon became the best way to move about the metropolis. An ever-growing number of bridges, tunnels, and highways, designed to facilitate commerce, now take, along with the subways, hordes of commuters into Manhattan in the morning and return them home at night. Hundreds of thousands of "outer borough" residents and suburbanites work in and travel to Manhattan every day, in one of the great marvels of urban planning. Except for Staten Island, each of the boroughs considered independently would rank among the largest cities in the United States. Borough legislators constantly complain that their concerns are ignored, and many believe that local interests are usually sacrificed for the welfare of New York county (Manhattan). This perception led Staten Island to contemplate seceding from New York City and becoming an independent city in the 1990s.

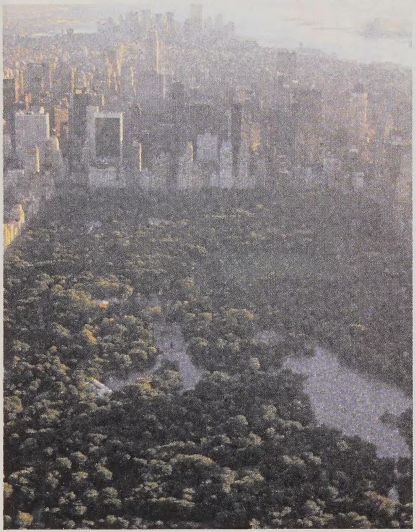
Manhattan. More than 30 million tourists visit New York annually, but most of these rarely see much beyond the 22.6 square miles of Manhattan island, the smallest city borough. Divided by 12 north-south avenues and crossed by 220 east-west streets, Manhattan is the original New York, boasts the world's largest collection of skyscrapers, and is overloaded with cultural institutions and places of enduring interest. Even to residents of the other boroughs, Manhattan is "the city," the administrative, business, and financial centre of the metropolis and the basis of their renown. In no other part of New York are there such stark contrasts between rich and poor. The high-rise elegance of Park Avenue and the Upper East Side



Central New York City.

rapidly gives way to the teeming streets of Harlem to the north and to the crowded bohemian existence of the Lower East Side and Greenwich Village to the south. This cruel modern dichotomy echoes the 19th-century city, where industrial millionaires lived in luxury in Fifth Avenue mansions (now largely converted into cultural centres) far from the immigrant masses on the Lower East Side.

Kent Knudson—Stock, Boston/PictureQuest



Central Park, New York City, looking southward toward midtown Manhattan.

Neighbourhoods

Within this formidable historical imbalance, Manhattan is really composed of neighbourhoods that offer peaceful havens to contented residents. Many areas of the island are world famous, among them such ethnic enclaves as Chinatown, Yorkville, Little Italy, and Spanish and Black Harlem. In the streets snaking north from the ancient Dutch Battery, twisting lanes remind walkers that Manhattan was a trade centre before Boston, Philadelphia, or Williamsburg existed. Wall Street, the financial centre of the globe, was originally a Dutch fortification (1653) against feared British or Native American attacks that never came. The jumble of pre-Revolutionary streets continues up to Houston Street, where the grid pattern becomes dominant and continues up the island. Soho (short for "south of Houston") covers much of the old immigrant East Side and now has been matched by a Noho neighbourhood. To the west is Henry James's Washington Square and beyond that Greenwich Village, formerly a haven for artists but today home to the affluent and professional classes. Chelsea and Gramercy Park offer diverse attractions before one reaches Times Square, the "Crossroads of the World," recently transformed from a sleazy strip to a centre of tourism. At Columbus Circle visitors may enter Central Park, some 840 acres (340 hectares) of greenery created by Frederick Law Olmsted and Calvert Vaux in the mid-19th century. The Upper West Side is filled with brownstone blocks and high-rise apartments and is home ground to the liberal, Democratic Party politics long identified with the modern city. East Harlem is Hispanic, as is Washington Heights, but the two are separated by Black Harlem and the academic bastion of Columbia University on Morningside Heights. At the far north of the island—where Manhattan actually spills into the Bronx—Irish influence predominates. Only in the few blocks of Marble Hill is Manhattan part of the mainland.

No area of New York demonstrates change and dynamism as fully as Manhattan. Millions enter it daily to seek their fortunes, and millions more come to marvel at their efforts. It is Manhattan that they label a "great place, but I wouldn't want to live there." More than half of the buildings in the world with 50 or more floors are located there, but its storied past can be partly recaptured at the South Street Seaport, on the Staten Island Ferry, or in its distinctive neighbourhoods. Manhattan means Tammany Hall, the archetype of the political machine, as well as the reformers that overthrew the "Tiger." It is supremely cosmopolitan, boasting the world's best restaurants and a myriad of cultural institutions, yet folksy enough to have block parties. Manhattan's variety and pace make New York the number one tourist city in America.

The Bronx. The Bronx is the northernmost borough and (except for a tiny sliver of Manhattan) the only part of New York on the mainland. It was first settled by farmers and for centuries remained rural. It was the scene of much conflict during the American Revolution, but afterward it became the area where wealthy politicians and merchants established summer homes. In the late 19th century it was home to a racetrack where the Belmont Stakes were run until 1889. Railroads, bridges, and commerce gradually bound the Bronx to the lower city, and in 1874 the towns of Morrisania, West Farms, and Kingsbridge were annexed by Manhattan. Elevated rail lines soon arrived, and vast parks were authorized; the modern borough, 42 square miles in area, is still one-fourth parkland. When additional land from the Bronx was added to New York in the consolidation of 1898, the modern borough was created. Prior to 1910 subway lines snaked their way north to facilitate population growth in the former farmland. By the time Bronx county was established in 1914, it had large groups of Italians, Jews, Irish, and Armenians. Many found work on public works projects, such as those that built parks, the Bronx Zoo, the New York Botanical Garden, or the Jerome Park Reservoir. Others laboured on the uptown campus of New York University, which is home to the country's first Hall of Fame (for Great Americans), expanded the subway system, or constructed Yankee Stadium (1923). Fordham Road became a major shopping street, and the Grand Concourse won favour as one of the most prestigious addresses in the city.

Early history

Few areas of the country experienced such a precipitous drop from prosperity as did the Bronx. For a decade after the mid-1960s, the Bronx became the scene of classic urban decay caused by crime, drug dealers, renegade landlords, and the strain of accepting wave after wave of immigrants. Puerto Ricans won political power when they elected Herman Badillo as borough president; they later sent him to the U.S. Congress. However, the reputation of the borough came not from enlightened ethnic advance but from the fires that consumed its buildings and the drug and gang wars that destroyed its young people. Although fully linked to the metropolis by railroads and such bridges as the Triborough (1936), Whitestone (1939), and Throgs Neck (1961), the South Bronx became a place to leave as quickly as possible. Jewish residents fled the Grand Concourse to Co-op City, an enormous housing complex near Eastchester Bay. The spread of slum conditions northward from Mott Haven, Hunt's Point, and Morrisania threatened to turn the entire borough into a blighted area.

Rebirth of the borough

During the last quarter of the 20th century, the tide of decay reversed, and the Bronx rebounded in remarkable fashion. Vacant lands were filled with single-family and row housing, thousands of apartments were rehabilitated or restored with city funds, and hundreds more were saved by individuals who refused to give in to lawlessness. Tensions between competing populations—the borough is one-third African American, one-third Hispanic, and one-third Asian and white—have eased, and attendance at the universities in the borough has increased. The population has risen, and the upper-class enclaves of Riverdale and

City Island once again ranked as sought-after housing areas for the city elite.

Brooklyn. The most populous borough of New York, Brooklyn occupies 81 square miles to the east of Manhattan on the western fringe of Long Island. Sections of the area were first settled by the Dutch in the 1630s, and six largely agricultural towns—Brooklyn, Flatlands, Flatbush, New Utrecht, Bushwick, and Gravesend—soon thrived. Consolidated as Kings county in 1683, the region grew modestly as an appendage of Manhattan. During the U.S. War of Independence, Brooklyn was the scene of the Battle of Long Island (Aug. 27, 1776). After the British occupied New York, their notorious prison ships were anchored in Wallabout Bay; a memorial to the thousands who died stands in Fort Greene Park. Early in the 19th century, Brooklyn became the world's first modern commuter suburb, and Brooklyn Heights was transformed into a wealthy residential community. Modern-day entrepreneurs have restored ferry service across the East River, and the esplanade along the heights rewards visitors with an unrivaled view of Manhattan's shore and skyline.

To the chagrin of New York, Brooklyn became an independent city in 1834. By the 1880s it had about 20,000 industrial jobs and handled more waterborne tonnage than its rival. Brooklyn had its own Academy of Music (1859) and Historical Society (1863) and, in Prospect Park (1870s), an urban green space that represented a more mature version of Olmsted's vision across the river; it ranked among the largest cities in the country in the last four decades of the 19th century. However, the construction of John Roebling and Washington Roebling's Brooklyn Bridge to Manhattan (completed 1883) doomed its independence, as business interests craved closer ties to the metropolis. Overcoming the opposition of the local Democratic machine, Brooklyn accepted consolidation by a margin of only 277 votes and became a part of Greater New York in 1898.

Contemporary Brooklyn retains much of the independent character it displayed as an industrial city. It has its own shopping mecca (around Flatbush Avenue), a Civic Center, and even a Chinatown in Sunset Park. Additional access to Manhattan came with the construction of the Williamsburg (1903) and Manhattan (1909) bridges and later through Battery Tunnel (1950). In the 1920s full subway service was extended as far as Coney Island, and in 1931 the borough became home to New York's first airport, Floyd Bennett Field (now part of Gateway National Recreation Area). Brooklyn had something that Manhattan could never match, a beloved baseball team, the Dodgers, playing in a wonderfully intimate ball park, Ebbets Field; many hearts were broken when the team decamped to California in 1957, and the field was subsequently demolished. Brooklyn remains famous for its multiplicity of houses of worship serving neighbourhoods as varied as Brighton Beach and Bensonhurst, Bay Ridge and Ridgewood, and Canarsie and Cobble Hill. The majority of its people live in apartments, mammoth housing projects, or upgraded row housing. Bedford-Stuyvesant and Brownsville have some of the worst slums in New York, with blocks of burned-out and abandoned buildings. Tensions between African Americans and Hasidic Jews in the biracial area of Crown Heights led to a prolonged conflict in the 1990s, and their relationship has remained strained. On the other hand, careful use of landmark protection legislation has enabled several historic neighbourhoods to restore their viability. The originality of the borough is visible in the creation of new areas such as DUMBO (Down Under the Manhattan Bridge Overpass).

The Dodgers

Queens. Queens county would constitute a major American city were it not a part of New York. Its 120 square miles, more than one-third of the city, feature a primarily middle-class population owning private homes, although in such areas as Forest Hills apartments predominate. During colonial times a significant battle for religious freedom, the Flushing Remonstrance (1657), was fought in Queens; it was a first victory for the tolerance necessary in an urban centre. In the 19th century Queens had several racetracks and two shorelines that attracted the wealthy, and it served as the final resting place for deceased New Yorkers. Its Calvary Cemetery is still the largest in the nation, while 7,000 veterans of the American Civil War are buried in Cypress Hills on its border with Brooklyn. The Long Island Rail Road (1836), originally intended to shorten the trip from New York to the Boston ferry, traversed land that was largely agricultural. That situation changed after 1870 when what essentially were company towns were established by William Englehardt Steinway (pianos) and Conrad Poppenhusen (rubber); the later development of the Newtown Creek area brought heavy industry and drew many immigrant workers into the county.

In 1894 the communities of western Queens endorsed the creation of Greater New York, but parts of its eastern territory ultimately became Nassau county. The borough grew rapidly once the Queensboro Bridge opened (1909) and the Long Island Rail Road was connected to Manhattan's Pennsylvania Station (1910), and subway service was established soon thereafter. Queens was the centre of the silent-film industry until displaced by Hollywood in the late 1920s. The growing borough had more than a million people even before it was lashed to the Bronx by three bridges and to Manhattan by the Midtown Tunnel (1940). Pioneer aviator Glenn Curtiss's flight from Albany to New York City in 1910 issued in the age of domestic aviation, and the flat, open spaces of Queens became popular for airfields. It became an international arrival centre when La Guardia Airport opened in 1939 and Idlewild International Airport in 1948, the latter subsequently renamed for President John F. Kennedy in 1963. Access to transportation and a lower-density population made Flushing Meadows in Queens a natural site for the two world's fairs held in the city in 1939–40 and 1964–65. The borough also hosts the annual United States Open Tennis Championships.

Ethnic diversity

In a diverse and cosmopolitan city, Queens ranks as the most ethnically varied of all the boroughs. It is perhaps too simple to refer to Irish Woodside, Greek Astoria, Polish-Lithuanian Maspeth, or Italian Corona, but those groups do predominate. Vast numbers of Chinese, Koreans, and East Indians have transformed Flushing into the largest of New York's three Asian centres and revived a once anemic local economy. More than half of the city's Latin Americans live in Queens, and their restaurants and travel agencies dominate entire neighbourhoods. African Americans are more fully integrated in Queens than elsewhere in the metropolis, residing primarily in areas such as Hollis, Cambria Heights, St. Alban's, and Springfield Gardens.

Staten Island. Geographically isolated at the juncture of Upper and Lower New York Bays, Staten Island is 5 miles removed from Manhattan by ferry and a mile from Brooklyn across the Narrows. Its 60 square miles are still the least densely populated, most rural part of the city, even though it ranks as the fastest-growing county in the state. When the English conquered New York in 1664, they decided that Staten Island would remain part of that province despite its proximity to New Jersey. A century later, in 1776, British troops launched their conquest of the city from the island. After independence, Richmond borough (later Staten Island) held forts to protect access to New York, quarantine stations for sick immigrants, homes for aged seamen and orphans, and railroad terminals for Manhattan's freight. When its voters chose to become part of the greater city, its population was slightly more than 65,000.

After 1900 a civic centre and borough hall were constructed in St. George near the ferry ramps. Water-system real estate speculators attempted to start a boom when Richmond was connected to the city, but the prospect faded away once direct subway access failed to materialize. Until the 1930s the borough experienced slow industrial and population growth, and only after the Goethals (1928), Outerbridge Crossing (1928), and Bayonne (1931) bridges were built did stagnation cease. Construction of the Verrazano-Narrows Bridge (1964) finally opened the borough to rapid development and made it a functional part of city life. Truck farming has ended and factories have closed on the island, but borough residents have managed to retain the integrity of their nearly 3,000-acre park, the Greenbelt, the largest such amenity in the metropolis.

Staten Island is the most homogeneous borough in New York; it has the lowest proportion of ethnic minorities and is the youngest and most politically conservative. Its politicians call the borough underserviced, its residents feel under attack by environmental pollutants from New Jersey, and everyone resents being home to New York's largest garbage disposal site. A dumping area since 1948, the Fresh Kills site will ultimately reach an elevation of 500 feet (150 metres), the highest point on the East Coast.

Planning the modern metropolis. Early city leaders dealt with the needs of citizens less than systematically. Administrations in the 19th century created the street grid, regulated the port and immigration, provided water and sewers, authorized transportation lines, and built parks. No one pretended that Manhattan offered a picture of rational planning, but with a consolidated population of more than three million, a more orderly approach was necessary. Uncontrolled building and atrocious housing conditions were among the primary concerns of progressive thinkers, and their first achievement was a Tenement House Law (1901) that required the installation of fire escapes and toilets in existing "old law" structures. City officials became the overseers of "new law" construction—six-story buildings with dumbwaiters, cooking facilities, hot water, and no inside rooms without windows—and within 15 years an additional 200,000 apartments were built. Progressivism's greatest accomplishment was the city zoning ordinance of 1916, the first attempt by any city to control density, regulate land use, and guarantee light and air to the streets by reshaping structures. By that time, Manhattan was already famed for its skyscrapers, and their height had escalated from the 11 floors of the Tower Building (1889) to the 20 of the Flatiron (1902) and finally to the unprecedented 792-foot Woolworth Building (1913). The new zoning code mandated building setbacks to permit daylight to reach the streets and altered the shape of future construction. Under its restrictions the Chrysler (1930) and Empire State (1931) buildings were completed, still two of the most famous silhouettes on earth. After World War II, a corridor of buildings was constructed along Park Avenue that has been called the architectural heart of the 20th century. In 1961 the zoning code was altered to encourage developers to add public amenities to their building plans in return for variances. The revision was less than successful, and in 1990 the City Planning Commission established new building districts in an attempt to decrease the flood of new building in Manhattan.

Tenement House Law

In 1921 the Port of New York Authority (PA) was formed to deal with regional transportation issues, and it quickly initiated a series of massive construction projects that still serve the city. The PA added the George Washington Bridge (1931), Lincoln Tunnel (1937), bus and Port Authority Trans-Hudson terminals, satellite communication centres, and the World Trade Center. Officials from the PA deferred to the judgments of Robert Moses, the dominant city planner from 1934 until the 1960s, who provided the city with 13 major bridges, more than 400 miles of high-speed highways, and hundreds of parks and playgrounds. He also led city efforts at slum clearance, urban renewal, and public housing. More than any other single individual, Moses shaped the contemporary city.

But not even Moses could totally control the chaos of development characteristic of New York. In truth, aside from a few farmhouses, little remains from the colonial era, and the construction boom after 1945 consumed 19th-century structures at a rapid pace. As Walt Whitman described it, the city had the "pull down and build over again spirit," which became a New York tradition. However, in 1963, when Pennsylvania Station went under the wrecking ball, outrage led to the creation of the Landmarks Preservation Commission (1965), whose purview was soon extended to interiors and to scenic landmarks. The commission has established historic districts, designated more than 1,000 individual landmarks, and preserved a past that has become increasingly important to New Yorkers.

In 1969 city planners offered a massive regional plan for development, but it failed to win approval. Instead, successive amendments of the city charter in 1975 and 1989 have been used to broaden popular input into city projects. Borough presidents and local community boards have now become involved in the preparation of new initiatives. In a city as complex as New York, architectural change is constant, and the total transformation of the Times Square district illuminates the power of design to alter the city. In the 1990s it went from being the national symbol of urban decadence and seediness to a centre of corporate consumerism that now draws families of tourists to its attractions. Elsewhere in the city, such prominent real estate developers as Donald Trump have often won approval for vast projects, but planning officials and local communities have often blocked what they saw as unsuitable land use.

Renewal of Times Square

THE PEOPLE

Ethnic and religious diversity. In a city that embraces change as its primary tradition, the shifting population base of New York remains its most dramatic story. Representatives of some 200 national groups are counted among its people. While people of European ancestry still make up one-third of the population, Hispanics account for nearly one-third, and African Americans about one-fourth. The fastest-growing component of the population is Asian, soaring from a tiny proportion in 1970 to about one-tenth. Dominicans were the most numerous immigrants during the last decade of the 20th century, but they were closely followed by Russians and Chinese. The Statue of Liberty, more than a century after its dedication in the harbour (1886), continues to welcome newcomers into the city's "golden door."

People from each ethnic group have climbed the ladder of acculturation, achieved their goals to a greater or lesser extent, and then, in turn, found fault with the masses that followed them. As early as 1643, Father (later Saint) Isaac Jogues catalogued 18 languages that were being used on the streets of New Amsterdam, and that cosmopolitan atmosphere was retained when Dutch control ended and Britain assumed power. Jews, Roman Catholics, and numerous ethnic groups lived in Manhattan before 1700, but political control remained in the hands of the established merchant elite. When the U.S. War of Independence began, more prominent Dutch families—the Van Cortlandts, De Peysters, and Schuylers—supported the cause than did their English counterparts. One unanticipated result of the fighting was that many slaves, perhaps one-fifth of the city population in 1776, won freedom. One of the first "history" books of New York was a satiric look at the merchant elite and the city's Dutch past written in 1809 by Diedrich Knickerbocker (Washington Irving). Spoken Dutch was heard on city streets until the late 19th century, when such families as the Roosevelts and the Vanderbilts were important members of Manhattan's elite.

The dedication of the first St. Patrick's Cathedral in 1815 signaled the rising prominence of the Irish. By 1844, 15 parishes served more than 80,000 Irish Roman Catholics, and it was clear even before the Great Famine immigration of 1845–49 that New York was becoming predominantly Irish. More than 24,000 Germans also lived in Manhattan, a number that vastly increased following the failed revolutions of the 1840s. Irish workers had to contend with signs warning "No Irish need apply," and their poor circumstances soon created one of New York's most notorious slums, the Five Points District. Germans, who were largely Protestant or Jewish, were more middle-class and perhaps had a slightly easier acclimation; they created the Kleindeutschland ("Little Germany") neighbourhood east of the Bowery. So great was the pressure of immigration that Castle Garden, near the Battery, was converted into a reception centre, a role it fulfilled from 1855 to 1890. By the time of the American Civil War, Irish, Germans, and several other ethnic groups made the city's population more than half foreign-born.

The Irish and Germans

The arrival of "new" immigrants from eastern and southern Europe after 1880 again changed Manhattan. The Irish and Germans, who by then held a vast proportion of political and economic power, deeply resented the Italians, Greeks, Russians, Hungarians, and Poles crowding into their city. Ellis Island, a new immigrant reception station, was built in 1892 to deal with the unprecedented numbers of newcomers, and by 1900 the Lower East Side recorded

one of the greatest population densities in world history. Ellis Island processed about 12,000 people per day, and in 1907 some 1.2 million entered the United States through the port. The austere *New York Times* wrote that "cleanliness is an unknown quality to these people. They cannot be lifted to a higher plane because they do not want to be." Tuberculosis became the "Jewish" disease, and New York's police commissioner played the demagogue in 1909 when he asserted that half of all city crime was committed by Russian Jews. Nevertheless, Jews were to transform labour and education in the city, while Italians would become the largest ethnic group. Yet toleration of "the other" became a New York virtue.

Internal migration. An often ignored force of change in New York is the constant internal migration it attracts. Over the years a large proportion of America's brightest and most ambitious and driven individuals have been drawn to Manhattan. New York displaced Boston as the national cultural centre as early as the mid-19th century, as its newspapers, magazines, and artistic freedom lured the different-minded. By 1900 both Mark Twain and William Dean Howells had lived in New York, and Greenwich Village emerged as a haven for nonconformity before World War I. Modern sculpture, Beat poetry, and Abstract Expressionism are only three of the 20th-century artistic movements that trace their origins to the Village scene.

African Americans

After 1900 the largest group of internal refugees were African Americans fleeing the rural South. New York was one of their preferred destinations, and the growth of Harlem as the "black metropolis" was the unintended result. In the first decade of the 20th century, the Afro-American Realty Company began to rent homes to African Americans in what was then a predominantly Jewish neighbourhood, and the churches they attended downtown soon relocated to the north. Growing ethnic and economic hostility led to a white exodus, although East Harlem did remain largely Italian, and by 1930 more than 200,000 African Americans lived in Harlem. Their artistic talents led to the Harlem Renaissance, and their musicians were leaders of the Jazz Age, but the reality remained that the Harlem they dominated was becoming the largest slum in the city. The Great Depression destroyed economic opportunity; high rents forced the subdivision of apartments; and the well-known pathologies of tenement life devastated a poor community. Harlem endured a long decline from which it did not emerge until the 1990s.

White ethnics found no difficulty in deciding that African Americans were ignorant, lazy, and prone to engage in criminal activities. As the first large group entitled to the social reforms of the New Deal era, African Americans were accused of being parasitic users of the welfare system. Similar accusations were later directed at Puerto Ricans, long a presence in the city but whose numbers soared after World War II. However, within a generation, the influx of Dominicans, Cubans, Colombians, and most recently Mexicans altered the fabric of New York in an unexpected manner. In the 1990s the Hispanic population of the city grew by about 400,000, and bilingualism became a reality. Some 2.2 million New Yorkers of Hispanic origin now constitute the largest single group in the city, and it is estimated that one-fifth of the city speaks only Spanish at home. Relations between African Americans and Hispanics have deteriorated, as one wave of early immigrants tends to disdain those who come later.

THE ECONOMY

Early industries. The seal of the city of New York, adopted in 1686, includes the beaver and the flour barrel, images that document the first major phase of Manhattan's economic history. New Amsterdam was important to the Dutch because it offered access to the immensely valuable fur trade of a continent. One of the richest men in 19th-century New York was John Jacob Astor, whose fortune was based on fur before he became a real estate speculator. After the British conquest in 1664, the city won a monopoly to grind and pack grain and sent its flour to all world markets. Merchant incomes soared as commerce, both legitimate and via smuggling, became the lifeblood of New York. Any threat to city prosperity was harshly dealt with, and William Kidd's turn from privateering to piracy led him to the gallows (in London) in 1701.

Shipping and transportation. The shipping enterprise has always characterized New York. Its Dutch-English merchant class dominated the colonial assembly and after 1756 controlled the annual salary grant awarded to the royal governor. A group of 20 merchants organized the country's first chamber of commerce (1768) at a time when small manufacturing establishments—cloth, timber processing, ropes, and sails—were becoming more common. Rapidly overcoming years of British occupation during the American Revolution, the city filled Caribbean, European, and coastal ports with its vessels within a decade of independence. New Yorkers were the ones who sent the *Empress of China* on its historic first voyage to East Asia in 1784, and Manhattan was the national leader in both exports and imports by the late 1790s. When inventor Robert Fulton's steamboat, the *Clermont,* made its first trip to Albany in 32 hours in 1807, it revolutionized transportation. New York launched the first scheduled shipping to Europe, and its thriving boatyards constructed every type of vessel from harbour lighters to inland steamers to transatlantic passenger ships. The yacht *America* (1851), first winner of the race henceforth called America's Cup, was built there as were many of the fabled clipper ships. From 1830 until the 1950s New York ranked as the busiest port in the world.

Shipbuilding

Banking and finance. Commercial banking began in Manhattan in 1784 when the Bank of New York opened for business. It was soon joined by a branch of the First Bank of the United States (1792) and the Manhattan Company (1799), ancestor of what is now The Chase Manhattan Corporation. The origins of the New York Stock Exchange (NYSE) can be traced to the Buttonwood Agreement of 1792, although the Exchange Board itself was not

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The trading floor of the New York Stock Exchange.

organized until 1817. After the Erie Canal opened in 1825, banking services became even more centred in the city, and when its merchants entered the cotton trade the commerce of the entire nation flowed into the port. Several financial panics in the 19th century could not prevent the city from dominating the national money markets. Investors and banks from the metropolis provided much of the capital that financed the industrialization of the United States. So great was the influence of New York that the country's largest firms found it expedient to locate their headquarters there even though—as with Carnegie Steel, American Tobacco, and Standard Oil—the focus of their manufacturing was elsewhere.

The development of industry and trade. Shipping and finance secured New York's international standing, but manufacturing provided jobs for its teeming population. A multitude of small businesses were centred in Manhattan by the 1850s, and the clothing, furniture, pianos, cigars,

and dozens of other products they created boosted city exports. By mid-century New York was the printing centre of the United States with more than 1,000 establishments; in the period 1865–85 the number of magazines published in the city quintupled to 3,300. The influx of skilled Jewish immigrants transformed an already dominant clothing industry into a gargantuan one, employing nearly half of all city workers by 1910. New York quickly developed advertising, insurance, and legal services to deal with the needs of its burgeoning manufacturing sector.

The centre of business. By the beginning of the 20th century, New York was the headquarters for more than two-thirds of the top 100 American corporations, and its 25,000 factories manufactured several hundred different industrial products. It led the nation in total factory workers, number of factories, capital valuation, and product value. New York held its leadership position for another three generations and provided nearly one million industrial jobs into the 1950s. In 1960–75 the city lost more than 600,000 of these jobs, as its old economy collapsed and an information age took shape. Banking and financial services became the new engine of development—abetted by the traditional print and advertising sectors of the economy—while white-collar workers with computer skills replaced most of the blue-collar labourers of the past. Although much has been made of the move of clothing production out of New York, it remains the city's leading industry, and sweatshop conditions reminiscent of the early 1900s still exist in small factories in the Bronx and Queens. The metropolitan area is still home to more than one-fifth of the Fortune 500 companies.

Economic collapse and recovery

The 1970s represented a low point for New York; its national reputation collapsed as the government experienced virtual bankruptcy. High rents, congestion, arson, and crime led to an exodus by businesses and the middle class even after the city began the rebuilding process. Industrial parks, where businesses were given cheaper rents, better utilities, and safety, were authorized in response to the crisis, and major tax incentives were granted to those corporations that remained in the city. The NYSE even threatened to leave, but in the late 1990s it agreed to remain in Manhattan and to construct a new facility. The port, where facilities were outmoded and corruption endemic, began to convert its docks for containerized shipping, to dredge deeper channels, and to plan a direct rail connection between Manhattan and Brooklyn.

By constantly enhancing its key economic advantages, New York has remained prosperous even as it underwent change, its strength lying in its diversity. The port, which lost some percentage of its shipping to other cities, is still the busiest port on the East Coast and generates billions of dollars of revenue, creates thousands of jobs, and is the focus of major plans for renewal and renovation. Manufacturing positions have declined, but smaller specialty producers of neckties, purses, and leather goods have joined the ready-made-clothing industry to maintain New York's dominance. A major portion of the country's software and computer-related industry has located itself in New York and built an urban "Silicon Alley" to mirror California's Silicon Valley. The city's continuing financial supremacy was apparent in the 1990s, a decade in which the Dow Jones average quadrupled. New York marketed its monetary expertise to the globe; its banks dealt with the Latin American debt crisis of the 1980s as well as the Asian financial meltdown of the late 1990s, and in the process the city became the "economic capital of the world." The vast numbers of bars, restaurants, hotels, health clubs, and theatres across New York are necessary to care for and feed the millions of visitors who come to the city annually.

ADMINISTRATION AND SOCIAL CONDITIONS

Government. New York City is administered by a mayor who chooses department heads and criminal-court justices and prepares the annual budget. Mayors hold considerable power but are constantly involved in legislative battles with the 51 members of the City Council. Both mayor and council members serve a maximum of two four-year terms. In general, beginning with Fiorello La Guardia in the 1930s, the mayors usually have led their own parties and have been stronger than other party leaders.

Two themes are constant in the administrative history of New York: tension between the city leadership and the superior authority of the state in the struggle for home rule, and the municipality's desire to contain the decentralizing tendencies caused by its component elements. In the Dutch colonial period, the director general of New Netherland was a city resident who ruled both province and burgh, but after 1664 England's provincial governor named a mayor. In the 1680s Governor Thomas Dongan granted New York its first municipal charter and permitted the election of aldermen, but he retained the right to appoint the mayor, recorder, clerk, and sheriff. Effective control remained in the hands of the governors until it was wrested away by the city aristocracy after 1740.

Colonial administration

During the time of the American Revolution, New York suffered from a long British occupation and two fires that destroyed one-third of its buildings. Federalist Mayor James Duane, whose own home had been burned to the ground, supervised rebuilding efforts in the 1780s, and his successor Richard Varick completed the reconstruction of city and government. Their efforts, abetted by those of DeWitt Clinton after 1803, established the foundations for New York's national dominance. After 1800 New York was the nation's largest city, a commercial dynamo that worked efficiently even as the city became a great melting pot of different peoples. Yet New Yorkers still lacked the right to elect their own mayor; only in 1834 did Jacksonian Cornelius Lawrence initiate democratic control, which subsequently has been characteristic of the metropolis. One area in which voters of all classes agreed was the need to improve city services, and in April 1835 they approved the creation of a new water supply. New York's Croton Aqueduct opened in 1842, inaugurating a century of city efforts to tap regional water resources and provide citizens with some of the nation's best-quality drinking water; this better water was also vital in ending the epidemics that periodically struck the city. Manhattan's desire for home rule was often at odds with the plans of upstate legislators, and in 1857 Albany authorized the Metropolitan Police District to cover four urban counties. Involvement by the state created two competing police forces, and their subsequent battles were ended only by the intervention of the state militia. Not until 1870—after massive bribery by "Boss" William Magear Tweed—was local police power restored. Tweed's charter increased the authority of the office of mayor in governance matters and, after the "Tweed ring" was overthrown in 1871, a reform charter added power to the office of comptroller. The Board of Estimate and City Council also were established to direct city development.

New York in the 19th century, while primarily under the control of the Tammany Hall political machine, constructed Manhattan's basic water, sewer, fire, police, transportation, and park facilities. There was, naturally, some corruption and a great deal of what insiders like George Washington Plunkitt called "honest graft," but the experience gained in building Manhattan permitted the greater city to construct an infrastructure capable of serving a far denser population. In 1899 social reformer Jacob Riis described a metropolis "barely yet out of its knickerbockers" yet poised for greatness; Riis believed its enduring challenge would be to care for the poor. Novelist Theodore Dreiser agreed, for in New York the strong "are so very strong, and the weak so very, very, weak—and so very, very, many." The wealth generated by economic success in New York was never totally subservient to the demands of the affluent.

Compassion is hardly part of the city's cold image, but caring for its less fortunate citizens has been a major theme of its modern history. In this most capitalist of all American cities, a strong element of socialist ideology fostered the creation of the nation's largest municipal hospital and university systems, vast areas of public housing, and generous welfare benefits for the poor. City programs exist in uneasy proximity to a remarkable collection of the world's best private hospitals, some of its most expensive apartments, and dozens of private universities. Social initiatives first attempted in New York became precursors of New Deal programs in the 1930s, while the city's American Labor and

Social programs

Liberal parties constantly advanced an agenda of public responsibility. Although the Democratic Party organization served many constituencies, it held political power because it never forgot the poorest citizens, who also voted. The enormous wealth of the city funded a wide range of altruistic programs without major difficulty until the 1960s, when welfare rolls exceeded one million people and crime rates soared. The vast decline in manufacturing and the taxes it provided also undermined the city economy, and New York suddenly became a metropolis out of control. Mayor John Lindsay never mastered the crisis; he attempted to create "superagencies" to deal with human resources, the environment, health, housing, and parks even as the borough presidents and community groups demanded greater local control. Lindsay's long feud with the state government eventually led to loss of central control over the school system in 1969. By 1975 the city nearly fell into bankruptcy, its finances were administered from Albany, and its social compact appeared on the verge of anarchy.

In the last decades of the 20th century, New York's rebirth was spectacular. Mayor Edward I. Koch restored fiscal security to the city, and his administration began the slow task of restoring lost confidence. Commercial construction boomed, and multibillion-dollar refurbishing programs of subsidized housing and transportation systems were instigated. Not even the great stock disaster of October 19, 1987—when the Dow Jones average dropped by more than one-fifth—halted the turnabout. The 1990s were a decade of unprecedented wealth accumulation in the country's richest city, but poverty and homelessness endured as societal realities.

In 1989 the U.S. Supreme Court declared that New York's government system, which gave equal representation to populous Brooklyn and underdeveloped Staten Island, violated the "one man, one vote" mandate of the Constitution. The Board of Estimate was to be abolished, and a November referendum decided that the City Council would be expanded to 51 members in order to enhance the power of minorities. Council authority over the budget, land use, zoning, and franchises was increased, and a new planning commission was established. The renovated council remained under Democratic control but now had the potential to oppose mayoral initiatives; when voters elected Republican Rudolph Giuliani as mayor in 1993, the urban political scene became confrontational. Battles over educational leadership, city planning, and spending projections marked Giuliani's administration, even as it successfully reduced city crime in all categories and slashed welfare rolls. Aggressively preventive tactics pioneered in New York substantially reduced the national crime rate, while "quality of life" policing made citizens feel safe on the streets. Acting with national welfare reform, Giuliani's administration established the country's largest workfare program. In 2001, near the end of his administration, Giuliani reversed the earlier perception that he had turned his back on the city's tradition of compassion by leading the vast rescue and recovery effort at the site of the World Trade Center disaster.

Crime prevention

Education. *Primary and secondary systems.* Ever since the first school opened in New Amsterdam in the 1630s, New York has sought fine schools, but until after the American Revolution education was largely handled by tutors. Public funds for education became available after 1795, and in Manhattan a Free School Society was formed to disperse the state money. The growing numbers of New York Roman Catholics were distressed by what they interpreted to be Protestant indoctrination within the school system. In the 1840s Archbishop John Hughes was instrumental in establishing a Catholic parochial school system, which has continued to offer an alternative to public education. Neither system ever achieved universal attendance during the 19th century, however, for not until 1874 was a compulsory attendance law for the primary grades enacted; new immigration subsequently overloaded all city schools. After consolidation, Greater New York launched a massive public building program to provide schools where a half-million eligible students could be educated each year. Secondary education was not even offered to its children until the late 19th century, but by 1920 massive construction made primary education, along with both ordinary and specialized high schools, available for everyone. Several New York high schools—Stuyvesant, Bronx Science, Brooklyn Tech, and Performing Arts—have retained national reputations for excellence, and the school system has also provided evening classes in adult education and practical skills for the city's large immigrant population.

In the late 1990s New York administered the nation's largest public school system; more than one million students attend in excess of a thousand public schools. In the last decades of the 20th century, education became a sphere of unending controversy. The postwar white exodus to suburbia drained students from public schools and transformed them into minority-dominated institutions most of whose instructors were white and Jewish. During the 1960s a series of strikes and ugly racial confrontations caused disorder in the city, and in 1969 the state legislature divided the city into 32 districts. Henceforth primary education was to be controlled by elected governing boards so that educational goals could be established by local communities. Each board would select its superintendent, but resources would still be allocated by a chancellor of the entire school system, who was named by a mayor-dominated Board of Education.

The unwieldy system worked only sporadically, and by the 1990s its failures were apparent. Wage levels declined relative to those of suburban systems, racial segregation in schools caused by housing patterns and economic stratification increased, and many tenured teachers were accused of ignoring the special needs of minority students. Dropouts increased, performance levels fell precipitously, and violence in schools appeared endemic. Colleges and businesses alike complained bitterly that schools turn out "functional illiterates." In the last two decades of the 20th century, the system was led by a dozen chancellors, and the mayor's role in their selection became as highly politicized as district appointment of school principals. In 1996 the state legislature once again intervened, ending local authority to name principals and attempting to remove party and ethnic politics from the system. In 1999 principals agreed to surrender their tenure rights in return for larger wage increases. The long decline of a once-praised system has benefited parochial and private schools in New York, although the cost of a nonpublic education has escalated considerably.

Decline of the system

Higher education. The metropolitan area has more than 80 colleges, including such nationally famed institutions as Columbia (1754), New York (1831), Fordham (1841), and Rockefeller (1901) universities and Cooper Union (1859). Its vast municipal system, the City University of New York (CUNY), has more than 20 units and traces its origin to City College (1847). However, the introduction of open admissions in the 1970s brought the ills of the high schools into the college system. CUNY's strong academic tradition soon mutated into what became derisively known as "Remediation U," and from the late 1990s university trustees were engaged in an effort to strengthen the baccalaureate. Even the most selective colleges found it necessary to enhance basic student skills. Despite these difficulties, New York remains one of the nation's premier university towns and, from Ivy League to community college, its streets pulsate with student life.

CULTURAL LIFE

As real as the bedrock beneath Manhattan is the cultural attraction generated by New York. For more than a century, talented but unrecognized artists as well as ambitious wanna-bes from every part of the globe and nation have gravitated to a city they feel is their spiritual home. A steady stream of the cultural elite flows toward the metropolis and creates an electric atmosphere. In virtually every artistic field—theatre, music, dance, painting, literature, fashion, film, print, and sports—the city is the "place to go" to see if you can "make it." No environment offers a harsher test of one's abilities. Literary figures as diverse as Washington Irving, Herman Melville, Walt Whitman, O. Henry, the members of the Algonquin Round Table, Rex Stout, and Ed McBain (Evan Hunter) have all attempted to explain the allure and the dangers of the city;

Role as an artistic centre

all succeeded and failed, to some degree. In the 19th century Manhattan was home to the Hudson River school of artists, and the Tenth Street Studio in Greenwich Village and its surrounding area shaped the national imagination. Willa Cather, who grew up in Nebraska, came to write of the West on Bank Street in the Village, while Jackson Pollock came from the West to create Abstract Expressionism and help change the direction of modern art. But perhaps the greatest proof of New York's dynamic appeal are the millions of annual visitors who come to experience its vibes, variety, and vitality. Whether artist, visitor, or resident, all seem united in the belief that New York is, as writer Joan Didion described it, "an infinitely romantic nation, the mysterious mixture of all love, money and power, the shining and perishable dream."

Undoubtedly culture is big business in New York, and no city in the country has more institutions and people dedicated to serving its demands. The Metropolitan Museum of Art (1870) is probably the best known and most visited of the city museums, but the metropolis has scores of concert halls, schools of art, music and acting, restaurants, and galleries, as well as agents, promoters, and hucksters of every type. It is the city of promoter P.T. Barnum, philanthropist James ("Diamond Jim") Brady, and financier Malcolm Forbes. It can fulfill every desire, from photography to pornography to publicity. The Cloisters (1938), part of the Metropolitan Museum, specializes in medieval art, while the avant-garde sensibility is catered to at the Museum of Modern Art (MOMA; 1929) and at the Whitney (1930) and Guggenheim (1939) museums. Natural sciences and the shape of the skies can be studied at the American Museum of Natural History (1869), while those who seek the best pre-Columbian or Egyptian art should journey to the Brooklyn Museum of Art (1823). Those interested in Native Americans, the tenement house, dolls, or African art will find institutions specific to their needs. Great stone lions, dubbed "Patience" and "Fortitude" by Mayor La Guardia, guard the New York Public Library (1895), whose mammoth holdings include the Schomburg Center (African American history) and are exceeded in the nation only by the Library of Congress. Researchers are also drawn to the Morgan Library (notably for medieval and Renaissance Europe) and Ellis Island (immigration). Whether the crowds who come to New York expect Fun City, the Big Apple, or Gotham, the city can fulfill every expectation of an admiring public.

Richard Drew—AP/Wide World Photos



West 44th Street in Manhattan's Theater District, just west of Times Square in New York City.

The arts. Ever since the 1890s Broadway has reigned as the "Great White Way," the major theatrical centre of the country. New York produces, casts, and consumes the legitimate plays and musical extravaganzas that Americans desire as well as thousands of other shows that only true supporters come to see. Theatre is New York's "fabulous invalid," periodically near death and at other times revived, and *Variety* (1905) is the news magazine that informs the world of its health. The city's Off Broadway and Off-Off Broadway venues are where experimental theatre apprentices playwrights, actors, dancers, and directors. In the last decades of the 20th century, major new stages in Times Square, skyscrapers, and a suddenly chic 42nd Street drew new audiences, and the increased price of tickets showed wider interest. For bargain seekers, Manhattan also offers free Shakespeare in Central Park, while cut-rate tickets to current productions are always available. In every borough local groups offer more performances than anyone can attend.

Lincoln Center for the Performing Arts

Completed in the 1960s, the Lincoln Center for the Performing Arts is a mecca for the arts patron. It is home to the Metropolitan Opera Association; the New York Philharmonic performs in Avery Fisher Hall; and the New York State Theater offers a variety of attractions, including the New York City Ballet, which has the highest reputation of any troupe in the country. The finest concerts in a very musical city are heard in Carnegie Hall (1891); the two million dollars donated by Andrew Carnegie for its construction have perhaps given more pleasure per dollar than any other philanthropic endowment. Town Hall in Manhattan and the Brooklyn Academy of Music, the latter the oldest performing arts centre in the nation, offer viable alternatives. Performance art is always available and is enjoyed by the complete range of audiences.

No city is as recognizable to other Americans as is New York; its glittering nightlife and its gritty neighbourhoods are equally part of the national consciousness. Film directors love to use the city as their set, and city administrations have increasingly encouraged them. Until World War I, Queens was the centre of the early film industry, and afterward New York remained vital to documentary and independent film production. Astoria regained its position as a studio centre in the 1980s. It is also fitting that the city that transmitted the first television signals became the setting for many of the most successful shows. From *The Goldbergs* to *I Love Lucy* to *All in the Family* to *Seinfeld,* New York City became part of the American cultural experience. The Museum of Television and Radio (1975) allows anyone to recapture famous episodes from this somewhat fictionalized yet also very real New York.

Recreation. New York never ignores the needs of its ordinary people. Since the colonial period, parades and festivals have been part of city life and the Halloween and Thanksgiving Day parades of modern times illustrate the strength of the tradition; in the 19th century parades also provided occasions for Roman Catholic and Protestant Irish to battle in the streets. Yiddish theatre was born on the Lower East Side, while vaudeville and burlesque were invented to draw audiences to more earthy delights. After 1898 the greater city understood that it had obligations to create green space beyond the expanses of Central and Prospect parks, so gardens, along with zoos in every borough, were provided for residents. New York has hundreds of parks, but its myriad of other entertainment possibilities include a miniature reproduction of the metropolis constructed in the Queens Museum, a restored Staten Island village at Richmondtown, or the jewel-like Orchard Beach in the Bronx. No public beach is as famous as Coney Island, and thousands of bathers often crowd there close to the sea; the Cyclone Roller Coaster at its amusement park became a national landmark in 1988.

Many professional as well as recreational sports are pop-

Baseball

ular in the metropolis, but probably no sport is as closely identified with New York as baseball. In 1903 a professional baseball club, the Highlanders, moved from Baltimore to New York and was renamed the Yankees in 1913. The team has since played in every borough except Staten Island, won more than two dozen world championships, and become history's most dominant sports franchise. Manhattan also loved its Giants baseball team, before the club's departure for San Francisco in 1957; Brooklyn lived for "next year" with the Dodgers; and Queens (since 1962) has been home to the New York Mets. New York teams have won professional championships in football, basketball, hockey, and association football (soccer) as well. Madison Square Garden, now in its fourth incarnation, has been the site of many championship boxing matches, innumerable other sporting matches, musical events, and political conventions and may well be the most storied indoor arena in American history. Whether in watching sports, picnicking in the parks, visiting museums, attending the theatre, capitalizing on the city's rich array of eateries (from ethnic delis and sidewalk carts to five-star restaurants), or simply watching its street life, the quality of cultural activities available in New York is unsurpassed.

History

THE COLONIAL CITY

As every schoolchild knows, Europe's desire to open trade with the East inspired the explorations that discovered the New World. Giovanni da Verrazzano (1524) and Henry Hudson (1609) were part of that long effort, and they were among the first Europeans to visit and gaze at the vast expanse of New York harbour. The primary result of Hudson's voyage, and his report of a protected anchorage near good farmland, was the Dutch West India Company's decision to place a trading post on the southern shore of Manna-hata Island; by 1626 a settlement called New Amsterdam was established. It was not the first Dutch settlement in North America, but the advantages of its location made it immensely valuable. In May 1626 Peter Minuit arrived with orders to secure title to the land. He quickly negotiated the real estate deal of the millennium, purchasing the area from a band of Native Americans who probably did not own it for trade goods worth the equivalent of 60 guilders (converted to the legendary $24). Minuit and his successor governors knew that expanding Dutch access to furs and trade were their primary tasks, and commerce fueled city development. In 1638 a new governor reported that one-fourth of all buildings were "grog shops" devoted to sailor demands. Despite revelries and intermittent clashes with local Native American tribes, the settlement gradually moved northward, laid out farms, and expanded trade with New England and the world.

Peter Stuyvesant

The most famous governor of the Dutch period was Peter Stuyvesant, director general of New Netherland in 1647–64. Stuyvesant's military background enabled him to spruce up a disorderly town, and he soon granted it recognition as an independent city (1653). The religious orthodoxy he attempted to impose on his already multicultural domain, however, soon led him to clash with the Quaker population of Flushing (1657). Ultimately, Stuyvesant was ordered by his superiors to "shut his eyes" to dissenters so long as they did not disrupt society or trade. The governor found such official blindness difficult, and his imperious nature continued to alienate town burghers. When a British fleet sent by James, Duke of York (the future James II), appeared off Gravesend in August 1664, Stuyvesant discovered that no one would fight for his colony. "Old Peg Leg" was soon forced to surrender without even firing a shot. Interestingly, he chose to take an oath of allegiance to the English crown and lived out his life in the city. Despite a brief Dutch reoccupation in 1673–74, the destiny of the colony (which had been renamed in honour of James) had shifted to London. Within the conquered city, resident Dutch and incoming English merchants got along quite well, and representatives of both groups constituted a city elite into the 19th century.

A series of English governors ruled New York and hoped that its commerce would make them rich. New York held the flour-bolting monopoly for the area (1680), was declared the sole port of entry for the colony, and its active community of merchants carried on a world trade. Thomas Dongan, a Roman Catholic governor, granted a royal charter of incorporation to the city in 1686 and furthered religious toleration and representative government within the colony. Following the Glorious Revolution in England (1688–89), the brief tenure of Jacob Leisler marked a period of intolerance new to the city and left a heritage of class factionalism that endured for several decades after his execution for treason in 1691. By 1700 the city had nearly 5,000 residents and was connected to the mainland for the first time by the construction of the Kings Bridge to the Bronx.

Tensions between merchant aristocrats, who sought to avoid imperial trade regulations, and venal governors, who were willing to turn a blind eye if they were suitably rewarded, were abundant. Class and ethnic conflict was present, and in 1712 and 1741 public fear of African Americans led to repression and numerous executions. Indicative of a growing spirit of independence was the libel case of John Peter Zenger, a journalist whose weekly journal criticized the political machinations and cupidity of Governor William Cosby. In 1735 a jury of his peers found Zenger not guilty, determining that he had published the truth. The decision was a signal victory for freedom of the press and demonstrated growing civic disobedience within New York during pre-Revolutionary decades. By 1756 assembly leaders humbled royal governors by forcing them to accept annual salary appropriations. The city hosted the Stamp Act Congress (1765), and the Sons of Liberty used violence to prevent the use of excise-tax stamps. New York's merchant community led the nonimportation program that forced repeal of the measure in 1766, even as the assembly refused to deliver food and cider to British soldiers quartered in the city. Clashes between the Sons of Liberty and soldiers were unending, and the first "battle" of the American Revolution was fought on Golden Hill (south of present City Hall) in January 1770. New York's "tea party" took place in April 1774, months after Boston's famous depredations, but it was held in daylight and without any disguises. New York issued the proclamation calling for a Continental Congress, and its citizens forced the resident royal governor to take refuge on a ship in the harbour long before independence was declared.

Growth of civic disobedience

Almost one-third of all the battles in the Revolution occurred in New York state, but the city's role was less than heroic. George Washington recognized the "infinite importance" of strategic New York, but in battles between August and October 1776 he was unable to defend the city. For seven years the city was occupied, during which its population declined and two fires destroyed many of its structures. Washington eventually returned to New York after the British evacuation in 1783. Quickly rebuilt, the city served both as state capital (until 1797) and as capital of the Confederation (1785–90); it hosted the inauguration of Washington as president, in April 1789. As the first capital of the United States, New York entertained the first meeting of Congress and the first sessions of the Supreme Court. When the capital was moved to Philadelphia for political reasons, Abigail Adams left the city in despair, for her new home would "not be Broadway."

GROWTH OF THE METROPOLIS

Despite the loss of the national government, New York's population skyrocketed in 1781–1800, and it became America's largest city. Once again trade grew rapidly, and not even the War of 1812 hindered development; an auction system for surplus British merchandise dumped in New York solidified the city's economic position after 1816. Even before the opening of the Erie Canal in 1825, New York enjoyed commercial primacy, but as trade from the interior continent flowed onto its piers the city also attained legal, insurance, and manufacturing primacy. Steamships, cheap transportation by rail and canal, abundant labour, and professional expertise made New York increasingly dominant. By the mid-1800s it handled more goods and people than all the other American ports combined. So secure was its position that in 1861 Mayor Fer-

nando Wood suggested it become a "free city" rather than fight against the South. New York instead provided more soldiers to the Union than any other city and survived the turbulent, violent Draft Riot of 1863. Despite the financial panics between 1837 and 1893, the city remained an economic juggernaut, and by 1900 it was the busiest port and one of the wealthiest cities in the world.

Prosperity in Manhattan was not shared by everyone. Two centuries of domination by the merchant elite ended in the city as the Democratic Party gradually assumed control of political power. Tammany Hall, a fraternal organization that formed in 1789, had been transformed into a party vehicle by Aaron Burr before the early 19th century; the group supported such popular reforms as universal male suffrage, the end of imprisonment for indebtedness, and lien laws. Most important, Tammany opposed the anti-Catholic attitudes of the elite and ministered to the needs of impoverished immigrants entering the city. By the 1850s it was able to count on their votes, and the resulting power base lasted for more than a century.

Draft riots of 1863

During the American Civil War, the city was shaken by its worst riots. For four days in July 1863 many thousands of rioters, mostly impoverished Irish immigrants who were infuriated by the new draft law that permitted a draftee to buy his way out of service, swept the city, looting, burning, and killing. African Americans were hanged from the streetlights and trees. Warships trained guns on the city, as rioters clashed repeatedly with the police, national guardsmen, and the army. At least 2,000 people were killed and thousands more wounded, and all business halted in the face of the armed conflict.

After the war there was a steady clamour in the city for a merger with Brooklyn, Queens, the Bronx, and Staten Island. The strongest resistance came from Brooklyn, a city in its own right; with good reason it feared that the corruption so evident in Tammany Hall under the first recognized political "boss," William Magear Tweed—who never rose higher in the city hierarchy than supervisor but who controlled mayors, governors, and legislatures—and later Richard Croker, would be extended to Brooklyn through any consolidation. "Tweed ring" corruption siphoned tens, perhaps hundreds, of millions of dollars into private hands until, in 1871, a coalition of reformers overthrew the boss. Tweed's successor as county leader, John Kelly, was a more astute politician who transformed the undisciplined hordes of Tammany into an army. Regimentation down to the block level replaced greed as a ruling party principle, although the organization always remained a source of food, legal help, and jobs for its faithful supporters.

GREATER NEW YORK

The Democratic machine reigned, its excesses became apparent, reformers arose and were temporarily triumphant, and then voters restored a chastened Tammany to power. A generation after Tweed fell, the Croker regime was successfully challenged by reformers who elected Mayor William Strong. Once consolidation won voter support, the addition of nearly 1.5 million people to the city and the opportunity to expand Tammany's patronage base lured Croker back to Manhattan. After January 1, 1898, the machine ruled Greater New York, its power constantly enhanced by new waves of arriving immigrants. As always, the machine added to urban infrastructure: the subways with their fixed five-cent fare, new bridges, and an expanded park system brought the boroughs together and added to its authority. The booming garment industry, ceaseless construction, and extensive manufacturing provided jobs for the strong, while an excellent educational system trained millions for the white-collar and civil-service jobs that would become increasingly preponderant after the mid-20th century. In the "good years" before World War I and in the "Roaring Twenties" that followed the war, Tammany, under the leadership of Charles Murphy, generally held sway.

Scandals and reforms

In the mid-1920s and early 1930s a series of municipal scandals, which led to another wave of reform, were perhaps the result of Mayor James Walker. A playboy addicted to the wonders of city nightlife, Walker left the mechanics of governing to Tammany. Despite the ravages of the Great Depression and the hardships of World War II, Fiorello La Guardia's administration represented a high point in the city's history. Enormous amounts of New Deal funding enabled the city to complete vast construction and other projects; the Tammany Tiger was caged, the government was centralized and modernized, and the subway system was completed and unified. La Guardia dominated the news, cracked down on crime, and even read comic strips to children during a newspaper strike. Only when he chose to retire did Tammany regain control.

Postwar New York experienced an era in which alarming structural problems in urban society became ever more apparent. New York port lost its dominance, manufacturing began its long decline, massive city debt made it increasingly difficult to fund expensive services, and levels of municipal bureaucracy proliferated. In the 1950s Robert Wagner initiated major housing programs and granted collective bargaining rights to city unions but was often accused of ignoring long-term problems. Ultimately, he found it expedient to publicly break with a Tammany Hall that had twice gotten him elected. Wagner destroyed the power of the machine and its last boss, Carmine DeSapio. He was able to install his own Manhattan county leader and undermine Tammany's influence in the outer boroughs, but he did little to deal with the looming problems. Wagner prepared the electorate for another reform administration, as Republican-Liberal candidate John Lindsay unexpectedly won election in 1965.

During Lindsay's two terms, New York's downward spiral accelerated as he attempted to impose administrative order. A massive transit strike coincided with his inauguration and was settled only with the first of several generous union contracts. Lindsay's attempt to further undermine the power of the machine by merging departments and creating "superagencies" only added new levels of bureaucratic structure. His efforts to decentralize the school system and broaden minority participation in government led to greater ethnic animosity. Above all, he failed to gain control of a soaring municipal budget, even though he increased taxes. Denied renomination in 1969 by outraged Republicans, Lindsay won reelection as a Liberal-Independent candidate, because the old Democratic machine had been gutted. His subsequent feud with a Republican governor led him to become a Democrat. During his last years in office, the metropolis continued to deteriorate financially.

Beame's administration

The election of Abraham Beame in 1973 was the last gasp of old-style politics in New York. Beame was a product of the organization, and as the first Jewish mayor he represented the ethnic succession to power that Irish and Italians had previously achieved. Conditions had changed, and Beame's term was dominated by fiscal disaster. In every way but formally the city went bankrupt, and in 1975 budgetary control was assumed by state agencies. The federal Securities and Exchange Commission later condemned Beame's fiscal policies. Much of the country, always suspicious of New York's foreignness and arrogance, cheered as the Big Apple was shown to be full of worms. Many believed it would be years before it could recover from the debacle.

In the late 1970s Edward Koch restored fiscal health to the city in a single term. By working closely with state officials, rigorously controlling expenditures, and instituting a modern accounting system, Koch once again marketed city notes. His extraordinary feat won him nomination by both major parties in 1981, a unique accomplishment but also clear proof that politics in the metropolis had changed. Democratic nominations were soon negotiated by five relatively equal borough organizations that had to be media-friendly. The Republicans were so powerless that they amassed fewer votes than the Liberal Party in the election of 1985. Koch was outspoken, intolerant of opposition, frequently capricious, and prone to see himself as above politics. Fittingly, his third term became a public relations nightmare when some of his important appointees and elected Democrats were involved in municipal scandals. His attempt to become the first four-term mayor ended when he lost the Democratic primary to David Dinkins, the borough president of Manhattan. Some saw Dinkins, an African American, as fulfilling the theme of ethnic succession, but he proved to be a poor administrator and was



The shattered remnants of the World Trade Center's south tower following the September 11 attacks.
Shawn Baldwin—AP/Wide World Photos

so dependent on African American votes that he alienated other parts of the coalition that elected him. Both ethnic tensions and crime statistics increased during his term, and he became the first black mayor of a major U.S. city to be denied reelection.

Race and competence, not party affiliation, were the major factors that led to the election of Republican Rudolph Giuliani in 1993. A successful career prosecutor, he pledged to reduce taxes, improve or privatize city services, and regain control of the streets from criminals. His great successes in reducing crime won him national fame. Giuliani nurtured his reputation as an angry man indifferent to criticism. Although New York reduced its welfare caseload and instituted a vast workfare alternative, the mayor was unable to eliminate other parts of the social "safety net." Courts consistently limited his initiatives in cases involving free speech, land use, and the rights of the homeless, and many observers held him responsible for instances in which the city's police department used excessive force in its war on crime. His elections may perhaps be best interpreted not as Republican triumphs but as mandates for a stern teacher empowered to deal with a disorderly classroom.

In the 1990s New York experienced sustained growth in both population and financial stability. Hundreds of thousands of immigrants were added to its population, while a sustained boom on Wall Street invigorated the economy of every borough. In addition, major renovations of its infrastructure were completed, such as the restoration of Grand Central Station.

Because of its prominence and its central role in world commerce, however, the city remained vulnerable to acts of terrorism, most notably two attacks on the World Trade Center complex. In 1993 a bomb in one of the complex's twin towers killed several people and injured some 1,000. The attacks of September 11, 2001, were far more devastating: Islāmic militants flew hijacked commercial airliners into the towers, leading to their collapse. The attacks on the towers killed some 2,800 people and badly shook the residents of both the city and the country. The aftermath of the attacks, near the end of Giuliani's term in office, was seen even by the mayor's detractors as his finest hour, when he stalwartly led the city through perhaps its greatest crisis. He was succeeded by fellow Republican Michael R. Bloomberg.

September 11 attacks

In spite of the attacks New York's importance did not wane. The host city of the United Nations, it continued to be the country's most international city and one of the world's foremost tourist destinations. New York, at the outset of the 21st century, remained the preeminent American city.

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New Zealand

New Zealand is an independent member of the Commonwealth. It is remote from other lands, being situated in the South Pacific more than 1,000 miles (1,600 kilometres) southeast of Australia, its nearest neighbour. The country comprises two main islands—the North and South islands—and a number of small islands, some of them hundreds of miles from the main group. New Zealand is about 1,000 miles long (north-south) and about 280 miles across at its widest point. The land area is approximately 100,000 square miles (268,000 square kilometres)—slightly smaller than the state of Colorado and a little larger than the United Kingdom. About two-thirds of the land is economically useful, the remainder being mountainous. Because of its numerous harbours and fjords, the country has an extremely long coastline relative to its area. The capital city is Wellington, and the largest urban area is Auckland, both located on the North Island. New Zealand administers the South Pacific island group of Tokelau and claims a section of the Antarctic continent. Niue and the Cook Islands are self-governing states in free association with New Zealand.

New Zealand was the largest country in Polynesia before it was annexed by the British in 1840. Thereafter it was, successively, a crown colony, a self-governing colony (1856), and a dominion (1907). By the 1920s it controlled almost all of its internal and external policies, although it did not become fully independent until 1947, when it adopted the Statute of Westminster.

The country's isolation has played an important part in its development. Nevertheless, New Zealand has been fully engaged in international affairs, being an active member of both the League of Nations and the United Nations. It has also participated in several wars, including World Wars I and II. Economically, the country was dependent on the export of agricultural products, especially to Great Britain, for much of the 20th century. The entry of Britain into the European Community in the early 1970s, however, forced New Zealand to expand its trade relations with other countries. It also has begun to develop a much more extensive and varied industrial sector. (J.W.R./M.A.Ro./Ke.S.)

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Physical and human geography

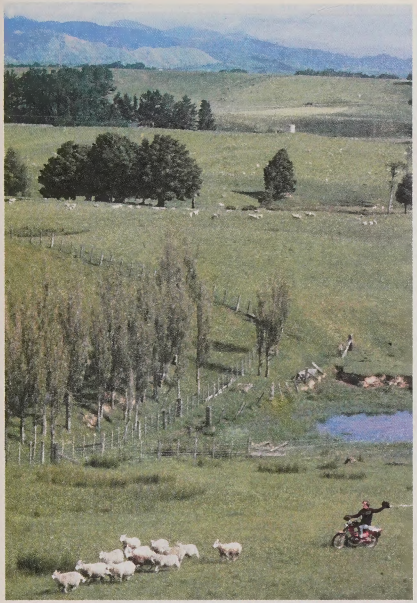
THE LAND

Relief. Although New Zealand is small, its geological history is as complex as that of a continent. Land has existed in the vicinity of New Zealand for most of the last 500,000,000 years. The earliest known rocks originated as sedimentary deposits of Late Precambrian (older than 570,000,000 years) or Early Cambrian age; their source area was probably the continental forelands of Australia and Antarctica, then part of a nearby single supercontinent. Continental drift (the movement of large plates of the Earth's crust) created a distinct island arc and oceanic trench structure by Carboniferous time (315,000,000 to 280,000,000 years ago), when deposition began in the synclines (trenches) of the sedimentary rocks that today make up some three-fourths of New Zealand. This environment lasted about 250,000,000 years and is typified by both synclinal oceanic sedimentary rocks and by terrestrial volcanic rocks. This period was terminated in the west at the beginning of the Cretaceous (about 135,000,000 years ago) by the Rangitata Orogeny (mountain-building episode), although synclinal deposition continued in the east. These mountains were slowly worn down by erosion, and the sea transgressed, eventually covering almost all of the land. At the end of Oligocene time (about 26,000,000 years ago) the Kaikoura Orogeny began, raising land above the sea again, including the Southern Alps of the South Island. Many of the great earth movements associated with this final orogeny took place (and take place today) along faults, which divide the landscape into great blocks, chief of which is the Alpine Fault of the South Island. The erosion and continued movement of these faulted blocks, together with the continuing volcanism of the North Island, define to a large extent the landscape of the country.

The role of continental drift

Both the North and South islands are roughly bisected, by mountains in the South and by ranges of hills in the North. Swift, snow-fed rivers drain from the hills, although only in the east of the South Island have extensive alluvial plains been built up. The alluvial Canterbury Plains contrast sharply with the precipitous slopes and narrow coastal strip of the Westland region on the west coast of the South Island. The Southern Alps are a 300-mile-long chain of fold mountains containing New Zealand's highest mountain—Mt. Cook (in Maori, Aorangi) at 12,316 feet (3,754 metres)—and some 20 other peaks that rise above 10,000 feet, as well as an extensive glacier system with associated lakes.

There are more than 360 glaciers in the Southern Alps. The Tasman Glacier, the largest in New Zealand, with a length of 18 miles and a width of more than one-half mile, flows down the eastern slopes of Mt. Cook. Other important glaciers on the eastern slopes of the Southern Alps are the Murchison, Mueller, and Godley; Fox and Franz Josef are the largest on the western slopes. The North Island has seven small glaciers on the slopes of Mt. Ruapehu.



Rounding up sheep by motorcycle on the Takapau Plains, near Hastings, North Island.
©Robert Frerck—Odyssey Productions

In the north of the South Island, the Alps break up into steep upswelling ridges. On their western face there are mineral deposits, and to the east they continue into two parallel ranges, terminating in a series of sounds. To the south, the Alps break up into rugged, dissected country of difficult access and magnificent scenery, particularly toward the western tip of the island (called Fiordland). On its eastern boundary this wilderness borders a high central plateau called Central Otago, which has an almost continental climate.

The North Island is much less precipitous than the South and has a more benign climate and greater economic potential. In the centre of the island the Volcanic Plateau rises abruptly from the southern shores of New Zealand's largest natural lake, Taupo, itself an ancient volcanic crater. To the east ranges form a backdrop to rolling country in which pockets of great fertility are associated with the river systems. To the south more ranges run to the sea. On the western and eastern slopes of these ranges the land is generally poor, although the western downland region is fertile until it fades into a coastal plain dominated by sand dunes. To the west of the Volcanic Plateau fairly mountainous country merges into the undulating farmlands of the Taranaki region, where the mild climate favours dairy farming even on the slopes of Mt. Egmont, an isolated, extinct volcano.

The northern shores of Lake Taupo bound a large area of high economic activity, including forestry. Even further north there are river terraces sufficiently fertile for widespread dairy and mixed farming. The hub of this area is Auckland, which is situated astride an isthmus with a deep harbour on the east and a shallow harbour to the west. The region north of Auckland, called Northland, becomes gradually subtropical in character, marked generally by numerous deep-encroaching inlets of the sea bordered by mangrove swamps.

Hydrography

Drainage. The mountainous country of both islands is cut by many rivers, which are swift, dangerous, and a barrier to communication. The longest is the Waikato, in the North Island, and the swiftest, the Clutha, in the South. Many of the rivers arise from or drain into one or other of the numerous lakes associated with the mountain chains. A number of these lakes have been used as reservoirs for hydroelectric schemes, and artificial lakes, including Lake Benmore, New Zealand's largest, have been created for hydroelectric purposes.

Soils. New Zealand's soils are often deeply weathered, lacking in many nutrients, and, most of all, highly variable over short distances. Soils based on sedimentary rock formations are mostly clays and are found over about three-fourths of the country. Pockets of fertile alluvial soil in river basins or along river terraces form the orchard and market-gardening regions of the country.

In the South Island, variations in mean annual rainfall have had an important effect. The brown-gray soils of Central Otago are thin and coarse-textured and have subsoil accumulations of lime, whereas the yellow-gray earths of much of the Canterbury Plains, as well as areas of lower rainfall in the North Island, are partially podzolized (layered) with a gray upper horizon. The yellow-brown soils that characterize much of the North Island are often podzolized from acid leaching in humid forest environments. Their fertility varies with the species composition of their vegetation. Forests of false beech (*Nothofagus*), as well as of tawa and taraire, indicate soils of reasonably high fertility, while forests of kauri pine and rimu indicate podzolized soils.

Climate. New Zealand's climate is determined by its latitude, its isolation, and its physical characteristics. Across such vast oceans as surround it, weather from elsewhere has little influence. There are no extremes of temperature.

A procession of high-pressure systems (anticyclones) separated by middle-latitude cyclones and fronts cross New Zealand from west to east. Characteristic is the sequence of a few days of fine weather and clear skies separated by days with unsettled weather and often heavy rain. In summer subtropical highs are dominant, bringing protracted spells of fine weather and intense sunshine. In winter middle-latitude lows and active fronts increase the blustery wet conditions, although short spells of clear skies also occur. Because of the high mountain chains that lie across the path of the prevailing winds, the contrast in climate from west to east is sharper than that from north to south. Mountain ranges are also responsible for the semicontinental climate of Central Otago.

Changes in altitude make for an intricate pattern of temperature variations, especially on South Island, but some generalizations for conditions at sea level can be made. The average seasonal and diurnal temperature range is about 18° F (10° C). Variation in mean monthly temperature from north to south is about 10° F (6° C). In most parts of the country daytime highs in summer are above 70° F (21° C), occasionally exceeding 81° F (27° C) in the north, while in winter daytime highs throughout the country are rarely below 50° F (10° C).

Rainfall is highest in areas dominated by mountains exposed to the prevailing westerly and northwesterly winds. Although mean annual rainfall ranges from an arid 12 inches (300 millimetres) in Central Otago to as much as 315 inches in the Southern Alps, for the whole country it is typical of temperate zone countries (25–60 inches), usually spread reliably throughout the year. Snow is common only in mountainous regions, but frost is frequent in inland valleys in winter. Humidity ranges from 70 to 80 percent on the coast, generally being 10 percent lower inland. In the lee of the Southern Alps, where the effect of the foehn (a warm, dry wind of leeward mountain slopes) is marked, humidity can become very low.

Plant and animal life. The indigenous vegetation of New Zealand consisted of mixed evergreen forest covering perhaps two-thirds of the total land area. The islands' prolonged isolation has encouraged the development of species unknown to the rest of the world; almost 90 per-


Scale 1:7,499,048
1 inch equals approx. 118 miles
0 25 50 75 100 125 mi
0 50 100 150 200 km
Cities over 100,000
Cities 25,000 to 100,000
Cities under 25,000
National capitals
Canals
Glaciers
National parks
Spot elevations in metres
170°
173°
176°
179°
167°
35°
38°
41°
44°
47°
THREE KINGS ISLANDS
Cape Reinga
North Cape
Great Exhibition Bay
Cape Kiwitan
Bay of Islands
Tauroa Point
Cape Brett
Kerikeri
Russell
Kaikohe
Hokianga Harbour
Whangarei
Dargaville
Tasman Bay
NORTH ISLAND
GREAT BARRIER ISLAND
Kaipara Harbour
Hauraki Gulf
Coromandel Peninsula
East Coast Bays
Auckland
Manukau
Papakura
Manukau Harbour
Pukekohe
Tuakau
Pukekura
Waiuku
Waiuku Beach
Morrinsville
Hamilton
Tauranga
Bay of Plenty
Te Aroroa
East Cape
Huiki
Te Awamutu
Matamata
Putaruru
Opotiki
Kawhia Harbour
Cambridge
Rotorua
Lake Rotorua
Waiotapu
Waiotapu
Tokaanu
Lake Taupo
Mokau
Taupo
Waikato
Waikato
Waitara
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cent of the indigenous plants are peculiar to the country. Today, dense "bush" survives only in areas unsuitable for settlement and in parks and reserves. On the west coast of the South Island this mixed forest still yields most of the native timber used by industry. Along the mountain chain running the length of the country, the false beech is the predominant forest tree.

European settlement made such inroads on the natural forest that erosion in high-country areas became a serious problem. The State Forest Service was established to repair the damage by forest-management techniques and reafforestation with exotic trees. Experimental areas on the Volcanic Plateau were planted with radiata pine, an introduction from California. This conifer has adapted to New Zealand conditions so well that it is now the staple plantation tree, growing to maturity in 25 years and having a high rate of natural regeneration. Large areas of the Volcanic Plateau, together with other marginal or subagricultural land north of Auckland and near Nelson, are now planted with this species.

European broadleafs are widely used ornamentally, and willows and poplars are frequently planted to help prevent erosion on hillsides. Gorse has acclimatized so readily that it has now become a menace, spreading over good and bad land alike, its only virtue being as a nursery for regenerating bush.

Because of New Zealand's isolation there was no higher animal life in the country when the Maori arrived (some 1,000 or more years ago). There were two species of lizard: the gecko, which is born directly instead of being hatched from an egg, and the tuatara, a "beak-headed" reptile extinct elsewhere for 100,000,000 years. There were also a few primitive species of frog and two species of bat. These are all extant, although confined to outlying islands and isolated parts of the country.

In addition to their domestic animals, Europeans also brought other species with them. The red deer, introduced for sport, and the Australian opossum (for skins) have multiplied beyond imagination and do untold damage when browsing in the high-country bush. The control of



Snowcapped Mitre Peak, reflected in the waters of Milford Sound, Fiordland National Park, South Island.
© Delias and John Heaton—CUCK/Chicago

goats, deer, opossums, and rabbits—even in the national parks—is a continuing problem.

Flightless birds

In the absence of predatory animals, New Zealand was a paradise for birds, the most interesting of which are flightless. The moa was a very large bird, easily exterminated by the Maori. The kiwi, another flightless species, is extant, though only in secluded bush areas. The weka and the notornis, or takahe (barely rescued from extinction), probably became flightless after arrival. The pukeko, a swamphen relative of the weka, is even now in the process of losing the use of its wings. Some birds, such as the saddleback and the native thrush (thought to be extinct), are peculiar to New Zealand, but many others, such as the tui, the fantail, and the bellbird, are closely related to Australian birds. Birds that breed in or near New Zealand include the Australian (Australasian) gannet, the skua, the penguin, the shag, and the royal albatross.

Because New Zealand is the meeting place of warm and cool currents, a great variety of fish is found in its waters. Tropical species such as tuna, marlin, and some big-game sharks are attracted by the warm currents, which are locally populated by snapper, trevally, and kahawai. The Antarctic cold currents, on the other hand, bring the blue and red cod and the hake, while some fish, tolerant to a considerable range of water temperature, are found off the entire coastline—tarakihi, grouper, and bass. Flounder and sole abound on tidal mudflats, and crayfish are prolific in rocky areas off the coastline.

(J.W.R./M.A.Ro./W.Mo.)

THE PEOPLE

Ethnic structure. New Zealand was one of the last sizable land areas suitable for habitation to be populated by human beings. It was first settled by Polynesians who came from somewhere in eastern Polynesia, possibly from what is now French Polynesia. They remained isolated in New Zealand until the arrival of European explorers, the first of whom was the Dutchman Abel Janszoon Tasman (1642). During that time they grew in numbers to between 100,000 and 200,000, living almost exclusively on North Island. They had no name for themselves but eventually adopted the name Maori (meaning "normal") to distinguish themselves from the Europeans, who, after the voyages of the Englishman Capt. James Cook (1769–77), began to come with greater frequency.

Threats to the Maori population

The Europeans brought with them an array of diseases to which the Maori had no resistance, and this precipitated a rapid decline in the Maori population. Their reduction in numbers was exacerbated by widespread intertribal warfare (once the Maori had acquired firearms) and by warfare with Europeans. By 1896 there were only about 42,000 Maori left. Early in the 20th century, however, their numbers began to increase as they acquired resistance to such diseases as measles and influenza and as their birth rate subsequently recovered.

Europeans had begun to settle in New Zealand in the 1820s; they arrived in increasing numbers after the country was annexed by Great Britain in 1840. By the late 1850s settlers outnumbered Maori, and in 1900 there were some 772,000 Europeans, most of whom by then were New Zealand-born. Although the overwhelming majority of immigrants were of British extraction, other Europeans came as well, notably from Scandinavia, Germany, Greece, Italy, and the Balkans. Groups of central Europeans came between World Wars I and II, and a large body of Dutch immigrants arrived after World War II. Asians coming to New Zealand have included Chinese and Indians and more recently a growing community of Pacific Islanders from Western Samoa, the Cook Islands, Niue, and Tokelau.

Contemporary New Zealand thus has a great majority of people of European origin, a significant minority of Maori, and smaller numbers of Pacific Islanders, Chinese, and Indians. This diverse society has produced some racial tensions, but they have been small compared with those found in other parts of the world. Although the Maori have legal equality with those of European descent (called *pakeha* by the Maori), many feel unable to take their full place in a European-type society without compromising their traditional values.

Language and religion. New Zealand is predominantly an English-speaking country. Virtually all Maori speak English, and about one-third of them also speak Maori. The Maori language is taught at a number of schools. The

only other non-English language spoken by any significant number of people is Samoan.

New Zealand is nominally Christian, some three-fifths of the population adhering to the Anglican, Presbyterian, Roman Catholic, and Methodist denominations. Minor Protestant sects, the Eastern Orthodox churches, Jewish congregations, and Maori adaptations of Christianity (the Ratana and Ringatu churches) account for nearly all of the rest, although a significant proportion of the population does not claim any religious affiliation. There is no established (official) religion, but Anglican cathedrals are generally used for state occasions.

Regional population. Because New Zealand is small and the population is relatively homogeneous, there are no sharply differentiated social or political regions. The North, however, is popularly regarded as being more enterprising, while the South is traditionally regarded as being conservative. While the west coast is romantically nostalgic for its rollicking gold-rush days, the east coast conjures up the picture of sheep barons on their extensive stations.

The New Zealand countryside is thinly populated, but there are many small towns and a number of provincial cities. Very small towns or villages are becoming more deserted as people drift to the bigger towns and cities.

The main urban areas are Auckland, the centre of the North and the main industrial complex; Hamilton, in the middle of the North Island; Wellington, centrally located at the southern tip of North Island and the political and commercial capital; Christchurch, in the middle of the South Island and the second largest industrial area; and finally, still farther south, Dunedin. Although New Zealand is notable for the strength of its rural sector, the great majority of people live in cities, and urban concentration is proceeding apace. There is also a marked difference in the degree of population growth of the two main islands—the North having about three-fourths of the total population, in sharp contrast to the earlier years of systematic settlement. As in the past, the great majority of Maori live on the North Island; since World War II, however, most Maori have become urban dwellers, as have the Pacific Islanders.

Demographic trends. The natural rate of increase has been highest for the Pacific Islanders and for the Maori, both having a more youthful population. Since World War II New Zealand has generally had an annual excess of arrivals over departures, a major contributor to overall population growth causing frequent debates over limiting immigration. Although in the past most immigrants came from Great Britain and The Netherlands, they have been surpassed by Pacific Islanders and Asians. Australia is the preferred destination of emigrants.

(J.W.R./M.A.Ro./Ke.S.)

THE ECONOMY

New Zealand has a small, developing economy with a relatively low standard of living compared with those of countries with similar economies, such as Australia and Canada. In the late 19th and early 20th centuries New Zealand's standard of living was one of the highest in the world, but since World War II the rate of growth has been one of the slowest among the developed countries. The main causes of this retardation have been the slow growth of the economy of the United Kingdom (which formerly was the main destination of New Zealand's exports) and the high tariffs imposed by the major industrial nations against the country's agricultural products (*e.g.*, butter and meat). Agricultural exports increased, however, after more liberalized international trade agreements took effect in the mid-1990s. Also, New Zealand attempted to evade these protectionist constraints by diversifying its farm economy and by expanding its manufacturing base. This has been achieved partly by large-scale government intervention.

Resources. Most minerals, metallic and nonmetallic, occur in New Zealand, but few are found in sufficient quantities for commercial exploitation. The exceptions are gold, which in the early years of organized settlement was a major export; coal, which is still mined to a considerable extent; iron sands, which are exploited both for export and for domestic use; and, most recently, natural gas. In addition to mining, construction materials, with which the country is well endowed, are quarried.

Apart from gold's brief heyday, biological resources have always been more significant than minerals. Domestic animals introduced from Europe have thrived in New Zealand. Forestry has always been important, but the emphasis has swung from felling the original forest for timber to afforestation with pine trees for both timber and pulp.

Use of hydroelectric power

The country has exploited its great hydroelectric potential to such an extent that hydroelectricity supplies a major percentage of the country's power. A notable feature of the New Zealand electricity grid is the direct-current cable linking the two main islands, enabling the South's surplus hydroelectric power to be used by the North's concentration of industry and people. Since the early 1970s geothermal and coal- and gas-fired stations have also been constructed. In addition, partnerships between government and private interests have undertaken the development of natural-gas reserves and the construction of the world's first plant producing gasoline from natural gas.

Agriculture, industry, and trade. New Zealand's farming base required a relatively complex economy. Highly productive pastoral farming, embracing extensive sheep grazing and large-scale milk production, was made possible by a temperate climate, heavy investment in land improvement (including the introduction of European grasses and regular application of imported fertilizers), and highly skilled farm management by owner-occupiers, who used one of the highest ratios of capital to labour in farming anywhere in the world. The farms supported and required many specialized services: finance, trade, transport, building and construction, and especially the processing of butter, cheese, and frozen lamb carcasses and their by-products. This economy could be described as an offshore European farm, which exported wool and processed dairy products and imported a variety of finished manufactured consumer and capital goods, raw materials, and petroleum.

Industry

Even in the 19th century New Zealand's relative geographic isolation made necessary a proportionately large industrial labour force engaged in the manufacture and repair of agricultural machinery and in shipbuilding, brewing, and timber processing. After the 1880s the factory processing of farm products swelled these numbers, while the temporary isolation of World Wars I and II stimulated the production of a wide range of manufactured goods that previously had been imported. Protectionist policies first espoused, although weakly, by governments in the late 19th century were strengthened after World War I. From the end of World War II until the early 1970s manufacturing industries were protected by import licensing fees in order to maintain full employment. Thus, there developed some labour-intensive, heavily protected, and uneconomic activities—such as automobile and consumer-electronics assembly—that have not been able to remain competitive (see below *Administration of the economy*).

Trade

Since the 1960s there has been a proportionate decline in pastoral farming in relation to growth in forestry (and the production of paper and other wood products), horticulture, fishing, and deer farming, as well as manufacturing. Tourism has also become an important component of the economy. There has been a related change in the composition of exports, although wool, meat, and dairy products have continued to predominate. Since the importance of trade with Great Britain has been reduced, that with Japan, the United States, and East Asian countries has grown. Trade with Australia has always been significant. A succession of trade agreements (1933, 1965, 1977) provided the basis of the Australia and New Zealand Closer Economic Relations Trade Agreement (CER), signed in 1983. This agreement eventually eliminated duties and commodity quotas between the two countries and was seen by some as the first step toward integrating their economies. In 1995 CER joined with the Association of Southeast Asian Nations Free Trade Area to promote trade and investment between the two regions.

Finance. Banking was established early in New Zealand. By the early 1970s an oligopolistic structure had emerged, consisting of several large trading banks (the largest being state-owned and the others foreign-owned), presided over

by a central bank—the Reserve Bank of New Zealand—and supplemented by other types of specialty institutions. Since the early 1980s the financial sector has been transformed by the trading banks' loss of their privileged position and by the removal of government controls over financial institutions. The capital market has become highly competitive, with new, often foreign-owned specialty institutions emerging. In addition, in the mid-1980s transactions in foreign exchange were freed, and for the first time the exchange rate was floated in a competitive market.

Transportation. In spite of the rugged nature of the country, most of the inhabited areas of New Zealand are readily accessible; the road system is good even in rural districts, and modern freeways have been built around the main cities. The private automobile has long been the most important mode of transportation. In addition, bus services link most centres. The difficult country makes for slow journeys, although the distances involved are seldom great.

The railway network, owned and operated by the Tranz Rail Limited is independent of direct government control. It comprises a main trunk line spanning both islands via roll-on ferries and branch lines linking most towns. Narrow tunnels limit the gauge of line, which until the late 20th century precluded the introduction of fast express trains. Rail travel is notoriously slow, discouraging passenger travel, but service is efficient for large-scale movement of goods over considerable distances. Long-standing regulations protecting the railways against competition by road carriers were abolished in the early 1980s, and as a consequence long-distance road cartage has increased.

The difficult terrain has greatly encouraged air travel in New Zealand; most provincial towns have airports, and all major centres are linked by air service. The main internal airline, Air New Zealand, was privatized in the late 1980s; it, along with several foreign airlines, handles the country's international service, with the main international air terminals at Auckland, Christchurch, and Wellington.

Administration of the economy. New Zealand has had a long history of government intervention in the economy, ranging from state institutions competing in banking and insurance to an extensive social security system. Until the early 1980s most administrations strengthened and supported this paternalism or state socialism, but since then government policy has generally shifted away from intervention, although no move has been made to dismantle the basic elements of social security. Some of the subsidies and tax incentives to agricultural and manufacturing exporters have been abolished, and such government enterprises as the Post Office have become more commercially oriented and depend less on government subsidies. In addition, the government has attempted to resolve the difficult issue of restrictive practices in the labour market, such as restrictions on the entry into some occupations.

The labour force has long been organized into strong trade unions. Like Australia, New Zealand evolved a system of compulsory arbitration in which the government played a major role. Beginning in the late 1960s, however, government policy generally alternated between periods of government-imposed freezes in wages and prices and periods of officially tolerated bargaining between unions and employers, although the strong link between the labour markets of New Zealand and Australia was a major constraint on the establishment of a set policy. However, compulsory union membership was ended in 1991, after which the number of union members fell dramatically.

Taxation

Taxation in New Zealand in relation to national income is not particularly high in comparison to other developed countries. Direct taxation (taxation of personal income) has traditionally been the primary tax. In the mid-1980s a value-added tax was introduced on goods and services.

(J.W.R./M.A.Ro./C.A.Bl./Ed.)

ADMINISTRATION AND SOCIAL CONDITIONS

Government. *Constitutional practice.* New Zealand has a parliamentary form of government. Legislative power is vested in the single-chamber House of Representatives (Parliament), the members of which are elected for three-year terms. There are two dominant parties, National and Labour; the party that commands a majority in the House forms the government. The leader of the governing party becomes the prime minister, who forms a cabinet. The cabinet is the central organ of executive power. Most legislation is introduced by the government; Parliament must then pass it by a majority vote before it can become law. The cabinet, however, has extensive regulatory powers that are subject to only limited parliamentary review. Because cabinet ministers sit in the House and because of invariably strong party discipline, legislative and executive authority are effectively fused.

The British monarch is the formal head of state and is represented technically by a governor-general appointed by the monarch (upon the recommendation of the New Zealand government) to a five-year term. The governor-general has only limited authority but does have some residual powers to protect the constitution and to act in a situation of constitutional crisis (*e.g.*, the governor-general can dissolve Parliament under certain circumstances).

The structure of the New Zealand government is relatively simple, but the country's constitutional provisions are more complex. Like that of Great Britain, New Zealand's constitution is a mixture of statute and convention. Where the two clash, convention has tended to prevail. The Constitution Act of 1986 simplified this by consolidating and augmenting constitutional legislation dating from 1852.

Electoral system. There is universal suffrage for those 18 years of age and older. In 1993 the electorate voted to replace the country's plurality system with the mixed-member proportional system, which gave each voter two votes, one for an individual candidate and one for a party. The new system also enlarged the Parliament to 120 seats, with 67 representatives elected (including 6 reserved for Maoris) from multi-member constituencies and 53 through party lists.

The two-party system

While the new system gave a boost to smaller parties, National and Labour remain New Zealand's two major parties. The National Party's base of support is in rural and affluent urban districts and among those involved in business and management. The Labour Party draws support from trade unions and urban blue-collar workers. Over time, however, both parties have broadened their electoral bases. Labour has gained the support of some areas of the business sector and has succeeded in attracting more professionals, while the National Party has had some success among higher paid workers in key small-town and provincial districts. Increasingly, ideological differentiation between the two parties has become complex, and intraparty differences in such areas as economic policy have often been greater than they have been between parties.

Bureaucratic organization. The business of government is carried out by some three dozen government departments of varying size and importance. Most departments correspond to a ministerial portfolio, department heads being responsible to their respective ministers for administration of their departments. Recruiting and promoting civil servants is under the control of the State Services Commission, which is independent of partisan politics. Heads of departments and their officials do not change with a change of government, thus ensuring a continuity of administration.

As a check upon possible administrative injustices, the office of parliamentary commissioner for investigations (ombudsman) was established in 1962; the scope of the office's jurisdiction was enlarged in 1968 and again in 1975. In addition, the Official Information Act of 1982 permits public access, with specific exceptions, to government documents.

There are also a certain number of non-civil service appointees within the government. These fill positions in government corporations—commercial ventures, such as the Broadcasting Corporation of New Zealand and the Bank of New Zealand, in which the government is the sole or major stockholder—and in a host of bodies with administrative or advisory functions. Political affiliations, as well as expertise and experience, often figure in appointment decisions for these institutions.

Local government. Local government, the power of which is limited to all but peculiarly local matters, is di-

rectly empowered by parliamentary statute. Local authorities are thus relatively autonomous, although they do depend upon the central government for financial assistance. The definition of their function and powers is constantly being revised to meet changing conditions.

Local bodies perform general-purpose duties such as those of counties, boroughs, cities, and town districts or else consist of ad hoc authorities with specialized functions such as harbour and electric-power boards. Every local authority activity is controlled by an elected council or board of local members, whose work is largely honorary. The platform for election is sometimes based on party affiliation, although this does not noticeably affect the working of the councils or boards.

Justice. New Zealand derives from the common law of Britain certain statutes passed before 1947 by the British Parliament. New Zealand law usually follows the precedents of English law. Nevertheless, the New Zealand courts have taken a more independent stance and have begun to play a more significant constitutional and political role with respect to public and administrative law. In addition, some members of the legal community have challenged the traditional doctrine that future Parliaments are not bound by laws passed by the Parliament, contending that certain common-law rights might override the will of Parliament.

The law is administered by the Ministry of Justice through its courts. The apex of New Zealand's judicial system is the Court of Appeal, which hears civil and criminal appeals from the High Court and District Courts. The British Privy Council is the final court of appeal for New Zealand. Law enforcement is the responsibility of the New Zealand Police, a cabinet-level department largely independent (with respect to law enforcement) of executive authority. (J.W.R./M.A.Ro./J.Vo./Ed.)

Education. Education in New Zealand is free and secular. It is compulsory between the ages of six and 16. In practice almost all children enter primary school at age five, while many of them have already begun their education in preschools, all of which are subsidized by the state. Education is administered by the Department of Education. Elected education boards control all of the primary and secondary state schools. There are also more than 100 private primary and secondary schools, most of them Roman Catholic or run by other religious groups. They also receive state subsidies and must meet certain standards of teaching and accommodation. State primary schools are coeducational, but there are still many single-sex secondary schools.

Technical institutes, community colleges, and teachers' colleges form the basis of higher education. There are also several universities and an agricultural college. Entry to the universities requires a modest educational achievement, which is often waived for people 21 years of age or older.

Since the early years of the colony, a great emphasis has been placed on education, and virtually the entire population is literate. There is a correspondence school that caters to children living in remote places, and various continuing education and adult education centres provide opportunities for lifelong education.

Social security

Welfare. New Zealand has one of the oldest social security systems in the world. Noncontributory old-age pensions paid for from government revenues were introduced in 1898. Pensions for widows and miners followed soon after, and child allowances were introduced in the 1920s. In 1938 the New Zealand government introduced the most extensive system of pensions and welfare in the world, which included free hospital treatment, free pharmaceutical service, and heavily subsidized treatment by medical practitioners.

Since then the system has been eroded in some respects but greatly extended in others. Doctors' fees, though still subsidized by the state, have become relatively high. Many people invest in private medical insurance and seek treatment in private hospitals. There is still a universal system called New Zealand superannuation, in which all citizens over the age of 65 are granted an income up to 65 percent of the average after-tax wage. However, this system was being phased out and was to be replaced by the retirement savings scheme in 2003; the transition to the new plan was expected to take more than 40 years.

There are numerous other pensions and welfare payments. These include an allowance for each child up to the age of 16 and additional "family care" payments for low-income families, as well as benefits for single parents, invalids, and the sick. Under the Accident Compensation Act of 1972, all persons suffering personal injury from any sort of accident, whether at work or not, can receive compensation for disability and loss of earnings, and they are covered by insurance for any medical or other treatment; in addition they waive the right to sue for damages. The act led to the establishment of the government-run Accident Compensation Corporation, to which all New Zealanders must pay premiums and which handles claims.

Nearly three-fourths of New Zealand's housing stock is owner-occupied. State agencies provide limited financial assistance toward home purchases and renovation work, as well as subsidized rental accommodations for those on low incomes. The state also subsidizes pensioner accommodations through local authorities.

CULTURAL LIFE

The cultural milieu in New Zealand is complex: it is predominantly European but also contains elements from many other peoples, particularly the Maori. Immigrant groups have generally tended to assimilate into the European life-style, although traditional customs are still followed by many Tongans, Samoans, and other Pacific Islanders. The Maori, however, have found themselves torn between the pressure to assimilate and the desire to preserve their own culture. The loss of much of their land in the 19th century undermined their political structures, and large-scale conversion to Christianity caused them to abandon traditional religious observances; but there has been a determined effort—especially since the mid-20th century—to preserve and revive artistic and social traditions. A renaissance has occurred in Maori wood carving and weaving and in the construction of carved and decorated meeting houses (*whare whakairo*). Maori songs and dances have become increasingly popular, especially among the young. Maori meetings—whether *hui* (assemblies) or *tangi* (funeral gatherings)—are conducted in traditional fashion, and ancient greeting ceremonies are strictly observed. The general public has become familiar with Maori art, which is displayed in numerous galleries and museums in New Zealand as well as worldwide.

Revival of Maori traditions

European cultural life has progressed rapidly since the early 20th century. Numerous writers were active in the late 19th century, the most successful of whom were historians, such as William Pember Reeves, and ethnologists, including S. Percy Smith and Elsdon Best. The work of the first genuinely original writers of fiction, the short-story writer Katherine Mansfield and the poet R.A.K. Mason, did not appear until the 1920s. During the difficult years of the Great Depression of the 1930s a group of poets appeared and established a national tradition of writing. Although influenced by contemporary English literature—T.S. Eliot and W.H. Auden were greatly respected—they wrote about their New Zealand experience. The most notable member of this group was Allen Curnow. A.R.D. Fairburn, Denis Glover, and Charles Brasch were other major poets. At the same time Frank Sargeson began writing the superb stories in New Zealand vernacular for which he became well known internationally.

Since World War II the work of these pioneering writers has been followed by that of such widely published and acclaimed poets as James K. Baxter and Kendrick Smithyman. Other notable poets include Ian Wedde and Elizabeth Smither. A number of novelists have also earned international reputations, notably Janet Frame, Keri Hulme, and Sylvia Ashton-Warner. These and other New Zealand writers have been greatly aided by the growth of the publishing industry in New Zealand during this time.

In the second half of the 20th century, painters began to rival writers in artistic accomplishment. The first to achieve international recognition, Frances Hodgkins, spent most of her life abroad. Since the 1960s, however, an unprecedented "art scene" has emerged, created initially by a

group of artists, including Colin McCahon and Don Binney, who were helped by the rise of private galleries in most large towns and cities. While often New Zealand in subject, the paintings from this group indicate how aware the painters were of international influences. This group paved the way for what has become a small legion of acclaimed artists.

Since the 1970s successful professional theatre companies have been established in the cities—including the Downstage in Wellington and the Mercury Theatre in Auckland—in contrast to the early companies that folded for want of sufficient audiences. Several symphony orchestras also have had growing support. New Zealand has produced some world-renowned singers, including Dame Kiri Te Kanawa, Inia Te Wiata, and Donald McIntyre. Some of the country's popular musical groups have also achieved international success.

Support of the arts

The state has moved progressively to assist and encourage the arts. The Queen Elizabeth II Arts Council through Creative New Zealand, its funding arm, gives annual grants in support of literature, theatre, music, modern dance and ballet, and opera, including for the preservation of Maori culture. In addition, New Zealand was one of the first countries to establish a fund to compensate writers for the loss of royalties on books borrowed from libraries rather than purchased. The national orchestra and a weekly cultural publication, the *New Zealand Listener,* are supported by the government through the Broadcasting Corporation of New Zealand, which controls Radio New Zealand and both channels of Television New Zealand. A Maori-language radio station began operations in 1996. The government also subsidizes a motion-picture industry that has received growing international recognition. The films by New Zealand directors Jane Campion and Peter Jackson have garnered particular notice.

Newspapers

Newspapers provide a high standard of reporting, with substantial coverage of world news provided largely by foreign agencies. No daily paper has a national circulation, but some from the large cities are distributed widely over their respective islands. Numerous local and regional dailies are also published.

Sports are the main leisure-time activity of most of the population in New Zealand. Participation in most major sports, particularly rugby football, is widespread. The inaugural World Cup of rugby, which New Zealand cohosted in 1987, was won by the country's national team, the All Blacks. Sailing is much enjoyed, particularly around Auckland, and New Zealand won the America's Cup yachting race in 1995 and again in 2000. Hiking and mountain climbing are popular outdoor activities; New Zealander Sir Edmund Hillary, who, with the Sherpa Tenzing Norgay, was the first to climb Mount Everest, became a national figure. The country has extensive ski slopes, especially on the South Island. Adventure sports have long been common on the islands, and in the late 20th century New Zealand helped popularize bungee jumping.

(J.W.R./M.A.Ro./Ke.S./Ed.)

For statistical data on the land and people of New Zealand, see the *Britannica World Data* section in the BRITANNICA BOOK OF THE YEAR.

History

DISCOVERY

The Maori

No precise archaeological records exist of when and from where the first human inhabitants of New Zealand came; but it is generally agreed that Polynesians from eastern Polynesia in the central Pacific reached New Zealand more than 1,000 years ago, possibly by AD 800 or even earlier. There has been much speculation on how these people made the long ocean voyage. Polynesians are known to have sometimes set sail in search of new lands, their canoes well-provisioned with food and plants for cultivation, and it is likely that the discoverers of New Zealand were on such a voyage. Few canoes probably made the dangerous journey, but the people from even one of these large, double-hulled craft could have produced the Maori population that the Europeans encountered in New Zealand in the 17th and 18th centuries. With them they brought the dog and the rat and several plants, including the kumara (a variety of sweet potato), taro, and yam.

The Polynesian period has been divided roughly into an early "Archaic" and a later "Classic Maori" phase. The transition between these two phases is uncertain, but it is thought to be linked to improvements in the raising and storage in a cooler climate of what had been tropical vegetables. In the South Island, if not elsewhere, the first Polynesians found moas (flightless birds) in immense numbers on tussock grasslands, and these became their major food supply. The agriculturalist Classic Maori encountered later by Europeans had only faint memories of the moa. The 18th-century Maori population was densest in the warmer northern parts of the country, where the Maori variant of Polynesian culture had reached its high point, particularly in the arts of war, canoe construction, building, weaving, and agriculture.

The first European to arrive in New Zealand was a Dutch sailor, Abel Janszoon Tasman, who sighted the coast of Westland in December 1642. His sole attempt to land brought only a clash with a South Island tribe in which several of his men were killed. After his voyage the western coast of New Zealand became a line upon European charts and was thought of as the possible western edge of a great southern continent.

In 1769–70 the British naval officer and explorer James Cook completed Tasman's work by circumnavigating the two major islands and charting them with a remarkable degree of accuracy. His initial contact with the Maori was violent, but harmonious relations were established later. On this and on subsequent voyages Cook, with the explorer and naturalist Joseph Banks, made the first systematic observations of Maori life and culture. Cook's journal, published as *A Voyage Towards the South Pole and Round the World* (1777), brought the knowledge of a new land to Europeans. He stressed the intelligence of the natives and the suitability of the country for colonization, and soon colonists as well as other discoverers followed Cook to the country he had made known.

EARLY EUROPEAN SETTLEMENT

European colonies

Apart from convicts escaping from Australia and shipwrecked or deserting sailors seeking asylum with Maori tribes, the first European New Zealanders sought profits—from sealskins, timber, New Zealand flax, and whale oil. Early New Zealand was an offshoot of Australian enterprise in whaling and other activities; Sydney, founded as a convict settlement in 1788, became a base for whaling in the South Pacific; and Kororareka (now called Russell), in the far north of New Zealand, became a stopping place for American, British, and French deep-sea whalers. Around both islands Australian firms set up tiny settlements of land-based bay whalers. Traders supplying whalers drew Maori into their economic activity, buying provisions and supplying trade goods, implements, muskets, and rum. Initially the Maori welcomed the newcomers; while the tribes were secure, the European was a useful dependent.

Maori went overseas, some as far as England. A northern chief, Hongi Hika, amassed presents in England, which he exchanged in Australia for muskets; back in New Zealand he waged devastating war on hereditary enemies. The use of firearms spread southward; a series of tribal wars, spreading from north to south, displaced populations and disturbed landholdings, especially in the Waikato, Taranaki, and Cook Strait areas. Europeans were soon to found colonies in these unsettled regions. Missionaries quickly followed the traders. Between 1814 and 1838 Anglicans, Wesleyan Methodists, and Roman Catholics set up stations. Conversion was initially slow, but by the mid-19th century most Maori adhered, for varying reasons, to some form of Christianity.

All of these newcomers had a profound effect upon Maori life. Warfare and disease reduced numbers, while new values, pursuits, and beliefs modified tribal structure. Christianity cut across the sanctions and prohibitions that had supplied Maori social cohesion. A capitalist economy, to which Maori were introduced both by traders offering new inducements (for instance, the brief demand for flax) and by missionaries bringing new agricultural techniques,

affected the whole material basis of life. At first in the north and later over the whole country a process of adjustment began, which has continued to the present day. By the late 1830s, chiefly through the Australian link, New Zealand had been joined to Europe. Settlers numbered at least some hundreds, and there were certain to be more. Colonization schemes were afoot in Great Britain, and Australian graziers were buying land from the Maori. These circumstances determined British policy.

ANNEXATION AND FURTHER SETTLEMENT

In 1838 the British government decided upon at least partial annexation. In 1839 it commissioned William Hobson, a naval officer, as lieutenant governor and consul to the Maori chiefs, and he, in the event, annexed the whole country, the North Island by the right of cession from the Maori chiefs and the South Island by the right of discovery. At first New Zealand was legally part of New South Wales; but in 1841 it became a separate crown colony, and Hobson was named governor. Before declaring the annexation of New Zealand, Hobson went through a process of discussion with the northern chiefs from which emerged the Treaty of Waitangi (February 1840). Under this instrument the Maori ceded sovereignty to the crown in return for protection and guaranteed possession of their lands; they also agreed to sell land only to the crown. Hobson promised an investigation into past "sales" of land to private individuals to ensure fair dealing. This treaty imposed a strong moral obligation upon the British government to act as guardian to the Maori.

The Treaty of Waitangi

Even before annexation had been proclaimed, the first organized planting of an English colony was under way. The New Zealand Association, founded in 1837 to colonize on the principles laid down by Edward Gibbon Wakefield, sent a survey ship, the *Tory*, in 1839. The agents on board were to buy land in both islands around Cook Strait. The company moved hastily because its founders were aware that British annexation was likely and would entail a crown monopoly of land sales and a consequent increase in price. "Purchases" were effected in great haste before Hobson could bring to an end such private transactions. Little effort was made to seek out the true Maori owners; this would have been difficult anyway, as Maori ownership was communal and titles had been disturbed by the warfare of the preceding quarter century. The company, combining skillful propaganda with outright trickery and brutality, enforced its claim to the land upon which New Plymouth, Wanganui, and Wellington in the North Island and Nelson in the South Island were founded in the 1840s. Later, through the crown, it secured other areas in the South Island where Otago (1848) and Canterbury (1850) were planted by separate associations. Meanwhile, Hobson moved the seat of government south from the Bay of Islands, bringing Auckland into existence (1840).

In the early 1840s settlement and government began to alarm the Maori. In the Cook Strait area a formidable chief, Te Rauparaha, obstructed settlement. Near the Bay of Islands there was open warfare, and Kororareka was repeatedly raided. Neither Hobson (died 1842) nor his successor, Robert FitzRoy, was able to overcome the Maori. George (afterward Sir George) Grey, who became governor in 1845, had money and troops and the will to use them. His victories brought a peace that lasted from 1847 until 1860. Hone Heke, the principal leader in the north, was thoroughly defeated (1846), and in the south a likely uprising was prevented. Racial strife had been accompanied by economic distress. In the mid-1840s the nascent economy was depressed until the Australian gold rushes of the 1850s offered a market for foodstuffs to the New Zealand farmer, settler and Maori alike.

War with the Maori

By the end of the 1840s racial and economic trouble gave way to political agitation. The leading settlements, apart from Auckland, began to campaign for representative government in place of Grey's personal rule. He, while refusing to give way, helped to draft the New Zealand Constitution Act of 1852, which was designed to meet all demands of the settlers. Grey sought not to prevent the introduction of self-government but to delay it until he had determined both native and land policy. He wished to begin the rapid assimilation of the Maori (with whom his relations were excellent) to the British pattern. He also wished to bring in a land policy that would safeguard the small farmer against the great owner. He believed he had secured these goals by the time of his departure at the end of 1853.

Responsible government. After the Constitution Act came into operation, New Zealand was divided into six provinces—Auckland, New Plymouth (Taranaki), Wellington, Nelson, Canterbury, and Otago—each with a superintendent and a provincial council. The central government consisted of a governor and a two-chamber legislature (General Assembly): a Legislative Council nominated by the crown, and a House of Representatives elected upon a low property franchise for a five-year term. This General Assembly did not meet until 1854; it then embarked upon a quarrel with the acting governor, Col. Robert Henry Wynyard, that was not ended until the achievement of full responsible government—*i.e.,* a system under which the governor could act in domestic matters only upon the advice of ministers enjoying the confidence of the elected chamber. Henry Sewell and James FitzGerald, of Canterbury, led the representatives in this struggle, against the opposition of Edward Gibbon Wakefield, who, having first moved the resolution for responsible government, then secretly opposed it while serving as extra-official adviser to the acting governor. The Colonial Office conceded responsible government in 1856. The next governor, Thomas (later Sir Thomas) Gore Browne, reserved Maori affairs to the competence of the governor alone.

For most purposes, during the 1850s New Zealand was administered not by central but by provincial institutions. These authorities (10 in number by the time of their abolition in 1876) directly affected the settler through their administration of land and control of immigration and public works. The native department, directly under the governor, bought land from the Maori; the provincial governments settled it, regulated immigration, and built roads and bridges. Until the wars of the 1860s the central legislature was less important, though its ultimate authority remained.

Provincial institutions

Each province disposed of a revenue arising from land sales, and upon this revenue depended its strength. Canterbury and Otago, with hardly any Maori, grew wealthy spending their money upon communications, immigration, and education. Other provinces were either less fortunate or less wise and enjoyed smaller success. In the North Island numerous and anxious Maori held onto desirable land. Here most of the land available for settlement had been taken up by the end of the 1850s, a good deal of it by speculators, and some of it was given away to attract immigrants. The island remained largely without roads until the 1870s, so impecunious were its governments. But by that time the major obstacle to settlement had been removed—the continuing power of the tribes. This was the result of a decade of war.

Racial conflict. In the 1850s race relations deteriorated. The settler population and the demand for land, especially pastoral land, increased. Many Maori, fearing for their future, became reluctant to sell more land. In the Taranaki Province, where the land shortage was acute, both settlers and those Maori willing to sell were opposed by Wiremu Kingi (Te Rangitake), chief of Te Atiawa. In the Waikato, where good land was coveted by settlers and speculators, an elderly chief, Te Wherowhero, became "king" in 1858, largely through the support of the Waikato and Maniopoto tribes, and reigned as King Potatau I. The Maori King Movement and also the unrest in the Taranaki headed by Wiremu Kingi (the two movements remained distinct though related) were opposed to further land sales.

Land sales

The likelihood of conflict was not reduced by any particular wisdom in government policy. Gore Browne was guided in native policy by the head of the Native Land Purchase Department, Donald (later Sir Donald) McLean, who, responsive to settler demands, increased pressure upon potential sellers. Grey's caution and his recognition that a chief could veto sales proposed by any section of his tribe were forgotten. McLean sowed a rich harvest of distrust. Christopher Richmond, the member of the Cabinet

in charge of native affairs, was also a Taranaki representative, fully responsive to the needs of his settler neighbours. The central ministry, theoretically unconcerned with native policy, could not, despite the promise of protection made to the Maori in the Treaty of Waitangi, neglect a matter so vital to the colony's future. In 1859 the representative of the crown unwittingly supplied the occasion for the outbreak of civil strife.

Gore Browne accepted an offer to sell from a Taranaki subchief, Te Teira, and ignored the veto imposed by the paramount chief, Wiremu Kingi. Early in 1860 troops were used to dislodge Kingi from the land in question, the Waitara block. A decade of fighting began. In 1861 Grey was sent back for a second term as governor in the hope that he would again prove to be a peacemaker. In fact he accelerated the extension of conflict. Fearing that Auckland was menaced by the followers of the Maori king, he took defensive measures that could easily be interpreted as acts of aggression, and the fighting subsequently spread from Taranaki to the Waikato. Imperial troops, colonial militia, and Maori allies (for not all the tribes supported the Maori nationalist movement) had no easy task, but their victory could not be postponed for long. By the mid-1860s Maori resistance in the Taranaki and Waikato was ended. But the "king" tribes were by no means crushed, and the fear that they would embark upon war again haunted the colony for many years.

In the later 1860s the fighting was of a different character, in which religion acted as a last, desperate stiffener of Maori resistance. Pai Marire (Hauhauism), an amalgam of Jewish, Christian, and native beliefs, was the first of many cults in which the Maori, rejecting the religion of settler and missionary, put their own imprint upon Christianity. Toward the end of the decade Te Kooti Rikirangi organized resistance on the east coast of North Island. He was the founder of another religious cult as well as a guerrilla of some note; his adaptation of Christianity, Ringatu, still has thousands of followers. Te Kooti was never finally defeated, but by the early 1870s he was forced to retreat into the "King Country" (the centre of the island), where he devoted the rest of his life to religious leadership.

An uneasy peace settled upon the colony in 1870. Casualties had not been high, but the loss of life was serious for the tribes concerned. Especially in those areas in which the Maori king retained some authority, defeat led to a period of withdrawal from settler society. Resentment was deepened by a punitive policy of land confiscation adopted by the victors, a policy improper in its nature and made worse in some places by undiscriminating application to "guilty" and "innocent" tribes alike. The Maori future looked black. By the Native Land Act of 1862, private land transactions between settler and Maori had been legalized, and during the next 40 years the Maori lost most of their best land. Many years were to elapse before Maori numbers, morale, and confidence could revive over the whole country.

Native Land Act

DEVELOPMENT OF THE COLONY

Fluctuation of the economy. Economic growth in the North Island had been considerably retarded by the wars. Meanwhile, the South Island, especially Canterbury and Otago, had grown increasingly prosperous. Pastoral farming expanded steadily, and the discovery of gold, first in Otago and then on the west coast, led to a sudden boom in production and trade. Population rose as diggers poured in; economic life quickened as gold brought prosperity, less to the digger than to bankers, merchants, land sellers, and farmers supplying provisions. The South Island share of the European population jumped from about 40 percent to 60 percent during the 1860s. The North Island did not recover its previous lead until the 20th century.

Discovery of gold

Attempts by other provinces to emulate the development of Canterbury and Otago normally ended in embarrassment (in one case in bankruptcy) as money was recklessly borrowed and spent. To preserve the colony's reputation, the central government in 1867 banned further provincial overseas borrowing. About this time depression struck the greater part of the country, especially the South Island, where the first alluvial gold had by then been worked out. The South Island was thus looking for a stimulus, while the ending of the wars now made further development possible in the North Island. It was widely agreed that only the central government could adequately revitalize the economy.

In 1870 a development policy was provided by Julius (later Sir Julius) Vogel, who at the time was colonial treasurer and who later served two terms (1873–75; 1876) as prime minister. He was convinced (not altogether accurately) that New Zealand was bursting with potential resources needing no more than the stimulus of capital and labour for their exploitation. He borrowed overseas capital for public works on an unprecedented scale and swelled the labour force with assisted immigrants.

Julius Vogel's development policy

Not all of Vogel's schemes were wisely conceived; the prosperity of the mid-1870s was more an investment boom than a solid growth of productivity. But the colony ended the decade with a doubled population (about 500,000) and the beginnings of efficient internal and external communications. Roads, bridges, railways, and telegraph systems had been built, and overseas shipping services improved. Private lending agencies contributed to the boom, and in a heady atmosphere land values and interest rates climbed alarmingly. The public debt greatly increased, and many of the men who had acquired land were in desperate financial straits. Falling overseas prices for farm products (chiefly wool and wheat), a declining gold output, a cautious note in government finance, and widespread unemployment marked the 1880s. Emigrant ships discharged their passengers at ports where unemployment was already rife. There had been growth in the 1870s, but it was succeeded by a depression that lasted until 1895.

Vogel abolished the provincial governments in 1876. They had earned his enmity by refusing to allow their lands to be used as security for public works and by blocking a forest conservation scheme. Essentially, they became outmoded when in the early 1870s the initiative in development passed to the central government. Provincial governments had been set up to colonize their districts; when the centre assumed this function they lost their raison d'être. Abolition came fairly painlessly; it was an affront more to local pride than to local prosperity. Only in Otago was there a strong attempt to resist change. Thereafter, provincial interests were long pursued by the respective delegates in the General Assembly, whose achievements were in no way diminished by the lack of particularist (provincial) institutions.

Economic depression

The governments of the 1880s, though led by men of some ability and imagination, such as Sir Robert Stout and Sir Harry Atkinson, did not deal effectively with the depression. The time-honoured remedy, spending loan money on development, was not fully given up until 1887. The basic problem was to find productive work for the country's labour force; closer land settlement was the remedy suggested in the 1880s and applied in the 1890s. Great areas, especially in the South Island, had fallen to large owners; these "monopolists" were attacked by the radicals, though probably the pastoral industry could not have been established under any other system. William Rolleston, minister of lands in the early 1880s, first proposed that the state should help men to become small farmers as state tenants; John (later Sir John) McKenzie and the Liberal government applied this remedy with vigour in the 1890s. But closer settlement and intensive farming did not of themselves create economic benefits, which in fact could not accrue until small farmers had a product to export and gained a good price for that product. Refrigeration and rising world prices provided the answer. It became possible in the 1880s to send to Great Britain refrigerated cargoes of butter, cheese, and meat; this encouraged the spread of small-scale intensive farming.

The Liberal era (1891–1912). The energetic Liberal government led by John Ballance, which took office in 1891, accelerated the process of change. It opened more land (much of it bought from the Maori), established farmers on perpetual state leaseholds, provided credit for land purchase and improvements, and built roads. So came into existence great dairying and meat producing areas, especially in the North Island. Dairy, meat, and also

wool prices rose in about 1895 and stayed generally high until about 1920.

This economic stimulus was not limited to farmers. Urban distress had been serious in the 1880s, for many recent immigrants had been townsmen who had stayed in New Zealand towns on arrival. The ultimate cure for their distress was for the towns to share in the farmers' high prices. Urban New Zealand depended upon the prosperity of the country. But other remedies were considered, and some of them were applied. In the 1880s there was serious discussion of insurance against sickness, poverty, and old age; the Old Age Pensions Act of 1898 was the first measure of social security. Tariff protection to foster industrial employment was halfheartedly applied in the late 1880s. Revelations of oppression in industry led in the 1890s to a labour code to protect workers.

But the chief Liberal industrial policy, formulated by William Pember Reeves, minister of labour from 1892 to 1896, was to encourage trade unions and to introduce, in the Industrial Conciliation and Arbitration Act of 1894, a conciliation and compulsory arbitration system intended to end industrial unrest and give the unions the means of protecting their members. The growth of unions was stimulated by the fact that only through them could the workers use the system. Reeves's act, amended and occasionally suspended but still essentially his own handiwork, remained in effect until the late 1960s. It enabled the worker in good times to resist wage cuts and to press for increases; but it did not manage to prevent cuts and unemployment when falling overseas prices brought depression to New Zealand. It was not strikingly radical in effect; employers and governments used it to break strikes, such as that of miners at Waihi in 1912. It built up the power of those majority elements in the unions that preferred coming to terms with capitalism to any effort to destroy it. Some occupations, such as transport, cargo handling, meat processing, and mining, fostered unions keen to relinquish arbitration for direct action, but they were in a minority and seldom, in the long run, successful. Farmers and governments have usually acted with severity in disputes affecting the movement of exports.

The growth of trade unions

The Liberal era, from 1891 to 1912, transformed political life. Previously politics had not been marked by neat party divisions. Local advantage had determined political behaviour in the development period during and after the 1870s; men had argued over the scope and details of policies and had advanced the claims of locality and province for a proper share of largess. Acute depression ended development and with it the politics of local advantage. In 1890 the Liberals began to act as a more or less unified party. Their 20 years in office, the success of their land and labour policies, and the formidable qualities of leadership discovered in Richard John Seddon, premier from 1893 to his death in 1906, welded the Liberals into a fairly coherent parliamentary and popular party.

R.J. Seddon as premier

Seddon was a portent of a new age. In 1893 this energetic goldfields trader-turned-politician provided a sharp contrast to the gentlemanly premiers who had preceded him. But his crudeness assisted rather than hindered the attainment of popularity none of them had known. He was devoted to political success and skilled in the manipulation of the means of success—parliamentary procedure, patronage, and party organization. By the time of his death he had established a kind of elective despotism over the country.

THE 20TH CENTURY

Seddon's successors, in his own and in other parties, were of the same stamp—men of the people devoted to a political career. Politics ceased to be a duty of the well-to-do amateur. The Liberal government, under Sir Joseph Ward, survived Seddon by six years. In 1912 it fell before a new party, Reform, led by a dairy farmer, William Ferguson Massey, prime minister until 1925. Based on prospering farmers and townsmen, especially of the North Island, and closely connected with their professional organizations, it was more narrowly sectional than the Liberals had been. Except for views borrowed from the Liberals, it had little positive policy. Reform made much of a promise to enable the state leaseholder to buy the freehold of his farm at original valuation; this promise was an emotional rallying cry for conservatives fearing land nationalization and complete socialism. Only a small minority of farmers were state tenants, and not all bought the freehold when the Reform government gave them the chance.

While the Liberals lost support in rural areas, they were further weakened by urban left-wing defections, which eventually led to a separate Labour Party. The initiative, on the right and on the left, was passing to other parties, and the Liberals were gradually eclipsed. The period before World War I was one of discontent and anxiety. Prosperity, though still considerable, had somewhat declined. The farmers were disturbed by what they took to be the threat of socialism, detected in the radicalism of a Liberal minority but chiefly in the rebirth of direct action in some trade unions. This change in temper arose from labour dissatisfaction with wage levels achieved under arbitration and from the growth of syndicalist and socialist ideas. After 1906 the Arbitration Court refused to grant further increases of real wages. Discontent flared up in the strikes of 1912–13, the biggest occurring on the waterfront when the farmers' government, headed by Massey, repressed a movement that had overtones of revolution.

Nationalism and war. By the late 19th century many New Zealanders were coming to regard themselves as a new nation. Most of them had been born in New Zealand and had no memories of or nostalgia for Britain, often called "home." In the 1890s New Zealand Natives Associations were established by native-born European New Zealanders. Their success in sports, especially rugby football, spurred national pride. An even greater influence was war. New Zealanders served on the British side during the South African War (1899–1902), during which time they earned a reputation as being superior to the British at fighting a guerrilla war. World War I greatly stimulated national sentiment. During the warfare at Gallipoli and later in France New Zealanders proved themselves to be excellent soldiers. But while the war boosted nationalist sentiment among both troops and civilians, the price was terrible: nearly one of every three men between the ages of 20 and 40 was killed or wounded. The loss in leadership in the following years was considerable.

At home the war brought prosperity, as export markets were assured and prices good. Domestic unity was hardly shaken by the antiwar feeling of a handful of left-wingers. Massey remained prime minister, but in the wartime coalition government (1915–19) Ward and the Liberals carried great weight. Reform stayed in office until 1928, led after Massey's death in 1925 by Joseph Gordon Coates. The party survived the first postwar depression but not that of the mid-1920s. Led by Ward, the Liberals, under the new name of United Party, were victorious in 1928; they thus had to face the deepening depression of 1929–30. After Ward's death (1930) and at the height of the depression, Reform and United formed a new coalition (1931) under the premiership of George Forbes, which lasted until the election of 1935 brought in a Labour government.

Some postwar developments were of great importance. In external affairs, Massey led a delegation to the peace conference, signed the Treaty of Versailles, and so committed New Zealand to membership in the League of Nations. New Zealand thus began to acquire the status of a sovereign state, though Massey denied this consequence. The Liberals, especially Seddon, had already taken steps toward autonomy within the empire. At the series of colonial and imperial conferences from 1887 onward, New Zealand had followed Canada and Australia in asserting its right to a voice in certain foreign policy issues. Seddon argued vehemently against British reluctance to acquire more Pacific islands while permitting German influence to grow in Samoa.

Sovereign status

New Zealand legislation to restrict Asian immigration was sharply and obstinately at variance with British policy. Western Samoa, which New Zealand had captured from the Germans in 1914 and over which it was granted a mandate in 1920, also provided occasions for British and New Zealand differences.

Reform leaders professed little love for the principle of

Commonwealth autonomy. New Zealand took a passive part in the conferences leading to the Statute of Westminster in 1931 and did not adopt it until 1947. But the substance of autonomy had been enjoyed before.

The major domestic achievement of the Reform administration was a system of export marketing agencies in which authority was shared by producer and state. These laid the foundations of a collectivist marketing structure. J.G. Coates was the most energetic minister in Forbes' coalition government. His attempts to counter depression concentrated upon the farmer in order to revive the country. To increase export receipts, he devalued the New Zealand pound; he protected the farmer against foreclosure and set up a credit agency.

When overseas prices began to recover in 1934, the country was financially strong, but little had been done for the unemployed. Conditions in towns and relief camps led to rioting, violence, and widespread discontent, all of which were favourable to the Labour Party. The Labour Party had been formed by socialist and radical groups in 1916. During the 1920s it was predominant only in working-class electorates. In its quest for votes, however, Labour increasingly abandoned its socialist theories and adopted welfare and credit-reform proposals, which had wider appeal. In the election of 1935 Labour won a considerable victory; successful in the towns, the party also won in many rural areas. Prices for dairy exports were slowest to recover, and many dairy farmers were drawn by Labour promises of a guaranteed price. The victory was particularly notable in terms of seats, for a right-wing third party (the Democrat Party) split the conservative vote to Labour's advantage. The National Party, successor to the coalition, was rendered temporarily ineffective.

Labour in power

The new ministers, among whom the most notable were Peter Fraser and Walter Nash, showed great energy; led by Michael Joseph Savage, they had the good fortune to govern a country to which prosperity was returning. The farmer enjoyed increased earnings; the worker, increased wages and shorter hours. Jobs were multiplied by a public works and housing program. The education system was revitalized. In 1938 the Social Security Act provided a state medical service, extended the pension system, and increased benefits. The expansion of secondary industry was accelerated after the outbreak of World War II in 1939.

World War II and after. The alacrity with which New Zealand went to war in 1939 showed that dominion autonomy had not weakened the country's ties with Great Britain. At first the war resembled that of 1914; troops were sent to Egypt to train for the European conflict. There they were directly involved by the enemy advance and saw action in Greece, Crete, North Africa, and Italy. After 1941 New Zealand was directly threatened by Japan, and New Zealand forces were also engaged in the Pacific. Well before the end of the war, the strain upon the country's manpower, together with the demands of home production, forced a reduction of commitments in the Pacific.

The Pacific theatre was dominated by the United States, the forces of which provided New Zealand's sole defense. The fact that disaster was averted by American and not by British forces required a change in New Zealand's attitudes; security was conferred by a foreign, though friendly, power. External relations in the postwar period reflected this new situation, chiefly through the ANZUS pact (1951), a defensive alliance between Australia, New Zealand, and the United States.

War economy

At home the total economy was mobilized in the war effort. Controls were extended over the whole economy. Conscription and direction (directed allocation of the labour force to strategic industries) sent manpower into the military forces and essential occupations; heavy taxation, war loans, bulk purchase, and controlled marketing kept the economy in a firm grip. They also kept inflation in check; with price control and wage restraint, they amounted to a complete policy of economic stabilization, applied by a Labour government that remained in power until 1949. Savage died early in the war. Fraser, his successor, and Nash were chiefly responsible for the tasks of administration during the war and of reconstruction after peace returned.

Sidney Holland led the revival of the National Party, which culminated in victory in 1949. Discontent with controls and with the rising cost of living helped to swing support away from Labour. The National government benefited from its vigorous handling of a serious waterfront dispute in 1951, but in later elections its majority narrowed until Labour returned in 1957. In 1960 the National Party, led by Keith Holyoake, was returned to power, which it retained until 1972. In that year Labour won a huge victory under Norman Kirk; his death in office in 1974 was the prelude to as great a National victory in 1975, under a new leader, Robert Muldoon.

After World War II New Zealand began to play a relatively independent role in world affairs. This development, in fact, began before the war, when the Labour government's attitude to the League of Nations was coloured by an idealism that clashed with British policy. During the war Fraser had insisted upon an independent voice in the councils of the Allied Powers. At the formation of the United Nations in 1945 he became a notable spokesman for the small powers and made a large impression upon the Trusteeship Council. None of these developments weakened New Zealand's close affinity with Great Britain, its loyalty to the Commonwealth, or its dependence upon the United States.

Postwar foreign policy

Geography and insecurity shaped postwar foreign policy. With Australia, New Zealand claimed a voice in settlement in the South Pacific Commission and in the transfer of authority in Western Samoa, successfully completed in 1962. New Zealand became deeply involved in Southeast Asia. From 1951 it provided assistance through the Colombo Plan. New Zealanders fought in Malaya, Korea, and Vietnam; further, New Zealand became a member of the Southeast Asia Treaty Organization (SEATO) in 1954 and supported the United States by sending troops to Vietnam. This reflected fear at the growth of Communist power in Asia. The independent spirit of the postwar years was modified to a greater dependence on Western powers during the 1950s and '60s. In the later 1960s involvement in the Vietnam War led to a vigorous and continuing public debate on foreign affairs. After Vietnam, debate turned largely on the problem of South African apartheid, especially in the contexts of sports relations with South Africa and with African countries at Commonwealth and Olympic games.

The 1970s and '80s were difficult economically for New Zealand. The combination in the early 1970s of high energy prices and Great Britain's entry into the EEC brought about a severe economic recession. Inflation skyrocketed, unemployment soared, and thousands emigrated to Australia. The response of Muldoon's National government was interventionism on an unparalleled scale: the government borrowed funds from overseas and ran up huge budgetary deficits, in part to finance large industrial developments; in the early 1980s it placed a freeze on wages and prices; and it attempted to regulate interest rates. Dissatisfaction with this program led in 1984 to the election of a Labour government, headed by David Lange.

(W.H.O./Ke.S.)

The Labour government initiated one of the most sweeping policy reversals in the country's history as, one after another, restrictions on free enterprise that had been imposed progressively over some 50 years were lifted. Among the reforms were the elimination of agricultural subsidies, the reduction of income tax rates, and the lifting of controls on wages, prices, interest rates, and foreign exchange. The government also took a strong stand against the proliferation of nuclear weapons in the region, and its decision to ban nuclear-powered and nuclear-armed vessels from New Zealand's ports strained relations with the United States. Popular support for the Labour program was reflected by the party's 1987 general election victory.

In the late 1980s, inflation had finally been brought under control, but unemployment continued to rise. Prime Minister Lange began to face substantial opposition within his own party, especially as a result of the privatization of state-owned enterprises, which was initiated in 1987, and over his conflict with finance minister Roger Douglas. Douglas was pushing for economic measures, such as a

flat-scale tax system and the deregulation of the labour unions, that the prime minister considered extreme. Lange dismissed Douglas in December 1988, but in August 1989, with the aim of shoring up Labour's poor standing in the polls, Labour MPs voted to return Douglas to the Cabinet. Lange resigned a few days later and was replaced by Geoffrey Palmer. In just 13 months, however, Palmer was himself replaced by Mike Moore, a former minister of foreign affairs, who held on to the position of prime minister for only eight weeks before the National Party's landslide victory in the October 1990 general election. Jim Bolger, the National Party leader, became prime minister. The National Party had campaigned for reduced government spending on social programs and the elimination of such labour practices as compulsory unionism but pledged to maintain New Zealand's antinuclear stand.

The National Party won a narrow victory over Labour in 1993. Bolger saw his popularity rise with strong economic growth and his condemnation in 1995 of France's nuclear testing in the South Pacific. In 1996 the country held its first elections under the mixed-member proportional system, which voters had approved by referendum three years earlier. Although no single party managed a majority, the National Party was able to form a coalition government with the New Zealand First Party. The new administration, however, was plagued by inexperience and factionalism. In addition, the government's inability to allay concerns over social welfare issues, particularly the country's superannuation (retirement savings) program, caused unrest.

In November 1997 Bolger resigned, and the National Party appointed Jennifer Shipley as the country's first female prime minister. However, the new government also struggled. After Shipley dismissed New Zealand First's Winston Peters as deputy prime minister and treasurer in 1998, the coalition dissolved, and Shipley oversaw a minority government. In 1999 the National Party was ousted by a coalition between Labour and the Alliance (a breakaway group of smaller parties), and Labour leader Helen Clark became prime minister. The government focused on labour relations, taxation, and the superannuation scheme. Clark was reelected as prime minister in 2002.

Ethnic relations emerged as a major issue in the late 20th century. The Maori sought the return of and compensation for natural resources under the terms of the Treaty of Waitangi of 1840. The validity of that treaty was in question, however, owing both to the circumstances of its signing (the chiefs who did sign had only a loose translation of the document in their language) and to the fact that the treaty had never been formally written into New Zealand's constitution. In 1975 the Treaty of Waitangi Act was passed, establishing a tribunal to examine and make recommendations on Maori claims. In the late 1980s, Maori activism intensified; demands included using the Maori language in education, broadcasting, and official settings and preserving Maori arts and culture. Maori land claims in the early 1990s involved a large proportion of New Zealand's territory, but the government faced pressure to turn land and water resources, in particular fisheries, over to profitable private enterprise. Beginning in 1993, however, the government began approving money, and later land, awards to the Maori, culminating in the 1997 settlement of the largest and oldest land claim in the country's history. The government also apologized for injustices inflicted on the Maori. Such acts were seen as positive steps toward reconciliation. (Ed.)

For later developments in the political history of New Zealand, see the BRITANNICA BOOK OF THE YEAR.

For coverage of related topics in the *Macropædia* and *Micropædia,* see the *Propædia,* sections 967 and 977, and the *Index.*

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(J.W.R./M.A.Ro./Ke.S./W.Mo./C.A.Bl./J.Vo./W.H.O.)

Newton

Isaac Newton, English physicist and mathematician, was the culminating figure of the scientific revolution of the 17th century. In optics, his discovery of the composition of white light integrated the phenomena of colours into the science of light and laid the foundation for modern physical optics. In mechanics, his three laws of motion, the basic principles of modern physics, resulted in the formulation of the law of universal gravitation. In mathematics, he was the original discoverer of the infinitesimal calculus. Newton's *Philosophiae Naturalis Principia Mathematica* (*Mathematical Principles of Natural Philosophy*), 1687, was one of the most important single works in the history of modern science.

By courtesy of the National Portrait Gallery, London



Newton, oil painting by Sir Godfrey Kneller, 1702. In the National Portrait Gallery, London.

Formative influences. Born on December 25, 1642 (January 4, 1643, new style), in the hamlet of Woolsthorpe, Lincolnshire, Newton was the only son of a local yeoman, also Isaac Newton, who had died three months before, and of Hannah Ayscough. That same year, at Arcetri near Florence, Galileo Galilei had died; Newton would eventually pick up his idea of a mathematical science of motion and bring his work to full fruition. A tiny and weak baby, Newton was not expected to survive his first day of life, much less 84 years. Deprived of a father before birth, he soon lost his mother as well, for within two years she married a second time; her husband, the well-to-do minister Barnabas Smith, left young Isaac with his grandmother and moved to a neighbouring village to raise a son and two daughters. For nine years, until the death of Barnabas Smith in 1653, Isaac was effectively separated from his mother, and his pronounced psychotic tendencies have been ascribed to this traumatic event. That he hated his stepfather we may be sure. When he examined the state of his soul in 1662 and compiled a catalog of sins in shorthand, he remembered "Threatning my father and mother Smith to burne them and the house over them." The acute sense of insecurity that rendered him obsessively anxious when his work was published and irrationally violent when he defended it accompanied Newton throughout his life and can plausibly be traced to his early years.

After his mother was widowed a second time, she determined that her first-born son should manage her now considerable property. It quickly became apparent, however, that this would be a disaster, both for the estate and for Newton. He could not bring himself to concentrate on rural affairs—set to watch the cattle, he would curl up under a tree with a book. Fortunately, the mistake was recognized, and Newton was sent back to the grammar school in Grantham, where he had already studied, to prepare for the university. As with many of the leading scientists of the age, he left behind in Grantham anecdotes about his mechanical ability and his skill in building models of machines, such as clocks and windmills. At the school he apparently gained a firm command of Latin but probably received no more than a smattering of arithmetic. By June 1661, he was ready to matriculate at Trinity College, Cambridge, somewhat older than the other undergraduates because of his interrupted education.

Influence of the scientific revolution. When Newton arrived in Cambridge in 1661, the movement now known as the scientific revolution was well advanced, and many of the works basic to modern science had appeared. Astronomers from Copernicus to Kepler had elaborated the heliocentric system of the universe. Galileo had proposed the foundations of a new mechanics built on the principle of inertia. Led by Descartes, philosophers had begun to formulate a new conception of nature as an intricate, impersonal, and inert machine. Yet as far as the universities of Europe, including Cambridge, were concerned, all this might well have never happened. They continued to be the strongholds of outmoded Aristotelianism, which rested on a geocentric view of the universe and dealt with nature in qualitative rather than quantitative terms.

Like thousands of other undergraduates, Newton began his higher education by immersing himself in Aristotle's work. Even though the new philosophy was not in the curriculum, it was in the air. Some time during his undergraduate career, Newton discovered the works of the French natural philosopher René Descartes and the other mechanical philosophers, who, in contrast to Aristotle, viewed physical reality as composed entirely of particles of matter in motion and who held that all the phenomena of nature result from their mechanical interaction. A new set of notes, which he entitled "Quaestiones Quaedam Philosophicae" ("Certain Philosophical Questions"), begun sometime in 1664, usurped the unused pages of a notebook intended for traditional scholastic exercises; under the title he entered the slogan "Amicus Plato amicus Aristoteles magis amica veritas" ("Plato is my friend, Aristotle is my friend, but my best friend is truth"). Newton's scientific career had begun.

Importance of the "Quaestiones"

The "Quaestiones" reveal that Newton had discovered the new conception of nature that provided the framework of the scientific revolution. He had thoroughly mastered the works of Descartes and had also discovered that the French philosopher Pierre Gassendi had revived atomism, an alternative mechanical system to explain nature. The "Quaestiones" also reveal that Newton already was inclined to find the latter a more attractive philosophy than Cartesian natural philosophy, which rejected the existence of ultimate indivisible particles. The works of the 17th-century chemist Robert Boyle provided the foundation for Newton's considerable work in chemistry. Significantly, he had read Henry More, the Cambridge Platonist, and was thereby introduced to another intellectual world, the magical Hermetic tradition, which sought to explain natural phenomena in terms of alchemical and magical concepts. The two traditions of natural philosophy, the mechanical and the Hermetic, antithetical though they appear, continued to influence his thought and in their tension supplied the fundamental theme of his scientific career.

Although he did not record it in the "Quaestiones," Newton had also begun his mathematical studies. He again started with Descartes, from whose *La Géometrie* he branched out into the other literature of modern analysis

with its application of algebraic techniques to problems of geometry. He then reached back for the support of classical geometry. Within little more than a year, he had mastered the literature; and, pursuing his own line of analysis, he began to move into new territory. He discovered the binomial theorem, and he developed the calculus, a more powerful form of analysis that employs infinitesimal considerations in finding the slopes of curves and areas under curves.

Development of the calculus

By 1669 Newton was ready to write a tract summarizing his progress, *De Analysi per Aequationes Numeri Terminorum Infinitas* ("On Analysis by Infinite Series"), which circulated in manuscript through a limited circle and made his name known. During the next two years he revised it as *De methodis serierum et fluxionum* ("On the Methods of Series and Fluxions"). The word fluxions, Newton's private rubric, indicates that the calculus had been born. Despite the fact that only a handful of savants were even aware of Newton's existence, he had arrived at the point where he had become the leading mathematician in Europe.

Work during the plague years. When Newton received the bachelor's degree in April 1665, the most remarkable undergraduate career in the history of university education had passed unrecognized. On his own, without formal guidance, he had sought out the new philosophy and the new mathematics and made them his own, but he had confined the progress of his studies to his notebooks. Then, in 1665, the plague closed the university, and for most of the following two years he was forced to stay at his home, contemplating at leisure what he had learned. During the plague years Newton laid the foundations of the calculus and extended an earlier insight into an essay, "Of Colours," which contains most of the ideas elaborated in his *Opticks.* It was during this time that he examined the elements of circular motion and, applying his analysis to the Moon and the planets, derived the inverse square relation that the radially directed force acting on a planet decreases with the square of its distance from the Sun—which was later crucial to the law of universal gravitation. The world heard nothing of these discoveries.

CAREER

The optics. *Inaugural lectures at Trinity.* Newton was elected to a fellowship in Trinity College in 1667, after the university reopened. Two years later, Isaac Barrow, Lucasian professor of mathematics, who had transmitted Newton's *De Analysi* to John Collins in London, resigned the chair to devote himself to divinity and recommended Newton to succeed him. The professorship exempted Newton from the necessity of tutoring but imposed the duty of delivering an annual course of lectures. He chose the work he had done in optics as the initial topic; during the following three years (1670–72), his lectures developed the essay "Of Colours" into a form which was later revised to become Book One of his *Opticks.*

Beginning with Kepler's *Paralipomena* in 1604, the study of optics had been a central activity of the scientific revolution. Descartes's statement of the sine law of refraction, relating the angles of incidence and emergence at interfaces of the media through which light passes, had added a new mathematical regularity to the science of light, supporting the conviction that the universe is constructed according to mathematical regularities. Descartes had also made light central to the mechanical philosophy of nature; the reality of light, he argued, consists of motion transmitted through a material medium. Newton fully accepted the mechanical nature of light, although he chose the atomistic alternative and held that light consists of material corpuscles in motion. The corpuscular conception of light was always a speculative theory on the periphery of his optics, however. The core of Newton's contribution had to do with colours. An ancient theory extending back at least to Aristotle held that a certain class of colour phenomena, such as the rainbow, arises from the modification of light, which appears white in its pristine form. Descartes had generalized this theory for all colours and translated it into mechanical imagery. Through a series of experiments performed in 1665 and 1666, in which the spectrum of a narrow beam was projected onto the wall of a darkened chamber, Newton denied the concept of modification and replaced it with that of analysis. Basically, he denied that light is simple and homogeneous—stating instead that it is complex and heterogeneous and that the phenomena of colours arise from the analysis of the heterogeneous mixture into its simple components. The ultimate source of Newton's conviction that light is corpuscular was his recognition that individual rays of light have immutable properties; in his view, such properties imply immutable particles of matter. He held that individual rays (that is, particles of given size) excite sensations of individual colours when they strike the retina of the eye. He also concluded that rays refract at distinct angles—hence, the prismatic spectrum, a beam of heterogeneous rays, *i.e.,* alike incident on one face of a prism, separated or analyzed by the refraction into its component parts—and that phenomena such as the rainbow are produced by refractive analysis. Because he believed that chromatic aberration could never be eliminated from lenses, Newton turned to reflecting telescopes; he constructed the first ever built. The heterogeneity of light has been the foundation of physical optics since his time.

Analysis of colour

There is no evidence that the theory of colours, fully described by Newton in his inaugural lectures at Cambridge, made any impression, just as there is no evidence that aspects of his mathematics and the content of the *Principia,* also pronounced from the podium, made any impression. Rather, the theory of colours, like his later work, was transmitted to the world through the Royal Society of London, which had been organized in 1660. When Newton was appointed Lucasian professor, his name was probably unknown in the Royal Society; in 1671, however, they heard of his reflecting telescope and asked to see it. Pleased by their enthusiastic reception of the telescope and by his election to the society, Newton volunteered a paper on light and colours early in 1672. On the whole, the paper was also well received, although a few questions and some dissent were heard.

Controversy. Among the most important dissenters to Newton's paper was Robert Hooke, one of the leaders of the Royal Society who considered himself the master in optics and hence he wrote a condescending critique of the unknown parvenu. One can understand how the critique would have annoyed a normal man. The flaming rage it provoked, with the desire publicly to humiliate Hooke, however, bespoke the abnormal. Newton was unable rationally to confront criticism. Less than a year after submitting the paper, he was so unsettled by the give and take of honest discussion that he began to cut his ties, and he withdrew into virtual isolation.

Colours in thin films

In 1675, during a visit to London, Newton thought he heard Hooke accept his theory of colours. He was emboldened to bring forth a second paper, an examination of the colour phenomena in thin films, which was identical to most of Book Two as it later appeared in the *Opticks.* The purpose of the paper was to explain the colours of solid bodies by showing how light can be analyzed into its components by reflection as well as refraction. His explanation of the colours of bodies has not survived, but the paper was significant in demonstrating for the first time the existence of periodic optical phenomena. He discovered the concentric coloured rings in the thin film of air between a lens and a flat sheet of glass; the distance between these concentric rings (Newton's rings) depends on the increasing thickness of the film of air. In 1704 Newton combined a revision of his optical lectures with the paper of 1675 and a small amount of additional material in his *Opticks.*

A second piece which Newton had sent with the paper of 1675 provoked new controversy. Entitled "An Hypothesis Explaining the Properties of Light," it was in fact a general system of nature. Hooke apparently claimed that Newton had stolen its content from him, and Newton boiled over again. The issue was quickly controlled, however, by an exchange of formal, excessively polite letters that fail to conceal the complete lack of warmth between the men.

Newton was also engaged in another exchange on his theory of colours with a circle of English Jesuits in Liège,

perhaps the most revealing exchange of all. Although their objections were shallow, their contention that his experiments were mistaken lashed him into a fury. The correspondence dragged on until 1678, when a final shriek of rage from Newton, apparently accompanied by a complete nervous breakdown, was followed by silence. The death of his mother the following year completed his isolation. For six years he withdrew from intellectual commerce except when others initiated a correspondence, which he always broke off as quickly as possible.

Influence of the Hermetic tradition. During his time of isolation, Newton was greatly influenced by the Hermetic tradition with which he had been familiar since his undergraduate days. Newton, always somewhat interested in alchemy, now immersed himself in it, copying by hand treatise after treatise and collating them to interpret their arcane imagery. Under the influence of the Hermetic tradition, his conception of nature underwent a decisive change. Until that time, Newton had been a mechanical philosopher in the standard 17th-century style, explaining natural phenomena by the motions of particles of matter. Thus, he held that the physical reality of light is a stream of tiny corpuscles diverted from its course by the presence of denser or rarer media. He felt that the apparent attraction of tiny bits of paper to a piece of glass that has been rubbed with cloth results from an ethereal effluvium that streams out of the glass and carries the bits of paper back with it. This mechanical philosophy denied the possibility of action at a distance; as with static electricity, it explained apparent attractions away by means of invisible ethereal mechanisms. Newton's "Hypothesis of Light" of 1675, with its universal ether, was a standard mechanical system of nature. Some phenomena, such as the capacity of chemicals to react only with certain others, puzzled him, however, and he spoke of a "secret principle" by which substances are "sociable" or "unsociable" with others. About 1679, Newton abandoned the ether and its invisible mechanisms and began to ascribe the puzzling phenomena—chemical affinities, the generation of heat in chemical reactions, surface tension in fluids, capillary action, the cohesion of bodies, and the like—to attractions and repulsions between particles of matter. More than 35 years later, in the second English edition of the *Opticks,* Newton accepted an ether again, although it was an ether that embodied the concept of action at a distance by positing a repulsion between its particles. The attractions and repulsions of Newton's speculations were direct transpositions of the occult sympathies and antipathies of Hermetic philosophy—as mechanical philosophers never ceased to protest. Newton, however, regarded them as a modification of the mechanical philosophy that rendered it subject to exact mathematical treatment. As he conceived of them, attractions were quantitatively defined, and they offered a bridge to unite the two basic themes of 17th-century science—the mechanical tradition, which had dealt primarily with verbal mechanical imagery, and the Pythagorean tradition, which insisted on the mathematical nature of reality. Newton's reconciliation through the concept of force was his ultimate contribution to science.

The Principia. *Planetary motion.* Newton originally applied the idea of attractions and repulsions solely to the range of terrestrial phenomena mentioned in the preceding paragraph. But late in 1679, not long after he had embraced the concept, another application was suggested in a letter from Hooke, who was seeking to renew correspondence. Hooke mentioned his analysis of planetary motion—in effect, the continuous diversion of a rectilinear motion by a central attraction. Newton bluntly refused to correspond but, nevertheless, went on to mention an experiment to demonstrate the rotation of the Earth: let a body be dropped from a tower; because the tangential velocity at the top of the tower is greater than that at the foot, the body should fall slightly to the east. He sketched the path of fall as part of a spiral ending at the centre of the Earth. This was a mistake, as Hooke pointed out; according to Hooke's theory of planetary motion, the path should be elliptical, so that if the Earth were split and separated to allow the body to fall, it would rise again to its original location. Newton did not like being corrected, least of all by Hooke, but he had to accept the basic point; he corrected Hooke's figure, however, using the assumption that gravity is constant. Hooke then countered by replying that, although Newton's figure was correct for constant gravity, his own assumption was that gravity decreases as the square of the distance. Several years later, this letter became the basis for Hooke's charge of plagiarism. He was mistaken in the charge. His knowledge of the inverse square relation rested only on intuitive grounds; he did not derive it properly from the quantitative statement of centripetal force and Kepler's third law, which relates the periods of planets to the radii of their orbits. Moreover, unknown to him, Newton had so derived the relation more than ten years earlier. Nevertheless, Newton later confessed that the correspondence with Hooke led him to demonstrate that an elliptical orbit entails an inverse square attraction to one focus—one of the two crucial propositions on which the law of universal gravitation would ultimately rest. What is more, Hooke's definition of orbital motion—in which the constant action of an attracting body continuously pulls a planet away from its inertial path—suggested a cosmic application for Newton's concept of force and an explanation of planetary paths employing it. In 1679 and 1680, Newton dealt only with orbital dynamics; he had not yet arrived at the concept of universal gravitation.

Correspondence with Hooke

Universal gravitation. Nearly five years later, in August 1684, Newton was visited by the British astronomer Edmond Halley, who was also troubled by the problem of orbital dynamics. Upon learning that Newton had solved the problem, he extracted Newton's promise to send the demonstration. Three months later he received a short tract entitled *De Motu* ("On Motion"). Already Newton was at work improving and expanding it. In two and a half years, the tract *De Motu* grew into *Philosophiae Naturalis Principia Mathematica,* which is not only Newton's masterpiece but also the fundamental work for the whole of modern science.

Significantly, *De Motu* did not state the law of universal gravitation. For that matter, even though it was a treatise on planetary dynamics, it did not contain any of the three Newtonian laws of motion. Only when revising *De Motu* did Newton embrace the principle of inertia (the first law) and arrive at the second law of motion. The second law, the force law, proved to be a precise quantitative statement of the action of the forces between bodies that had become the central members of his system of nature. By quantifying the concept of force, the second law completed the exact quantitative mechanics that has been the paradigm of natural science ever since.

The quantitative mechanics of the *Principia* is not to be confused with the mechanical philosophy. The latter was a philosophy of nature that attempted to explain natural phenomena by means of imagined mechanisms among invisible particles of matter. The mechanics of the *Principia* was an exact quantitative description of the motions of visible bodies. It rested on Newton's three laws of motion: (1) that a body remains in its state of rest unless it is compelled to change that state by a force impressed on it; (2) that the change of motion (the change of velocity times the mass of the body) is proportional to the force impressed; (3) that to every action there is an equal and opposite reaction. The analysis of circular motion in terms of these laws yielded a formula of the quantitative measure, in terms of a body's velocity and mass, of the centripetal force necessary to divert a body from its rectilinear path into a given circle. When Newton substituted this formula into Kepler's third law, he found that the centripetal force holding the planets in their given orbits about the Sun must decrease with the square of the planets' distances from the Sun. Because the satellites of Jupiter also obey Kepler's third law, an inverse square centripetal force must also attract them to the centre of their orbits. Newton was able to show that a similar relation holds between the Earth and its Moon. The distance of the Moon is approximately 60 times the radius of the Earth. Newton compared the distance by which the Moon, in its orbit of known size, is diverted from a tangential path in one second with the distance that a body at the surface of

the Earth falls from rest in one second. When the latter distance proved to be 3,600 (60 × 60) times as great as the former, he concluded that one and the same force, governed by a single quantitative law, is operative in all three cases, and from the correlation of the Moon's orbit with the measured acceleration of gravity on the surface of the Earth, he applied the ancient Latin word *gravitas* (literally, "heaviness" or "weight") to it. The law of universal gravitation, which he also confirmed from such further phenomena as the tides and the orbits of comets, states that every particle of matter in the universe attracts every other particle with a force that is proportional to the product of their masses and inversely proportional to the square of the distance between their centres.

Charge of plagiarism

When the Royal Society received the completed manuscript of Book I in 1686, Hooke raised the cry of plagiarism, a charge that cannot be sustained in any meaningful sense. On the other hand, Newton's response to it reveals much about him. Hooke would have been satisfied with a generous acknowledgment; it would have been a graceful gesture to a sick man already well into his decline, and it would have cost Newton nothing. Newton, instead, went through his manuscript and eliminated nearly every reference to Hooke. Such was his fury that he refused either to publish his *Opticks* or to accept the presidency of the Royal Society until Hooke was dead.

International prominence. The *Principia* immediately raised Newton to international prominence. In their continuing loyalty to the mechanical ideal, Continental scientists rejected the idea of action at a distance for a generation, but even in their rejection they could not withhold their admiration for the technical expertise revealed by the work. Young British scientists spontaneously recognized him as their model. Within a generation the limited number of salaried positions for scientists in England, such as the chairs at Oxford, Cambridge, and Gresham College, were monopolized by the young Newtonians of the next generation. Newton, whose only close contacts with women were his unfulfilled relationship with his mother, who had seemed to abandon him, and his later guardianship of a niece, found satisfaction in the role of patron to the circle of young scientists. His friendship with Fatio de Duillier, a Swiss-born mathematician resident in London who shared Newton's interests, was the most profound experience of his adult life.

Warden of the mint. Almost immediately following the *Principia*'s publication, Newton, a fervent if unorthodox Protestant, helped to lead the resistance of Cambridge to James II's attempt to Catholicize it. As a consequence, he was elected to represent the university in the convention that arranged the revolutionary settlement. In this capacity, he made the acquaintance of a broader group, including the philosopher John Locke. Newton tasted the excitement of London life in the aftermath of the *Principia.* The great bulk of his creative work had been completed. He was never again satisfied with the academic cloister, and his desire to change was whetted by Fatio's suggestion that he find a position in London. Seek a place he did, especially through the agency of his friend, the rising politician Charles Montague, later Lord Halifax. Finally, in 1696, he was appointed warden of the mint. Although he did not resign his Cambridge appointments until 1701, he moved to London and henceforth centred his life there.

In the meantime, Newton's relations with Fatio had undergone a crisis. Fatio was taken seriously ill; then family and financial problems threatened to call him home to Switzerland. Newton's distress knew no limits. In 1693 he suggested that Fatio move to Cambridge, where Newton would support him, but nothing came of the proposal. Through early 1693 the intensity of Newton's letters built almost palpably, and then, without surviving explanation, both the close relationship and the correspondence broke off. Four months later, without prior notice, Samuel Pepys and John Locke, both personal friends of Newton, received wild, accusatory letters. Pepys was informed that Newton would see him no more; Locke was charged with trying to entangle him with women. Both men were alarmed for Newton's sanity; and, in fact, Newton had suffered at least his second nervous breakdown. The crisis passed, and Newton recovered his stability. Only briefly did he ever return to sustained scientific work, however, and the move to London was the effective conclusion of his creative activity.

Nervous breakdown

As warden and then master of the mint, Newton drew a large income, as much as £2,000 per annum. Added to his personal estate, the income left him a rich man at his death. The position, regarded as a sinecure, was treated otherwise by Newton. During the great recoinage, there was need for him to be actively in command; even afterward, however, he chose to exercise himself in the office. Above all, he was interested in counterfeiting. He became the terror of London counterfeiters, sending a goodly number to the gallows and finding in them a socially acceptable target on which to vent the rage that continued to well up within him.

Interest in religion and theology. Newton found time now to explore other interests, such as religion and theology. In the early 1690s he had sent Locke a copy of a manuscript attempting to prove that Trinitarian passages in the Bible were latter-day corruptions of the original text. When Locke made moves to publish it, Newton withdrew in fear that his anti-Trinitarian views would become known. In his later years, he devoted much time to the interpretation of the prophecies of Daniel and St. John, and to a closely related study of ancient chronology. Both works were published after his death.

Leader of English science. In London, Newton assumed the role of patriarch of English science. In 1703 he was elected President of the Royal Society. Four years earlier, the French Académie des Sciences (Academy of Sciences) had named him one of eight foreign associates. In 1705 Queen Anne knighted him, the first occasion on which a scientist was so honoured. Newton ruled the Royal Society magisterially. John Flamsteed, the Astronomer Royal, had occasion to feel that he ruled it tyrannically. In his years at the Royal Observatory at Greenwich, Flamsteed, who was a difficult man in his own right, had collected an unrivalled body of data. Newton had received needed information from him for the *Principia,* and in the 1690s, as he worked on the lunar theory, he again required Flamsteed's data. Annoyed when he could not get all the information he wanted as quickly as he wanted it, Newton assumed a domineering and condescending attitude toward Flamsteed. As president of the Royal Society, he used his influence with the government to be named as chairman of a body of "visitors" responsible for the Royal Observatory; then he tried to force the immediate publication of Flamsteed's catalog of stars. The disgraceful episode continued for nearly 10 years. Newton would brook no objections. He broke agreements that he had made with Flamsteed. Flamsteed's observations, the fruit of a lifetime of work, were, in effect, seized despite his protests and prepared for the press by his mortal enemy, Edmond Halley. Flamsteed finally won his point and by court order had the printed catalog returned to him before it was generally distributed. He burned the printed sheets, and his assistants brought out an authorized version after his death. In this respect, and at considerable cost to himself, Flamsteed was one of the few men to best Newton. Newton sought his revenge by systematically eliminating references to Flamsteed's help in later editions of the *Principia.*

Difficulties with Flamsteed

In Gottfried Wilhelm Leibniz, the German philosopher and mathematician, Newton met a contestant more of his own calibre. It is now well established that Newton developed the calculus before Leibniz seriously pursued mathematics. It is almost universally agreed that Leibniz later arrived at the calculus independently. There has never been any question that Newton did not publish his method of fluxions; thus, it was Leibniz's paper in 1684 that first made the calculus a matter of public knowledge. In the *Principia* Newton hinted at his method, but he did not really publish it until he appended two papers to the *Opticks* in 1704. By then the priority controversy was already smouldering. If, indeed, it mattered, it would be impossible finally to assess responsibility for the ensuing fracas. What began as mild innuendoes rapidly escalated into blunt charges of plagiarism on both sides. Egged on by followers anxious to win a reputation under his auspices,

Priority dispute with Leibniz

Newton allowed himself to be drawn into the centre of the fray; and, once his temper was aroused by accusations of dishonesty, his anger was beyond constraint. Leibniz's conduct of the controversy was not pleasant, and yet it paled beside that of Newton. Although he never appeared in public, Newton wrote most of the pieces that appeared in his defense, publishing them under the names of his young men, who never demurred. As president of the Royal Society, he appointed an "impartial" committee to investigate the issue, secretly wrote the report officially published by the society, and reviewed it anonymously in the *Philosophical Transactions*. Even Leibniz's death could not allay Newton's wrath, and he continued to pursue the enemy beyond the grave. The battle with Leibniz, the irrepressible need to efface the charge of dishonesty, dominated the final 25 years of Newton's life. It obtruded itself continually upon his consciousness. Almost any paper on any subject from those years is apt to be interrupted by a furious paragraph against the German philosopher, as he honed the instruments of his fury ever more keenly. In the end, only Newton's death ended his wrath.

Final years. During his final years Newton brought out further editions of his central works. After the first edition of the *Opticks* in 1704, which merely published work done 30 years before, he published a Latin edition in 1706 and a second English edition in 1717–18. In both, the central text was scarcely touched, but he did expand the "Queries" at the end into the final statement of his speculations on the nature of the universe. The second edition of the *Principia*, edited by Roger Cotes in 1713, introduced extensive alterations. A third edition, edited by Henry Pemberton in 1726, added little more. Until nearly the end, Newton presided at the Royal Society (frequently dozing through the meetings) and supervised the mint. During his last years, his niece, Catherine Barton Conduitt, and her husband lived with him. He died on March 20 (March 31, N.S.), 1727, in London.

MAJOR WORKS

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A standard biography of Newton is DAVID BREWSTER, *Memoirs of the Life, Writings, and Discoveries of Sir Isaac Newton*, 2 vol. (1855, reprinted 1965). A more modern work by RICHARD S. WESTFALL, *Never at Rest: A Biography of Isaac Newton* (1980, reissued 1990), also available in a shorter version, *The Life of Isaac Newton* (1993), is a comprehensive study of Newton in light of new scholarship. GALE E. CHRISTIANSON, *In the Presence of the Creator: Isaac Newton and His Times* (1984), includes much contextual information. FRANK E. MANUEL, *A Portrait of Isaac Newton* (1968, reprinted 1990), offers a fascinating Freudian analysis, and his *The Religion of Isaac Newton* (1974) is a thorough discussion of his religious thought. DEREK GJERTSEN, *The Newton Handbook* (1986), comprises hundreds of brief entries on topics related to Newton and his era.

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Nietzsche

Friedrich Nietzsche, a 19th-century German philosopher and writer, was one of the most influential modern thinkers. His attempts to unmask the root motives that underlie traditional Western religion, morality, and philosophy deeply affected generations of theologians, philosophers, psychologists, poets, novelists, and playwrights. He thought through the consequences of the triumph of the Enlightenment's secularism, expressed in his observation that "God is dead," in a way that determined the agenda for many of Europe's most celebrated intellectuals after his death in 1900. Although he was an ardent foe of nationalism, anti-Semitism, and power politics, his name was later invoked by Fascists to advance the very things he loathed.

Louis Held—Deutsche Fotothek, Dresden



Nietzsche, 1888.

The early years. Nietzsche was born on Oct. 15, 1844, in Röcken, a village in Prussian Saxony. His home was a stronghold of Lutheran piety. His paternal grandfather had published books defending Protestantism and had achieved the ecclesiastical position of superintendent; his maternal grandfather was a country parson; his father, Carl Ludwig Nietzsche, was appointed pastor at Röcken by order of King Friedrich Wilhelm IV of Prussia, after whom Friedrich Nietzsche was named. His father died in 1849, before Nietzsche's fifth birthday, and he spent most of his early life in a household consisting of five women: his mother Franziska, his younger sister Elisabeth, his maternal grandmother, and two maiden aunts.

In 1850 the family moved to Naumburg on the Saale River, where Nietzsche attended a private preparatory school, the Domgymnasium. In 1858 he earned a scholarship to Schulpforta, Germany's leading Protestant boarding school. He excelled academically at Pforta, received an outstanding classical education there, and, having graduated in 1864, went to the University of Bonn to study theology and classical philology. Despite efforts to take part in the university's social life, the two semesters at Bonn were a failure, owing chiefly to acrimonious quarrels between his two leading classics professors, Otto Jahn and Friedrich Wilhelm Ritschl. Nietzsche sought refuge in music, writing a number of compositions strongly influenced by Robert Schumann, the German Romantic composer. In 1865 he transferred to the University of Leipzig, joining Ritschl, who had accepted an appointment there.

University years

Nietzsche prospered under Ritschl's tutelage in Leipzig. He became the only student ever to publish in Ritschl's journal, *Rheinisches Museum* ("Rhenish Museum"). He began military service in October 1867 in the cavalry company of an artillery regiment, sustained a serious chest injury while mounting a horse in March 1868, and resumed his studies in Leipzig in October 1868 while on extended sick leave from the military. During the years in Leipzig, Nietzsche discovered Arthur Schopenhauer's philosophy, met the great operatic composer Richard Wagner, and began his lifelong friendship with fellow classicist Erwin Rohde (author of *Psyche*).

The Basel years (1869–79). When a professorship in classical philology fell vacant in 1869 in Basel, Switz., Ritschl recommended Nietzsche with unparalleled praise. He had completed neither his doctoral thesis nor the additional dissertation required for a German degree; yet Ritschl assured the University of Basel that he had never seen anyone like Nietzsche in 40 years of teaching and that his talents were limitless. In 1869 the University of Leipzig conferred the doctorate without examination or dissertation on the strength of his published writings, and the University of Basel appointed him extraordinary professor of classical philology. The following year Nietzsche became a Swiss citizen and was promoted to ordinary professor.

Nietzsche obtained a leave to serve as a volunteer medical orderly in August 1870, after the outbreak of the Franco-Prussian War. Within a month, while accompanying a transport of wounded, he contracted dysentery and diphtheria, which ruined his health permanently. He returned to Basel in October to resume a heavy teaching load, but as early as 1871 ill health prompted him to seek relief from the stultifying chores of a professor of classical philology; he applied for the vacant chair of philosophy and proposed Rohde as his successor, all to no avail.

During these early Basel years Nietzsche's ambivalent friendship with Wagner ripened, and he seized every opportunity to visit Richard and his wife, Cosima. Wagner appreciated Nietzsche as a brilliant professorial apostle, but Wagner's increasing exploitation of Christian motifs, as in *Parsifal,* coupled with his chauvinism and anti-Semitism proved to be more than Nietzsche could bear. By 1878 the breach between the two men had become final.

Nietzsche's break with Wagner

Nietzsche's first book, *Die Geburt der Tragödie aus dem Geiste der Musik* (1872; *The Birth of Tragedy from the Spirit of Music*), marked his emancipation from the trappings of classical scholarship. A speculative rather than exegetical work, it argued that Greek tragedy arose out of the fusion of what he termed Apollonian and Dionysian elements—the former representing measure, restraint, harmony, and the latter representing unbridled passion—and that Socratic rationalism and optimism spelled the death of Greek tragedy. The final 10 sections of the book are a rhapsody about the rebirth of tragedy from the spirit of Wagner's music. Greeted by stony silence at first, it became the object of heated controversy on the part of those who mistook it for a conventional work of classical scholarship. It was undoubtedly "a work of profound imaginative insight, which left the scholarship of a generation toiling in the rear," as the British classicist F.M. Cornford wrote in 1912. It remains a classic in the history of aesthetics to this day.

By October 1876 Nietzsche requested and received a year's sick leave. In 1877 he set up house with his sister and Peter Gast, and in 1878 his aphoristic *Menschliches, Allzumenschliches* (*Human, All-Too-Human*) appeared. Because his health deteriorated steadily he resigned his professorial chair on June 14, 1879, and was granted a pension of 3,000 Swiss francs per year for six years.

Decade of isolation and creativity (1879–89). Apart from the books Nietzsche wrote between 1879 and 1889,

it is doubtful that his life held any intrinsic interest. Seriously ill, half-blind, in virtually unrelenting pain, he lived in boarding houses in Switzerland, the French Riviera, and Italy, with only limited human contact. His friendship with Paul Rée was undermined by 1882 by their mutual if unacknowledged affection for Lou Salomé (author, later the wife of the Orientalist F.C. Andreas, mistress of the poet Rainer Maria Rilke, and confidant of Sigmund Freud) as well as by Elisabeth Nietzsche's jealous meddling.

Nietzsche's acknowledged literary and philosophical masterpiece in biblical narrative form, *Also sprach Zarathustra* (*Thus Spoke Zarathustra*), was published between 1883 and 1885 in four parts, the last part a private printing at his own expense. As with most of his works it received little attention. His attempts to set forth his philosophy in more direct prose, in the publications in 1886 of *Jenseits von Gut und Böse* (*Beyond Good and Evil*) and in 1887 of *Zur Genealogie der Moral* (*On the Genealogy of Morals*), also failed to win a proper audience.

Nietzsche's final lucid year, 1888, was a period of supreme productivity. He wrote and published *Der Fall Wagner* (*The Case of Wagner*) and wrote a synopsis of his philosophy, *Die Götzen-Dämmerung* (*Twilight of the Idols*), *Der Antichrist* (*The Antichrist*), *Nietzsche contra Wagner* (Eng. trans., *Nietzsche contra Wagner*), and *Ecce Homo* (Eng. trans., *Ecce Homo*), a reflection on his own works and significance. *Twilight of the Idols* appeared in 1889, *Der Antichrist* and *Nietzsche contra Wagner* were not published until 1895, the former mistakenly as book one of *The Will to Power,* and *Ecce Homo* was withheld from publication until 1908, 20 years after its composition.

Collapse and misuse. Nietzsche collapsed in the streets of Turin, Italy, in January 1889, having lost control of his mental faculties completely. Bizarre but meaningful notes he sent immediately after his collapse brought Franz Overbeck to Italy to return Nietzsche to Basel. Nietzsche spent the last 11 years of his life in total mental darkness, first in a Basel asylum, then in Naumburg under his mother's care and, after her death in 1897, in Weimar in his sister's care. He died on Aug. 25, 1900. Informed opinion favours a diagnosis of atypical general paralysis caused by dormant tertiary syphilis.

Nietzsche's sister's misuse of his literary estate

The association of Nietzsche's name with Adolf Hitler and Fascism owes much to the use made of his works by his sister Elisabeth. She had married a leading chauvinist and anti-Semite, Bernhard Förster, and after his suicide in 1889 she worked diligently to refashion Nietzsche in Förster's image. Elisabeth maintained ruthless control over Nietzsche's literary estate and, dominated by greed, produced collections of his "works" consisting of discarded notes, such as *Der Wille zur Macht* (1901; *The Will to Power*). She also committed petty forgeries. Generations of commentators were misled. Equally important, her enthusiasm for Hitler linked Nietzsche's name with that of the dictator in the public mind.

Nietzsche's mature philosophy. Nietzsche's writings fall into three well-defined periods. The early works, *The Birth of Tragedy* and the four *Unzeitgemässe Betrachtungen* (1873; *Untimely Meditations*), are dominated by a Romantic perspective influenced by Schopenhauer and Wagner. The middle period, from *Human, All-Too-Human* up to *The Gay Science,* reflects the tradition of French aphorists. It extols reason and science, experiments with literary genres, and expresses Nietzsche's emancipation from his earlier Romanticism and from Schopenhauer and Wagner. Nietzsche's mature philosophy emerged after *The Gay Science.*

In his mature writings Nietzsche was preoccupied by the origin and function of values in human life. If, as he believed, life neither possesses nor lacks intrinsic value and yet is always being evaluated, then such evaluations can usefully be read as symptoms of the condition of the evaluator. He was especially interested, therefore, in a probing analysis and evaluation of the fundamental cultural values of Western philosophy, religion, and morality, which he characterized as expressions of the ascetic ideal.

The ascetic ideal is born when suffering becomes endowed with ultimate significance. According to Nietzsche the Judeo-Christian tradition, for example, made suffering tolerable by interpreting it as God's intention and as an occasion for atonement. Christianity, accordingly, owed its triumph to the flattering doctrine of personal immortality, that is, to the conceit that each individual's life and death have cosmic significance. Similarly, traditional philosophy expressed the ascetic ideal when it privileged soul over body, mind over senses, duty over desire, reality over appearance, the timeless over the temporal. While Christianity promised salvation for the sinner who repents, philosophy held out hope for salvation, albeit secular, for its sages. Common to traditional religion and philosophy was the unstated but powerful motivating assumption that existence requires explanation, justification, or expiation. Both denigrated experience in favour of some other, "true" world. Both may be read as symptoms of a declining life, or life in distress.

Nietzsche's etymological approach to the interpretation of morality

Nietzsche's critique of traditional morality centred on the typology of "master" and "slave" morality. By examining the etymology of the German words *gut* ("good"), *schlecht* ("bad"), and *böse* ("evil"), Nietzsche maintained that the distinction between good and bad was originally descriptive, that is, a nonmoral reference to those who were privileged, the masters, as opposed to those who were base, the slaves. The good/evil contrast arose when slaves avenged themselves by converting attributes of mastery into vices. If the favoured, the "good," were powerful, it was said that the meek would inherit the earth. Pride became sin. Charity, humility, and obedience replaced competition, pride, and autonomy. Crucial to the triumph of slave morality was its claim to being the only true morality. This insistence on absoluteness is as essential to philosophical as to religious ethics. Although Nietzsche gave a historical genealogy of master and slave morality, he maintained that it was an ahistorical typology of traits present in everyone.

God is dead

"Nihilism" was the term Nietzsche used to describe the devaluation of the highest values posited by the ascetic ideal. He thought of the age in which he lived as one of passive nihilism, that is, as an age that was not yet aware that religious and philosophical absolutes had dissolved in the emergence of 19th-century Positivism. With the collapse of metaphysical and theological foundations and sanctions for traditional morality only a pervasive sense of purposelessness and meaninglessness would remain. And the triumph of meaninglessness is the triumph of nihilism: "God is dead." Nietzsche thought, however, that most men could not accept the eclipse of the ascetic ideal and the intrinsic meaninglessness of existence but would seek supplanting absolutes to invest life with meaning. He thought the emerging nationalism of his day represented one such ominous surrogate god, in which the nation-state would be invested with transcendent value and purpose. And just as absoluteness of doctrine had found expression in philosophy and religion, absoluteness would become attached to the nation-state with missionary fervour. The slaughter of rivals and the conquest of the earth would proceed under banners of universal brotherhood, democracy, and socialism. Nietzsche's prescience here was particularly poignant, and the use later made of him especially repellent. For example, two books were standard issue for the rucksacks of German soldiers during World War I, *Thus Spoke Zarathustra* and *The Gospel According to St. John.* It is difficult to say which author was more compromised by this gesture.

Nietzsche often thought of his writings as struggles with nihilism, and apart from his critiques of religion, philosophy, and morality he developed original theses that have commanded attention, especially perspectivism, will to power, eternal recurrence, and the superman.

Perspectivism is a concept which holds that knowledge is always perspectival, that there are no immaculate perceptions, and that knowledge from no point of view is as incoherent a notion as seeing from no particular vantage point. Perspectivism also denies the possibility of an all-inclusive perspective, which could contain all others and, hence, make reality available as it is in itself. The concept of such an all-inclusive perspective is as incoherent as the concept of seeing an object from every possible vantage point simultaneously.

Critical responses to Nietzsche's concept of perspectivism

Nietzsche's perspectivism has sometimes been mistakenly identified with relativism and skepticism. Nonetheless, it raises the question of how one is to understand Nietzsche's own theses, for example, that the dominant values of the common heritage have been underwritten by an ascetic ideal. Is this thesis true absolutely or only from a certain perspective? It may also be asked whether perspectivism can be asserted consistently without self-contradiction, since perspectivism must presumably be true in an absolute, that is a nonperspectival sense. Concerns such as these have generated much fruitful Nietzsche commentary as well as useful work in the theory of knowledge.

Nietzsche often identified life itself with "will to power," that is, with an instinct for growth and durability. This concept provides yet another way of interpreting the ascetic ideal, since it is Nietzsche's contention "that all the supreme values of mankind *lack* this will—that values which are symptomatic of decline, *nihilistic* values, are lording it under the holiest names." Thus, traditional philosophy, religion, and morality have been so many masks a deficient will to power wears. The sustaining values of Western civilization have been sublimated products of decadence in that the ascetic ideal endorses existence as pain and suffering. Some commentators have attempted to extend Nietzsche's concept of the will to power from human life to the organic and inorganic realms, ascribing a metaphysics of will to power to him. Such interpretations, however, cannot be sustained by reference to his published works.

The doctrine of eternal recurrence, the basic conception of *Thus Spoke Zarathustra,* asks the question "How well disposed would a person have to become to himself and to life to crave nothing more fervently than the infinite repetition, without alteration, of each and every moment?" Presumably most men would, or should, find such a thought shattering because they should always find it possible to prefer the eternal repetition of their lives in an edited version rather than to crave nothing more fervently than the eternal recurrence of each of its horrors. The person who could accept recurrence without self-deception or evasion would be a superhuman being (*Übermensch*), a superman whose distance from the ordinary man is greater than the distance between man and ape, Nietzsche says. Commentators still disagree whether there are specific character traits that define the person who embraces eternal recurrence.

Nietzsche's influence. Nietzsche once wrote that some men are born posthumously, and this is certainly true in his case. The history of 20th-century philosophy, theology, and psychology are unintelligible without him. The German philosophers Max Scheler, Karl Jaspers, and Martin Heidegger laboured in his debt, for example, as did the French philosophers Albert Camus, Jacques Derrida, and Michel Foucault. Existentialism and deconstructionism, a movement in philosophy and literary criticism, owe much to him. The theologians Paul Tillich and Lev Shestov acknowledged their debt as did the "God is dead" theologian Thomas J.J. Altizer; Martin Buber, Judaism's greatest 20th-century thinker, counted Nietzsche among the three most important influences in his life and translated the first part of *Zarathustra* into Polish. The psychologists Alfred Adler and Carl Jung were deeply influenced, as was Sigmund Freud, who said of Nietzsche that he had a more penetrating understanding of himself than any man who ever lived or was ever likely to live. Novelists like Thomas Mann, Hermann Hesse, André Malraux, André Gide, and John Gardner were inspired by him and wrote about him, as did the poets and playwrights George Bernard Shaw, Rainer Maria Rilke, Stefan George, and William Butler Yeats, among others. Nietzsche is certainly one of the most influential philosophers who ever lived; and this is due not only to his originality but also to the fact that he was the German language's most brilliant prose writer.

MAJOR WORKS

Definitive editions of Nietzsche's collected works have been edited by Giorgio Colli and Mazzino Montinari, *Werke: Kritische Gesamtausgabe* (1967–), projected for 30 vol., of which 21 had been published by 1984, and *Sämtliche Werke: Kritische Studienausgabe,* 15 vol. (1980). These strictly chronological editions render all earlier collections obsolete. All books authorized for publication by Nietzsche exist in English translations, the most reliable of which are by Walter Kaufmann. The original works in the following list have been translated and edited by Walter Kaufmann unless noted otherwise: *Die Geburt der Tragödie* (1872; *The Birth of Tragedy*); *Unzeitgemässe Betrachtungen,* 4 vol. (1873–76; *Untimely Meditations,* trans. by R.J. Hollingdale); *Menschliches, Allzumenschliches* (1878; *Human, All-Too-Human,* trans. by Marion Faber and Stephen Lehmann); *Morgenröte* (1881; *Daybreak,* trans. by R.J. Hollingdale); *Die fröhliche Wissenschaft* (1882), new ed. augmented by book 5 and *Lieder des Prinzen Vogelfrei* (1887; *The Gay Science*); *Also sprach Zarathustra,* parts 1–3 (1883–84) and part 4 (1885; *Thus Spoke Zarathustra*); *Jenseits von Gut und Böse* (1886; *Beyond Good and Evil*); *Zur Genealogie der Moral* (1887; *On the Genealogy of Morals*); *Der Fall Wagner* (1888; *The Case of Wagner*); *Götzen-Dämmerung* (1889; *Twilight of the Idols*); *Der Antichrist* (1895; *The Antichrist*); *Nietzsche contra Wagner* (1895); *Ecce Homo* (1908). A selection from Nietzsche's notes never intended for publication appeared as *Der Wille zur Macht* (1901; *The Will to Power,* trans. by Walter Kaufmann and R.J. Hollingdale). An important translation and selection of Nietzsche's early unpublished writings is *Philosophy and Truth* (1979), ed. and trans. by Daniel Breazeale. The fundamental chronological edition of Nietzsche's letters by Giorgio Colli and Mazzino Montinari, *Briefwechsel: Kritische Gesamtausgabe* (1975–), is planned for 20 vol., of which 17 had appeared by 1984, containing the correspondence of 1850–89. A fine selection in English is *Selected Letters of Friedrich Nietzsche* (1969), ed. and trans. by Christopher Middleton.

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North Africa

The geographic entity North Africa has no single accepted definition. It has been regarded by some as stretching from the Atlantic shores of Morocco in the west to the Suez Canal and the Red Sea in the east, though this is more commonly referred to as northern Africa. Others limit the designation to the countries of Morocco, Algeria, and Tunisia, a region known by the French during colonial times as Afrique du Nord. The more commonly accepted definition, and the one used here, includes the three above-mentioned countries, as well as Libya, but excludes Egypt. The regions encompassed by both the second and third definitions, however, have also been called Northwest Africa.

Seen from across the Mediterranean Sea in Europe, from which it is separated by only 8 miles (13 kilometres) at the Strait of Gibraltar and 85 miles at the Strait of Sicily, North Africa has often been called the Barbary States, or simply Barbary, after the name of the indigenous Berbers, who are now outnumbered by Arabs and Arabized Berbers. Frequently, the countries of Morocco, Algeria, and Tunisia have also been known as the Atlas Lands, after the long mountain ranges that dominate their northern landscapes, although all three countries, especially Algeria, incorporate sizable sections of the Sahara desert. Farther east in Libya, only the northwestern and northeastern parts of the country, known as Tripolitania and Cyrenaica respectively, are outside of the desert.

Seen through Arab eyes from the east, North Africa is known as the Maghrib (the West), an extensive area that is frequently further differentiated into the Maghrib al-Adna (the Near West), comprising Libya and Tunisia; the Maghrib al-Ausat (the Middle West), including Algeria; and the Maghrib al-Aqṣā (the Far West), comprising Morocco and sometimes Western Sahara and Mauritania. The Atlas Lands are often graphically called Djezirah (Jazīrat) al-Maghrib (the Western Isle), signifying their isolated position above the empty Sahara and the Mediterranean Sea.

North Africa as defined here stretches from longitudes 13° W to 25° E and from latitudes 19° N to nearly 38° N. Covering more than 1,830,000 square miles (4,750,000 square kilometres), it is about half the size of the United States or China, but well over four-fifths of the area is desert.

The result of unusual evolution, peculiar geographic circumstances, and isolation, North Africa is, in fact, neither wholly African nor European nor Middle Eastern, but it has its own distinctive identity and internal diversity. Its transitional position—between the Mediterranean and the Sahara, between Europe and Africa, and between West and East—gives rise to much of its distinctiveness.

Geologically, the Atlas Mountains constitute part of the Tertiary fold mountains (*i.e.*, those that formed about 66.4 to 1.6 million years ago) that characterize so much of southern Europe, whereas most of the Sahara is underlain by Precambrian crystalline rock (dating from 3.96 billion to 570 million years ago) or horizontally bedded limestone characteristic of the vast plateau surfaces of Africa. Climatically, the Maghrib is greatly affected by Mediterranean conditions in winter and by Saharan conditions in summer. The resulting north-south climatic and vegetational gradient, from Mediterranean to steppe to desert, is well marked and is generally associated with a decline in agricultural activity and population density.

Culturally, North Africa is the only part of Africa to have been continuously in contact with Europe over millennia, culminating during classical times with the imprint of Greece and Rome and during the 19th and 20th centuries with the colonial impact of France, Italy, and Spain, of which only the Spanish enclaves of Ceuta and Melilla remain. Its relative isolation from sub-Saharan Africa was breached only by hazardous trans-Saharan caravan trade. Bringing slaves as well as goods into the region, trans-Saharan trade also led to black admixtures with the prevailing white populations of North Africa. Cultural influences from the Middle East were much more profound, bringing Arabization of the language, the development of cities, and the near religious uniformity of the region in Islām. Yet, its high degree of cultural uniformity, particularly in contrast to black Africa, has not been enough to bring about political unity—a luxury North Africa has never known. Now, separated by political boundaries—many of which, largely delineated by Turks and Europeans, follow geometric lines across the deserts—the four main states have developed distinctive political identities and economies.

Ecological contrasts between the Mediterranean, steppe, and desert zones have led to traditional contrasts between sedentary cultivation in the north and various types of seminomadic and nomadic pastoralism in the steppes and deserts. Regional contrasts were intensified during colonial rule, whose impact was greatest in the Mediterranean zone, with the growth of export agriculture, mining, and city-ports. This situation has been reinforced by the exploitation and export of oil from Libya and Algeria from the 1950s on. Today, large cities are heightening the urban-rural contrast and are increasingly polarizing the region's population distribution. The principal cities are Casablanca (in Morocco), Algiers (in Algeria), Tunis (in Tunisia), and Tripoli (in Libya).

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Physical and human geography

THE LAND

Relief, drainage, and soils. *Relief and drainage.* The relief of North Africa falls into two broad categories: the Atlas Lands and the Sahara. The Atlas Mountains, a group of related ranges stretching some 1,200 miles (2,000 kilometres) in length from southwestern Morocco to northeastern Tunisia, are the result of complex mountain-building processes that occurred during the Tertiary Period. Limestone and sandstone deposited upon an older surface of Hercynian age (roughly 374 to 286 million years old) were pressured upward and folded and faulted by northward movements of the African Plate, in the process incorporating blocks of older rocks that resisted the pressures and that today form intervening plateaus between the ranges. Evidence of persistent structural instability in the ranges is seen in the periodic occurrence of earthquakes, such as the one that devastated Agadir, Mor., in 1960.

Atlas Mountains

The Atlas system runs from southwest to northeast roughly adjacent and parallel to the Mediterranean coastline, one of the reasons why there are so few natural harbours along the coast (Bizerte in northern Tunisia being a notable exception). In the far northwest along the northern coast of Morocco, the Rif Mountains stretch in an arc from Tangier to the Moulouya basin, whose river flows irregularly into the Mediterranean. To the south of the Rif Mountains lies the plain of the Sebou River, which brings water down from the highly dissected Middle Atlas range, a source of water also for the tilted Moroccan Plateau to the west as well as for the Moulouya River. The Middle Atlas stretches southwest to the High Atlas, both ranges together creating a formidable barrier around Atlantic Morocco. The High Atlas are the highest and most spectacular mountains in North Africa, with many snow-capped peaks south of Marrakech exceeding 12,800 feet (3,900 metres) and culminating in Mount Toubkal at 13,665 feet (4,165 metres). Some 500 miles long, they dominate south-central Morocco, their well-watered northern slopes contrasting sharply with their arid southern ones. To the southwest the triangular plain of the Wadi Sous is a synclinal depression separating the High Atlas from the parallel-trending Anti-Atlas range, an uplifted edge of the Saharan shield.

Eastward in Algeria and Tunisia the Atlas system is not as lofty, and the ranges gradually converge. In the north lie the coastal Tell Atlas mountains, sometimes known as the Maritime Atlas, which comprise younger limestones and sandstones in a varied assemblage of massifs, hills, valleys, and plains. East of Algiers the Tell Atlas culminate in the heavily dissected Great Kabylie (Kabylia) Massif, a centre of Berber culture. In Tunisia, the coastal Kroumirie and Mogod mountains are known as the Northern Tell.

The High Plateau

South of the Tell Atlas lies the monotonous High Plateau of Algeria, which stretches some 500 miles from the Moulouya valley in the west to the Aurès Mountains in the east. Lying between 2,500 and 3,300 feet in elevation and being higher in the west than in the east, the High Plateau has a surface comprising a series of closed basins of interior drainage that are occupied by numerous salt flats known as chotts (*shaṭṭ*); hence the fact that the region is often called the Plateau of the Chotts.

Bordering the High Plateau to the south is a series of low mountains—the Ksour, Amour, and Oulad Naïl—collectively termed the Saharan Atlas. Heavily eroded and largely buried in their own debris, the Saharan Atlas mountains are more impressive from the south than from the north. They gradually die out in the east where they merge with the High Plateau to form a natural routeway between the desert south and cultivated north.

Farther east are the weathered ridges of the Aurès Mountains, which extend northeast toward the High Tell Mountains of Tunisia, a series of ridges, domes, and basins often referred to as the Tunisian Dorsale, or backbone of that country. Between the High Tell and the Northern Tell lies the fertile Majardah valley, since ancient times a rich agricultural area, much altered now by irrigation developments. South of the High Tell lie the High and Low Steppes of Tunisia, extensive plains broken in places by a few ridges representing the last remnants of the Atlas ranges. South of the Low Steppes is the Shaṭṭ al-Jarīd, a dry salt lake that effectively defines the edge of the desert.

In Libya, only the northwestern and northeastern corners of the country (known as Tripolitania and Cyrenaica, respectively), separated by the southward projection of the Gulf of Sidra, lie outside of the Sahara. The Al-Jifārah (Gefara) Plain, running along the Mediterranean coast of Tripolitania, is an eastward extension of the Tunisian plain south of Qābis (Gabès) and is backed by the Nafūsah Plateau, a crescentic limestone escarpment that rises to more than 2,600 feet in elevation and, as in the mountains of Tunisia, is remarkable for the profusion of fortified granaries, or *ksour*s, it contains. The Mediterranean coast of northeastern Libya is dominated by the limestone Akhḍar (El-Achdar) Mountains, which stretch some 20 miles inland and are deeply dissected by narrow gorges.

Saharan landforms

To the south lie the vast expanses of the Sahara. Underlain by crystalline rocks of the African Shield, the Sahara is essentially a vast platform that was folded and denuded to a peneplain and afterward covered by younger deposits, especially limestone of Cretaceous age (144 to 66.4 million years old), which now forms prominent escarpments and whose basins are associated with accumulations of petroleum.

The great aridity of the desert means that watercourses are rare and their flow irregular. Termed wadis or oueds, meaning ephemeral streams, they often have dimensions reflecting earlier, more pluvial phases of climate. The longest wadi is the Saoura, which runs nearly 600 miles south from the High Atlas to the Saharan interior, where it eventually dies out. Wadis also radiate from the rugged volcanic peaks of the Ahaggar Mountains in southern Algeria, which rise to 9,573 feet (2,918 metres) at Tahat Peak.

The vast sand seas, known as ergs, which are characteristic of the Sahara, result from the prolonged weathering and erosion of deposits of Tertiary and Quaternary age (at least 1.6 million years old) that make up much of the surface. The Great Western and Great Eastern ergs of Algeria are the most impressive, though expanses of sand almost as huge occur in the Libyan desert. Two prominent erosional desert landforms found extensively in the Sahara are the hammada, a bare plateau covered with boulders and exposed bedrock, and the reg, a gravel- and pebble-strewn plain. Both are products of the desert's unusually strong and nearly continual wind erosion.

Soils. Soil development is extremely limited in the arid landscapes of the Sahara. Low organic matter content and lack of biological activity in the desert's unstable windblown deposits impedes soil development processes. In semiarid areas thin, light-coloured soils with limited humus occur. Soil development is also minimal in the higher altitudes of the Atlas Mountains, where weathered material is thin and easily eroded downslope. It is only in the more stable moister areas, such as on terraced slopes and in valley bottoms, that soil depth and humus



The barren landscape of the Ahaggar Mountains, in the Sahara, southern Algeria.
Geoff Renner/Robert Harding Picture Library

accumulation are appreciable. There brown and reddish brown soils occur together with rendzinas and terra rossas in the numerous areas with a limestone substrate.

Climate. Climate exerts a major influence on the ecology and all aspects of life in North Africa. Ranging as it does from the temperate shores of the Mediterranean and Atlantic to the snowcapped peaks of the High Atlas to the heart of the Sahara, North Africa is a region of climatic extremes. The region is particularly affected by the seasonal movement of the Azores high-pressure cell, which in summer merges with the Iberian high and bars cyclones from entering the Mediterranean, while in winter it moves south over North Africa, permitting their entry. Consequently, in summer Saharan climatic conditions prevail over the whole of North Africa, complete with frequent incursions of the desert's hot desiccating winds.

Local winds

Variously known as the sirocco in Algeria, the *chehili* in Tunisia, and the *chergui* in Libya, these winds are accompanied by marked rises in morbidity and mortality. In contrast, winter brings the northern parts moister and cooler Mediterranean climatic conditions, which gradually fade south toward the interior.

North Africa is therefore largely transitional between a Mediterranean climate in the north and a desert climate in the south with an intervening steppe, or semiarid, zone. The line dividing the Mediterranean and steppe climates is usually taken to be the 16-inch rainfall isohyet, broadly corresponding to the limit of wheat and barley cultivation without irrigation, and that between steppe and desert the 4-inch isohyet, but naturally these limits are only approximate.

Generally, however, average rainfall diminishes toward the interior while rainfall variability, evaporation, and temperature range all increase, though the simple alignment of climatic zones from Mediterranean in the north to steppe farther south and then desert is complicated by the arrangement of coasts and relief. In the far west, for example, much of Morocco coastward of the mountains benefits from the ameliorating effects of Atlantic maritime conditions, which lower annual temperatures and increase orographic, or relief, rainfall. To a lesser extent, eastern Tunisia, notably the As-Saḥil coast, is also favoured by maritime effects, but farther east the southward projection of the Gulf of Sidra brings the Libyan desert virtually to the shores of the Mediterranean Sea.

The Mediterranean climatic zone, characterized by mild moist winters and hot dry summers, includes the northern part of Morocco as far south as the northern and western slopes of the Middle and High Atlas, all of the Mediterranean coast east to Tunisia, the Tell Atlas, northern Tripolitania, and the Akhḍar Mountains of Cyrenaica. The variety of relief within this area means, however, that maritime, semicontinental, and mountain subtypes occur in places. Many mountain locations receive more than 32 inches of rainfall, with higher elevations receiving twice that amount. Most precipitation falls during the three winter months, and autumn rains generally exceed spring rains, but variations in this pattern occur frequently over space and time.

Steppe climate

The steppe climatic zone, lying between the 16-inch and the 4-inch rainfall isohyets, covers about two-thirds of the Atlas Lands, in particular the Moroccan Plateau, the plains of eastern Morocco that lie in the rain shadow of the Middle Atlas, the High Plateau and Saharan Atlas of Algeria, the steppes and Al-Jifārah Plain of Tunisia and Libya, and the rain-shadowed southern slopes of the Akhḍar Mountains in northeastern Libya. Summer drought in the steppe zone normally lasts from five to six months, but in bad years it may last much longer. Only where the steppes reach the coast is humidity higher and dewfall appreciable. Rainfall reliability generally diminishes southward, and rainfall is often more torrential when it occurs, causing flash floods that sometimes devastate huge areas.

The climate of the Sahara is examined separately in AFRICA. Suffice it to say that there is an increase in climatic extremes of aridity, rainfall unreliability, and high temperature toward the interior of the Sahara.

Plant life. The vegetational patterns of North Africa are greatly influenced by climate, relief, and soils. The Mediterranean climatic zone has vegetation typical of the western Mediterranean floristic region, with adaptations to summer drought and with most growth occurring in spring and autumn. Forests are sparse and are dominated by xerophilous oaks and conifers. In the wetter areas on siliceous rocks, especially in the Rif and Tell Atlas mountains, cork oaks and holm oaks occur, but they give way in drier areas and on limestone to Aleppo pines, Barbary cedars, and junipers. Cedar and juniper forests also are found at higher altitudes in Morocco—in the Rif and the Middle and High Atlas mountains. Deforestation has been extensive, variously caused by the spread of cultivation, especially in Roman and colonial times, and by the depredations of livestock and the collection of firewood for charcoal. As a result, bushes and shrubs are more common than woodland. Maquis thickets of laurel, thyme, myrtle, lentisc, arbutus, broom, and rosemary exhibiting characteristic xerophytic features, such as spiny and waxy leaves and thorns, abound. Sometimes, especially on thin, rocky soils, the shrub vegetation degenerates into a poor variety mixed with heath, known as garigue, in which gorse and lavender provide colour and aroma.

Deforestation

The steppes have much poorer vegetation. Trees give way to shrubs, except along wadis where jujube trees and dwarf palms are found, especially in Morocco and west-



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High Plateau (Hauts Plateaux), *region* ..... 34 00 N 0 00
Hoggar, see Ahaggar
Iforas Massif ..... 20 00 N 2 00 E
Jarabub, see Al-Jaghbūb Oasis
Jarbah (Djerba or Jerba) Island ..... 33 48 N 10 54 E
Jarid, Shaṭṭ al- (Chott el-Djerid), *salt flat* ..... 33 42 N 8 26 E
Lesser Atlas, see Anti-Atlas
Libyan Desert (Libiyah, Aṣ-Ṣaḥrāʾ al-) .... 24 00 N 25 00 E
Maghreb (Al-Maghrib), *region* ..... 30 00 N 5 00 E
Maritime Atlas, see Tell Atlas
Mediterranean Sea ..... 35 00 N 20 00 E
Mekerrhane Salt Flat ..... 26 22 N 1 20 E
Melrhir, Chott, *intermittent wetland* ..... 34 20 N 6 20 E
Middle (Moyen) Atlas Mountains ... 33 30 N 4 30 W
Moulouya, *river* ... 35 06 N 2 20 W
M'zab, *area* ..... 32 35 N 3 20 E
Naftūsah (Nefusa) Plateau ..... 31 50 N 12 00 E
Qābis, see Gabes, Gulf of
Rharb (Gharb) Plain ..... 34 30 N 6 00 W
Rheris, *river* ..... 30 39 N 4 26 W
Rif Mountains ... 35 00 N 4 00 W
Sahara, *desert* ... 26 00 N 13 00 E
Saharan Atlas Mountains ..... 34 00 N 2 00 E
Saoura, Wadi ..... 28 48 N 0 50 W
Sebou, *river* ..... 34 16 N 6 41 W
Seliff, see Chelif
Sidi al-Yatā'im, *tomb* ..... 34 57 N 10 31 E
Sidra (Sidra, Surt, or Syrtis), Gulf of .. 31 30 N 18 00 E
Sirtica, *region* ... 30 30 N 17 30 E
Souf Oasis ..... 33 25 N 6 50 E
Sous, *river* ..... 30 22 N 9 37 W
Syrtis Minor, see Gabes, Gulf of
Tell (Maritime) Atlas, *mountains* ... 36 00 N 1 00 E
Tensift, *river* ..... 32 02 N 9 21 W
Ti-N-Amzi, Wadi ... 18 20 N 4 32 E
Ti-N-Tarabine, Wadi ..... 21 16 N 7 24 E
Tibesti Mountains ..... 21 30 N 17 30 E
Tinghert (Tinrhert), *desert upland* ... 29 00 N 9 00 E
Tirahart, Wadi .... 23 48 N 4 00 E
Touat (Tuat) Oasis ..... 27 30 N 0 15 W
Toubkal, Mount ... 31 03 N 7 55 W
Toubkal National Park ..... 31 05 N 7 53 W
Tunis, Gulf of .... 37 00 N 10 30 E
Zamzam, Wadi ... 31 24 N 15 17 E
Ziz, *river* ..... 30 39 N 4 26 W

ern Algeria. Dwarf palms are a source of local fibre, but farther east the wild olive, Atlantic turpentine, and Barbary almond are more prominent. Degradation of steppe vegetation leads to a secondary growth of thorn shrub dominated by ziziphus lotus, a hardy bush whose fruits provide succour in times of drought and famine. Farther south alfa grass is widespread on the sandy drier areas of the steppes, and esparto grass, common on the High Steppes of Tunisia and Algeria, has long been exported for paper production. On more fertile loams and clays, artemisia and dwarf sage are common, while Barbary figs appear on the better soils along the wadis. On saline soils near the salt flats, saltbush is commonly found.

The vegetation of the desert is generally sparse, with scat-

tered concentrations of grasses, shrubs, and trees in the highlands, in oases, and along wadis. Various halophytes (salt-tolerant plants) occupy the chott depressions, while some drought- and heat-tolerant grasses and shrubs are found on the arid plains and plateaus (see AFRICA: *Sahara*).

Animal life. North Africa forms part of the Palaearctic zoogeographic region. Its fauna is similar to that of the Middle East, though its birdlife is more like that of the southern Mediterranean. Species are far less numerous and diverse than in the Ethiopian and Madagascan zoogeographic regions that lie in sub-Saharan Africa. Rupestrian art (*i.e.,* inscribed on rock) bears witness to greater diversity during past pluvial climatic phases, but climate alone is not to blame for the region's faunal degradation; many wild animals have disappeared or become extremely rare through widespread killing by humans over the centuries, some quite recently: elephants, bears, lions, leopards, hyenas, ostriches, and cheetahs to name but a few. The wild boar, Barbary red deer, jackal, lynx, and Barbary sheep, or aoudad, are still found in forested mountain areas, however, and gazelles and oryx still inhabit the desert. Reptiles and insects are also fewer than in other parts of Africa, though locust swarms occasionally do tremendous damage to vegetation. In recent years greater efforts have been made to control and conserve the region's wildlife.

Settlement patterns. North Africa's close juxtaposition of Mediterranean, steppe, and desert climates has had a profound influence on the region's patterns of population distribution and settlement. So also have the varied traditions, histories, and priorities of the peoples who have dominated parts of the region, which, over the centuries, have included Berbers, Greeks, Phoenicians, Romans, Arabs, Turks, French, Spanish, and Italians. They have come as conquerors, colonists, pillagers, tax-collectors, rulers, pirates, missionaries, and proselytizers. Viewing the local peoples and landscapes from different origins and perspectives, they utilized them in different ways and left different imprints upon the landscapes and settlements, especially in the more accessible lowlands. Thus, whereas the Romans and, much later, the French established vast rectilinear olive plantations in eastern Tunisia, pastoral nomadism was prevalent during the intervening centuries. The mountains, on the other hand, have acted more as refuges for traditional modes of life, particularly that of the Berbers.

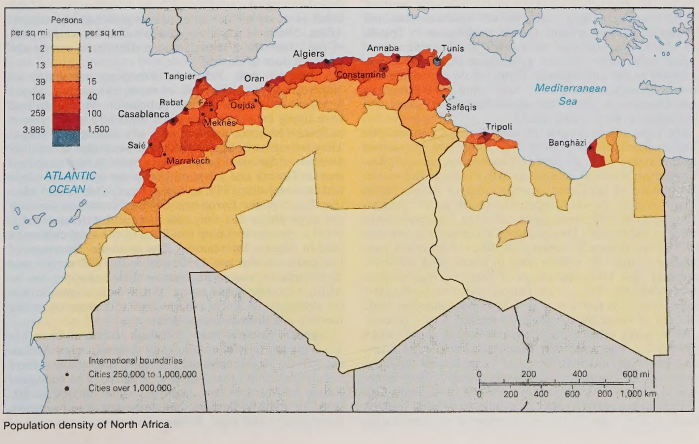
"Tell" and "sahara"

The Mediterranean coastal zone has always been the preferred environment for settlement. Known to North Africans as "the tell," it is the area where harvests are more regular, where pastures are rarely completely scorched, and where olives, figs, and almonds grow without irrigation. Inevitably its more favoured lands attracted sedentary cultivators, villagers and town-dwellers, and a much greater concentration of population than either the steppe or the Sahara. Indeed, for Algerians at least, all that was not tell was "sahara," the area where harvests are very unreliable, where cultivation depends on irrigation, and where pastoral nomadism has prevailed in the past. This duality between tell and sahara can be overstressed, as it undoubtedly oversimplifies the situation, but it does help to facilitate a broad understanding of the social, economic, and political past, for North Africa has long been a region of contact between the desert and the sown, between nomadic and sedentary societies.

Rural settlements. In rural landscapes the types and patterns of settlement reflect, to a large extent, the different agrarian systems, the availability of water, the traditions of the people, and the needs for defense. These influences have varied over space and time, especially as the domain of nomadism and the levels of security have changed. Sedentary cultivators in the Mediterranean zone, in oases, and in areas like the As-Sāḥil coast of Tunisia have traditionally lived in villages rather than in dispersed settlements, although in the Kabylie region of Algeria small hamlets are common. European colonization in the 19th and 20th centuries introduced dispersed farm settlements, often of a characteristically similar style. They contrast markedly today with the more picturesque traditional villages, which are usually made up of flat-roofed, windowless, earthen or stone houses set around a mosque and often a bathhouse. Frequently arranged like terraces on hillslopes, the villages overlook their cultivated areas below. For defensive purposes they sometimes have been situated on hilltops, despite the difficulties of water supply. In moister areas ridge and red tiled roofs occur, as in the Rif.

Along the Saharan fringe, by contrast, houses are often built of vaulted rooms (*ghorfas*), which are characteristically grouped into large fortified granaries known as *ksours* in southern Tunisia and as *agadirs* in southern Morocco. For centuries these structures provided defensive strongholds and food reserves, but many in the mountains have been deserted, sometimes for sites on the plains. Cave dwellings are also common along the Saharan fringe, as in the Ksour Mountains of southern Tunisia and the Nafūsah Plateau of northwestern Libya, where they are carved out of soft limestone.

More commonly in the semiarid areas the tent has been the main dwelling of nomadic peoples. Formerly arranged



Population density of North Africa.

Nomad dwellings

in groups, or douars, tent settlements have become less agglomerated as security has increased. Not all nomads live in tents, however. Many occupy temporary shelters, known often as *gourbis*, which are made of local materials such as straw, diss grass, brushwood, palm trunks, stones, and earth. In Morocco bottle-shaped straw huts (*nouallas*) reflect West African influences. Sedentarization of nomads has meant that many now have fixed abodes for at least part of the year.

Many villages have weekly markets, or souks (suqs), which are widespread throughout North Africa, and in arid areas they are often located in open sites to serve the nomadic peoples. Souks in a particular area are organized on different days of the week, so that traders move cyclically from one to another.

Urban settlement. Town life has ancient traditions in North Africa. Many town sites date back nearly 2,500 years, and the remains of Phoenician, Greek, and Roman cities abound, as at Cyrene, Leptis Magna, Sabratha, Carthage, Thysdrus, and Thugga. The creation of Arab cities in medieval times, however, has had the greatest impact on the region, for most of the sites form the bases of the urban pattern today. The Arab medinas (native quarters) of cities like Tripoli, Tunis, Al-Qayrawān (Kairouan), Tlemcen, Fès, Meknès, and Marrakech became the main centres of North African urban life. Surrounded by walls and dominated by a fort, or casbah, as the centre of government and by the minaret of the great mosque, the medinas were very compact. Along some of the winding narrow streets were souks, or bazaars, in which each trade—reflecting an elaborate hierarchy—focused its activity on a particular street, the more noble trades being located near the great mosque and the noisier and smellier ones occupying positions toward the gates. Peoples of different origins lived in identifiable quarters, but with the expansion of the cities new quarters emerged around the gates. Today these old medinas pose considerable problems for urban planners, as they are virtually impregnable to modern traffic.

European colonial activities resulted in rapid expansion of many urban areas. With four-fifths of the Europeans living in towns and with the colonial export economies growing rapidly, port cities such as Casablanca, Oran, Algiers, Annaba (Bône), Tunis, Şafāqis (Sfax), Tripoli, and Banghāzī all developed into major metropolitan centres. Towns in the interior grew less rapidly except where they became important administrative and service centres, as at Marrakech, Fès, Meknès, and Constantine. In the main cities Europeans created their own quarters. In Algiers this led to the destruction of much of the city's old medina; in Tunisian and Libyan cities the new quarters were built alongside, or even around, the old medinas, as in Tripoli; in Morocco a policy of twin cities, the European town being built some distance away from the medina, was adopted at Fès and Meknès. Plans for similar twin cities, however, were submerged by early rapid growth in cities like Casablanca, where the layout became confused and shantytowns proliferated quickly.

The rapid urban growth initiated during European rule has persisted to the present day, stimulated by various factors such as war, drought, independence, the oil industry, industrialization, and the growth of the service sector. With some of the fastest-growing cities in Africa, North Africa is now the most urbanized region on the African continent. In 1960, immediately after the independence of three of the region's four countries and shortly before that of Algeria, its largest country, less than a third of the population of about 28 million lived in towns. By 1990 about one-half of a total population of some 64 million were town dwellers. The urban growth rate was particularly high in oil-rich Libya at 5 to 10 percent annually, while in each of the other countries it averaged 3 to 4 percent.

As in many other parts of the developing world, urban growth has been especially localized in the major cities, and by 1990 North Africa could boast several "millionaire" cities: Casablanca with nearly three million inhabitants, Algiers with almost two million, and Tunis and Tripoli with a million each. This rapid growth has resulted from a high natural rate of increase of the population as well as from strong rural-urban migration, which has, since independence, focused almost exclusively upon the major cities, all of which are their countries' capitals and also their main industrial centres. Heavy centralization of activities upon such principal cities poses special problems of unemployment and housing, both of which have been easier to ameliorate in oil-rich and underpopulated Libya than in the other three overpopulated countries of the Maghrib.

THE PEOPLE

Ethnic composition. North Africa is vastly more uniform ethnically than anywhere in Africa south of the Sahara. It is principally inhabited by Arabs and Berbers, who are scarcely distinguishable physically. The Berbers are the indigenous people, but their origin is obscure. An ancient people speaking an Afro-Asiatic language, they were in North Africa when the Phoenicians came as traders. Their name, however, derives from the Latin Barbari, which meant all people foreign to the Romans. Of the numerous peoples with whom they came into contact, they were most affected by the Arabs, who invaded between the 7th and 11th centuries. From them they eventually accepted Islām and many other aspects of Arab culture. Calling themselves Imazighen, or free men, Berbers comprised both nomadic and settled tribes that congregated periodically, especially in mountain refuge areas. A rural society with elaborate forms of social stratification, Berber groups have been mainly concerned with preserving their local autonomy rather than with establishing a national political identity. Open to Arab invasions from the east, Libya and Tunisia now contain only small pockets of Berbers and Arabized Berbers in hilly areas; in Algeria Berbers are more common, as in the Aurès Mountains and Kabylie region. They are most numerous, however, in the mountainous areas of Morocco; among them the Shluh (Chleuh) tribe are well-known traders. In the Sahara the most famous of all Berbers are the wide-ranging, nomadic Tuareg. The Berbers are a minority people overall, greatly outnumbered by the Arabs; nonetheless, they have left a strong and pervasive influence on the culture of North Africa.

Indigenous Berbers

The Arabs came initially as invaders and later as pastoralists, bringing with them Islām, Islāmic civilization, the Arabic language, and new customs. Gradually they assimilated more and more Berbers into their culture, as their nomadic members spread the Arabic language and Arab culture and as their cities acted as centres of Islāmic religion and civilization. Because Arabs are so widely dispersed throughout northern Africa, including parts of the Sahel zone, as well as along the coastal zone of eastern Africa, North Africa is considered to be the western end of the Arab world, though also a distinctive part at the southern door of Europe.

During the early 1950s the European population of North Africa reached a peak of nearly two million, about 9 percent of the region's total population. More than half were living in Algeria, though a third of a million were in French Morocco and a quarter of a million in Tunisia. They were mostly French, but there were also substantial numbers of Spaniards, especially in Spanish Morocco; Italians in Tunisia and Libya, although the Italians in Libya had declined after 1939; as well as many Greeks and Maltese. Most of the Europeans lived in towns, particularly the large cities, but they also occupied extensive cultivated areas—as much as two-fifths of the total cultivated land in Algeria, for example. The dramatic departures of Europeans in the late 1950s and early '60s meant that decolonization was more massive than anywhere else in Africa. One significant aspect of this mass migration was the departure of half a million Jews to Europe or to the recently established state of Israel.

Departure of Europeans

Linguistic composition. Although North Africa has much greater linguistic uniformity than any other African region—the Arabic language prevailing throughout—there is more variability than might be expected. The colloquial Arabic of Morocco, for example, would not be understood in the Middle East, and there are sharp contrasts between city and rural dialects. Moreover, the Arabic of

newspapers differs considerably from classical Arabic, the language of the Qur'ān (Koran). Efforts have been made in Libya to promote Arabic against the persistent penetration of English, but in Morocco, Algeria, and Tunisia a distinctive Arab-French culture has evolved that has been sustained by scholarship and by the continuous back-and-forth flow of migrant workers to France. The Berber language is spoken by less than a fifth of the population, and it is not generally written, except by the Tuareg.

Religions. With the departure of Europeans and Jews during decolonization, North Africa became almost uniformly Muslim, in its Sunnite form. It constitutes the western extremity of the Muslim world, which stretches across Africa and Asia to Indonesia. As with any of the major historical religions, Islām's influence has been pervasive, extending into all aspects of life: demographic characteristics, through its exaltation of marriage and the family and its impact upon the role of women in society; commerce, through its condemnation of moneylending; urban life, through the construction of mosques and the cloistering of women; land tenure, through the provision of a juridical framework; and community service, through the importance it places on the pious foundation, or *habous,* for carrying out local religious and charitable tasks.

Pervasive influence of Islām

Two particular features of Islām in North Africa have in the past had an important pacifying influence on the tribes: first, the growth of religious brotherhoods to which most men of religion were affiliated; and second, maraboutism, or the cult of saints and holy men, whose piety, asceticism, and teachings carried out in local *zāwiyahs* (religious lodges) attracted emulation and whose many shrines dot the landscape.

Demographic trends. North Africa has had a rapidly growing population throughout the latter half of the 20th century. Its rapid growth has been caused largely by sharp declines in mortality, along with much more modest declines in fertility, resulting in annual rates of natural increase well above average for the developing world. Death rates in all four countries in the region have dropped to very low levels, owing to better medical facilities, improved sanitation, better nutrition, and higher standards of living. Its death rates, in fact, are lower than in many more developed countries because of the relatively youthful age structures of the populations—generally about 40 percent of the population in each country is under 15 years of age—a factor contributing also to the region's high fertility. There is still much progress to be made in reducing infant mortality rates, however, which remain a high 40 to 80 deaths per 1,000 live births. Life expectancy has risen steadily in the region since the 1950s to between 64 and 69 years, being lowest in Morocco and highest in Tunisia.

Birth rates in North African countries have fallen more than in most countries in the more traditional Middle East. Tunisian women bear about four children each, while Moroccan women have four to five, and Algerian and Libyan women five or more. Several factors account for these differences. There has been a considerable increase in the use of contraception in Tunisia and to a lesser extent in Morocco, the former being a pioneer Muslim country in family planning and in raising the status of women. Divorce reform, later age of marriage, increased educational opportunities for women, and the entrance of women into the labour force have all been promoted in Tunisian society. These changes have come more slowly in Morocco, Algeria, and Libya, but a demographic transition throughout the region has been initiated.

A demographic transition in progress

Oil-rich Libya's long-term labour shortage has understandably influenced its attitudes toward fertility, as it relies upon hundreds of thousands of migrant workers from other North African countries, the Middle East, and other parts of the world. In contrast, Morocco, Algeria, and Tunisia have long been sources of migration, as hundreds of thousands of their workers have gone abroad, especially to the cities of France, but now also to Italy, Spain, and elsewhere in search of employment.

THE ECONOMY

Overview. The economy of North Africa has changed qualitatively between each of its three main historical phases: precolonial, colonial, and postcolonial. The precolonial period was marked by the prevalence of a largely subsistence agriculture dominated by pastoral nomadism on the steppes and sedentary cultivation in the mountains and more favoured Mediterranean zone. Pastoralists migrated northward and to better pastures in higher country in the summer, often participating in the harvests of cereals and tree crops, especially olives. Economic well-being was heavily dependent on the vicissitudes of climate, and urban life was restricted to a few important cities where handicrafts were the main industries. Transport was greatly influenced by the ubiquity of nomadism, and thus pack animals, able to go almost anywhere, prevailed over wheeled vehicles, which were rare.

The colonial phase saw the steady growth of public and private colonization superimposed on the traditional economy. The more favoured agricultural areas were especially affected, and the development of modern, commercialized colonial agriculture geared to the growth of cash crops for export—especially wheat, barley, wine, citrus fruits, olive oil, dates, and early vegetables—proceeded on a large scale. The impact of colonialism was particularly great in Algeria and Libya, which were administered as parts of France and Italy respectively, and was somewhat less in the two French protectorates of Tunisia and Morocco. Generally, pastoralism was pushed south and experienced little modernization. At the same time, mineral resources were exploited, mainly phosphates and iron ore, though in the final years of French rule in Algeria the export of petroleum began. Industrialization evolved only gradually, being impeded by limited investment, lack of coal resources, and little potential for hydroelectric power. Industries were concentrated in the larger, rapidly growing cities, which were connected by a sound, modern transport network of railways, roads, and, later, airways. Such a network facilitated control over the countries and enhanced the evolution of a matured colonial economy involving the export of mostly raw materials and the import of manufactured goods.

The impact of colonialism

During the relatively brief postcolonial period there has inevitably been persistence of some aspects of both the previous periods, but there have been important transformations as well. Because of the massive exploitation of oil that has gone on in Libya, its economic situation has been transformed the most. Algeria and to a lesser extent Tunisia have also benefited greatly from oil extraction. The per capita gross national product (GNP) of the region's countries during the 1980s reflects this situation: Libya sustained the highest figure in all Africa and Algeria the third highest (though only half that of Libya), while Tunisia and Morocco—both of which also ranked high among African countries—had significantly lower figures. Despite the growth of oil exports, all four countries have tried to reduce their dependence on the export of raw materials, often by processing them prior to export to give them added value.

All faced shortages of skilled labour for industrialization and initially had to rely upon foreign expertise, especially Libya, which also suffered, unlike the other countries, from a shortage of unskilled and semiskilled labour, making it dependent on a large foreign labour force like the other oil-rich countries of the Middle East. Despite much progress in industrialization in the postcolonial period, including heavy industries, industrialization by itself has not proved to be the answer to all North Africa's economic problems; it has, moreover, accelerated the process of urbanization by attracting labour from the countryside.

Skilled labour shortages

The redistribution of colonial lands in rural North Africa in the 1950s and '60s and the collectivist solution to agricultural development in Algeria also did not solve the related problems of trying to increase agricultural production and reduce its annual fluctuations. All the countries faced severe difficulties in supplying sufficient food to their rapidly growing populations. The considerable expansion of tourism in Morocco and Tunisia transformed parts of their coastal zones and provided some promise for development, but the long-term benefits of tourism have been questioned, especially as it is vulnerable to changes in the international economic and political climate.

The four countries have all adopted very different economic policies. Algeria's initial stance as a centrally planned economy has been relaxed to permit some development of the private sector. Under Colonel Muammar al-Qaddafi, Libya has been economically radical and individualistic. Tunisia abandoned its early socialist experiment in agricultural collectivization and, with increasing privatization, has become economically liberal, while Morocco under monarchic rule has retained conservative economic policies. All four countries, however, have been unable to avoid the influence of external forces on their economies, in particular the fluctuations in the economies of the European Community (EC), which have affected trade, investment, tourism, and the movements of migrant workers. Such fluctuations have not been offset by intraregional trade or cooperation, which has been limited despite various agreements.

Morocco, Algeria, and Tunisia all faced severe debt in the late 20th century owing to extravagant developments in the early decades of independence and to heavy borrowing. Morocco was forced to reschedule its debts under International Monetary Fund–Paris Club arrangements, a fate that would have befallen Algeria and Tunisia had they not introduced reforms to reduce budget deficits.

Resources. Although Africa is rich in numerous mineral resources, North Africa's mineral wealth is limited primarily to its petroleum and natural gas reserves. The Libyan and Algerian deserts have about 2 percent and 1 percent respectively of the proven world reserves of petroleum, and Algeria about 3 percent of the reserves of natural gas. In contrast, North Africa's other energy resources are minor. Coal deposits are small and remotely located, mainly in eastern Morocco, and hydroelectric power potential is limited—except in Morocco—largely by the aridity of the region.

Petroleum and natural gas reserves

The two other major mineral resources of North Africa are phosphates, found especially in Morocco and Tunisia, and iron ore, found in Algeria, Tunisia, and Libya. Many other minerals have been mined in smaller quantities when world prices have been favourable, including lead, zinc, manganese, cobalt, antimony, copper, and molybdenum. In addition, the region's abundant limestone deposits are used for cement production in all countries.

Agriculture, forestry, and fishing. North Africa's agricultural and timber resources are limited by its dry climate, and its agricultural products are those typical of the Mediterranean, steppe, and desert regions: wheat, barley, olives, grapes, citrus fruits, early vegetables, dates, sheep, and goats. It is not a region noted for its timber resources, though cork is an unusual product.

Agriculture employs between 20 and 25 percent of the working population in Algeria and Tunisia, less in Libya, but about 40 percent in less urbanized Morocco. Since independence, agricultural production has failed to keep pace with population growth and has remained susceptible to large annual fluctuations. All four countries have only small areas of prime arable land and no large reserves suitable for expansion. Cropland occupies about one-third of Tunisia and one-fifth of Morocco, the two countries where agriculture contributes most to the gross domestic product (GDP), but less than one-thirtieth of Algeria and one-sixtieth of Libya. Countries that were formerly important food exporters saw a marked decline in export production in the 1970s, with severe social consequences. Not only were these countries compelled to increase food production rapidly for their growing populations, but they also had to import more food because of changed consumption patterns resulting from rising standards of living. Some export crops, moreover, like wine grapes, citrus fruits, tobacco, and cotton, have suffered from strong international competition, though others, like sugar beets in Morocco, have expanded.

Decline in nomadism

Desertification in the drier areas has contributed to a decline in nomadism and to the settlement of nomads. Both trends have also been intensified by the growth of the oil and gas industries in Libya and Algeria and by the extension of arable farming into marginal lands. Livestock farming, however, especially of sheep and goats, still plays an important role in the region's economy.

The bulk of North Africa's forestry production is for local firewood, charcoal, and industrial timber, but cork is produced for export from the large areas of cork oak (*Quercus suber*) trees that grow near the Mediterranean, especially in the west.

As a region, North Africa is not a major contributor to the continent's fish catch, accounting for less than one-tenth of the total take, but Morocco, with its cool, plankton-rich Atlantic waters and access to the Mediterranean, is the largest fish producer in the Arab world. Pilchards, sardines, bream, hake, sea bass, anchovies, and mullet are the principal species landed, with the unusual addition of sponges in Tunisian waters. Although comprising only a small part of the total economy, fish processing and canning occurs in many North African ports. The introduction of exclusive economic zones beyond territorial waters beginning in the 1970s has led to disputes over fishing rights between Morocco and Spain and between Tunisia and Italy.

Industry. North Africa's industries are largely related to the mining and processing of its energy and mineral resources. Following discoveries of oil in the desert in the 1950s and '60s, Libya and Algeria both became major petroleum producers. Although Tunisia is only a minor producer, oil is prominent in its economy as well, being its chief export. Libya is particularly reliant upon its petroleum production, which accounts for a high percentage of its GDP. To capitalize on their petroleum resources, Algeria and Libya have both developed major oil-refining and petrochemical industries. Most production goes to Europe and the United States.

Natural gas was an underutilized resource until it was exported in liquefied form to European and American markets. Since the late 1980s significant expansion of Algeria's gas exports has occurred with the completion of a gas pipeline linking Algeria with Sicily via Tunisia and the Mediterranean. Algeria is now one of the world's largest producers of natural gas, with about 2 percent of the total world production. Natural gas is also produced in Libya, though on a much smaller scale. The only other important mineral production is of phosphate rock in Morocco and Tunisia. Both countries have large ancillary superphosphate industries. Iron ore production from eastern Algeria is also significant and no doubt has stimulated the huge investments in that country's iron and steel industry.

Most electricity is generated in thermal installations, but hydroelectric power production accounts for a small share of the electricity generated. In Morocco, the country most dependent on hydropower, it accounts for more than one-tenth of the electricity produced and constitutes more than a quarter of net installed electricity-generating capacity. In 1990 a valuable electricity interchange link was established between Morocco, Algeria, and Tunisia. Rural electrification has made much progress in the final decades of the 20th century, though nearly all electricity generated is still transmitted to the cities.

Industrial diversification

All the countries of North Africa have tried to increase and diversify their industries, equating industrialization with modernization. Morocco and Tunisia, less endowed with oil and gas, have been forced to more diversification than either Libya or Algeria. Inevitably industrial development has not met with quick success, as EC and other major markets have not been easy to penetrate. Agriculture-related and food industries still produce a considerable proportion of all industrial output, but there have been important developments in metallurgy, automobile assembly, radio and television, pharmaceutical products, and textiles and clothing.

Tunisia and Morocco both attract millions of European tourists annually to their beaches and historic cities, and tourism has become an important industry in both countries, especially in terms of employment. For political and social reasons Algeria and Libya have not developed their tourist industries to the same extent.

Trade. Minerals and mineral products are the region's main exports, notably petroleum and petroleum products (Libya, Algeria, Tunisia), natural gas (Algeria, Libya), phosphates and superphosphates (Morocco, Tunisia), and iron and steel (Algeria). Agricultural products such as

wheat, olives, olive oil, citrus fruits, and dates, once mainstays of the export economy, have been surpassed by manufactured products, which now contribute substantially to the exports of Morocco and Tunisia. Imports include food, industrial supplies and machinery, consumer goods, and transport equipment.

Algeria and Libya generally export far more than they import, but both Morocco and Tunisia suffer from chronic trade imbalances. Foreign trade is dominated by the former colonial powers, France and Italy, with Spain, Germany, the United States, and Belgium as other important trading partners.

Transportation. Because of the extensive rail network built by the French during the colonial period, Morocco, Algeria, and Tunisia have emphasized railways in their transportation infrastructures. The modern network includes new electrified lines, such as those between Casablanca and Rabat, and light rapid-transit systems in major cities like Algiers and Tunis. Road building has been given less emphasis in these three countries than in Libya, where the old Italian railways failed to survive and where a major road-building program has been implemented. Consequently, Libya has almost as many vehicles as the much more populous countries of Algeria and Morocco.

Major ports

The major port cities of Casablanca, Oran, Algiers, Tunis, and Tripoli handle most of the region's general traffic, while the smaller ports of Marsā al-Burayqah, Ra's al-Unūf, Skikda, and Arzew are sites of the main oil terminals. Other smaller ports handle mineral products or are important for fishing (*e.g.,* Safi, Larache, Ṣafāqis). International airways have become particularly important to Morocco and Tunisia because of their considerable tourist traffic, and each country has a number of international airports. However, the larger countries of Algeria and Libya have a bigger network of domestic airports to handle their internal communications. (J.I.C.)

History

ANCIENT NORTH AFRICA

Geography and prehistory. North Africa as here used means the area of present-day Morocco, Algeria, Tunisia, and Libya. In ancient times the Greeks used the word Libya, derived from the name of a tribe on the Gulf of Sidra, to describe the land north of the Sahara, the territory whose native peoples were subjects of Carthage, and also as a name for the whole continent. The Romans applied the name Africa (of Phoenician origin) to their first province in the northern part of Tunisia, as well as to the whole area north of the Sahara and also to the entire continent. The Arabic term Jazirat al-Maghrib, meaning island of the west, applied first of all to land west of Egypt but more particularly to present-day Tunisia, Algeria, and Morocco. French scholars regularly use Maghrib in this sense, and it is so used here. The Arabs used the word Barbar (Berber), perhaps derived from the Latin *barbari,* to describe the non-Latin-speaking peoples of the Maghrib at the time of the Arab conquest, and it has been used in modern times to describe the non-Arabic-speaking population (French *Berbères*). A frequent usage refers to the non-Phoenician and non-Roman inhabitants of classical times, and their language, as Berber. It should be stressed, however, that the theory of a continuity of language between ancient inhabitants and the modern Berbers has not been proved; consequently, the word Libyan is used here to describe these people in ancient times.

Ancient Libya

The description of the area as an island refers to its isolation, bounded as it is by the sea to the north and west and by the Sahara to the south and east. Since antiquity, the desert has been the dominant factor in the North African environment, though it has not always been as dry as it is today. At various times during the past million years there have been periods of abundant rainfall, the last occurring about the 6th millennium BC at the beginning of the Neolithic Period (see below). A major trade route connecting the Mediterranean with the African world existed along the Ahaggar-Tibesti ridge in the central Sahara, and it is probable that communications existed across the western Sahara also. Nevertheless, the Sahara always constituted a formidable barrier to the movement of technology and peoples. In ancient historical times much of North Africa was evergreen forest or scrub, and the fauna included animals such as the elephant, zebra, and ostrich.

The mountains were of the utmost importance in the historical development of the area. They run generally from east to west, parallel to the coast, with their highest elevations in the Atlas Mountains. They are not continuous but constitute separate blocks, especially in the coastal areas. Although it was in the mountains that the rainfall was highest, the forest there was intractable, and early settlements tended to choose the plains and valleys between or south of the mountains. The Mediterranean coast, for much of its length, is extremely inhospitable, offering few natural harbours and still fewer natural lines of communication into the interior. Even the major rivers, such as the Majardah (Medjerda) and Chelif, are unnavigable. Only in northeastern Tunisia is the coastline more favourable, and the main movement of culture and conquest has naturally been from there westward.

The coastal strip in the area of Tripoli (Ṭarābulus) in western Libya is an extension of Tunisia's coastal plain. To the east, some 800 miles of the Surt Desert separates it from Cyrenaica (Barqah) at the eastern end of modern Libya, which thus has had a very different history from the Maghrib. Settlement there was effectively confined to the Akhḍar Mountains and did not extend more than about 70 miles south of the coast. Cyrenaica's contact with Egypt was limited by an intervening 600 miles of semidesert.

The Maghrib provides the paradox of being an area in which various cultures have imposed some measure of uniformity, while political unity has been rare; for this, geography is largely responsible. The area of settlement is of vast length but little breadth and has no natural centre from which political uniformity could be imposed; its natural communications have never been easy, and the mountain blocks have been large enough to maintain populations to a greater or lesser degree independent of and hostile to those that controlled the plains.

Earliest inhabitants

Although there is uncertainty about some factors, Aïn el-Hanech (in Algeria) is the site of one of the earliest traces of hominid occupation in the Maghrib. Somewhat later but better attested are sites at Ternifine (near Tighennif, Alg.) and at Sidī ʿAbd ar-Raḥmān, Mor. The former produced hand axes associated with the hominid *Homo erectus,* a more primitive being than the Neanderthaloids of the same period. Sidī ʿAbd ar-Raḥmān produced evidence of the same hominid, with a date of at least 200,000 BC.

Succeeding these early hand-ax remains are the Levalloisian and Mousterian industries similar to those of the Levant. It is claimed that nowhere did the Middle Paleolithic evolution of flake-tool techniques reach a higher state of development than in North Africa. Its high point in variety, specialization, and standard of workmanship is named Aterian, after the type site of Bīʾr al-ʿAtīr in Tunisia; assemblages of this material occur all over the Maghrib and the Sahara. Radiocarbon testing from Morocco indicates a date for early Aterian material of about 30,000 BC. Its diffusion over the region appears to have taken place during one of the periods of desiccation, and the carriers of the tradition were clearly adept desert hunters. The few associated human remains are Neanderthaloid, with substantial differences between those found in the west and those in Cyrenaica. In the latter area, a date of about 43,000 BC for the Levalloisian and Mousterian industries has been obtained (at Haua Fteah). The tools and a fragmentary human fossil of Neanderthaloid type are almost identical to those of Palestine.

The earliest blade industries of the Maghrib, associated as in Europe with the final supersession of Neanderthaloids by *Homo sapiens,* are named Ibero-Maurusian, or Oranian (type site, La Mouilla, near Oran in western Algeria), an industry of obscure origin, which seems to have spread along all the coastal areas of the Maghrib and Cyrenaica between about 15,000 and 10,000 BC. Following the Ibero-Maurusian was the Capsian, the origin of which is also obscure. Its most characteristic sites are in the area of the great salt lakes of southern Tunisia, the type site being al-Maqtaʿ (el-Mekta), near Qafṣah (Capsa, or Gafsa). The cli-

mate during both Ibero-Maurusian and Capsian appears to have been relatively dry and the fauna one of open country, ideal for hunting. Between about 9,000 and 5,000 BC, upper Capsian spread northward to influence the Ibero-Maurusian and also eastward to the Gulf of Sidra. Since there is much evidence that the Neolithic culture of the Maghrib was not introduced by invasion but through the acceptance of new ideas and technologies by the Capsian peoples, it is probable that they were the ancestors of the Libyans known in historic times.

Neolithic culture

The spread of early Neolithic culture in Libya and the Maghrib occurred during the 6th and 5th millennia BC and is characterized by the domestication of animals and the shift from hunting and gathering to self-supporting food production (often still including hunting). The pastoral economy, with cattle the chief animal, remained dominant in North Africa until the classical period. Although the new type of economy may have originated in Egypt or the Sudan, the character of the flint-working tradition of the Maghribian Neolithic argues in favour of the survival of much of the earlier culture, which has been called Neolithic-of-Capsian tradition. Accordingly, the technology of the transition, if not of independent local origin, is best explained by the gradual diffusion of new techniques rather than by the immigration of new peoples.

The Neolithic-of-Capsian tradition in the Maghrib persisted at least into the 1st millennium BC with relatively little change and development; there was no great flourishing of late Neolithic culture and little that can be described as a Bronze Age. North Africa was wholly lacking in metallic ores other than iron, hence most tools and weapons continued to be made of stone until the introduction of ironworking techniques.

Prehistoric rock carvings have been found in the southern foothills of the Atlas south of Oran and in the Ahaggar and Tibesti ranges. While some are relatively recent, the great majority appear to be of the Neolithic-of-Capsian tradition. Some show animals now locally or even totally extinct, such as the giant buffalo, elephant, rhinoceros, and hippopotamus, in areas now covered by desert. While Egyptian-like patterns may be discerned, the character of the rock art is so different from that of Egypt that it can hardly be said to derive from it. On the other hand, it is very much later than the rock paintings of Paleolithic times in southwestern Europe, and an independent development is probable. The art is primarily that of a culture that remained largely, though not exclusively, dependent on hunting and that survived on the Saharan fringes until historical times.

Prehistoric fauna

There are many thousands of large, stone-built surface tombs in North Africa that appear to have no connection with earlier megalithic structures found in northern Europe, and it is unlikely that any of them is earlier than the 1st millennium BC. Large structures in Algeria such as the tumulus at Mzora (177 feet [54 metres] in diameter) and the mausoleum known as the Medracen (131 feet in diameter) are probably of the 4th and 3rd centuries BC and show Phoenician influence, though there is much that appears to be purely Libyan.

The Carthaginian period. *The Phoenician settlements.* North Africa (with the exception of Cyrenaica) entered the mainstream of Mediterranean history with the arrival in the 1st millennium BC of Phoenician traders, mainly from Tyre and Sidon in modern Lebanon. The Phoenicians were not looking for land to settle but for anchorages and staging points on the trade route from Phoenicia to Spain, a source of silver and tin. Points on an alternative route by way of Sicily, Sardinia, and the Balearic Islands also were occupied. The Phoenicians lacked the manpower and the need to found large colonies as the Greeks did, and few of their settlements grew to any size. The sites chosen were generally offshore islands or easily defensible promontories with sheltered beaches on which ships could be drawn up. Carthage (from the Phoenician Kart-Hadasht, New City), destined to be the largest Phoenician colony and in the end an imperial power, conformed to the pattern.

Tradition dated the foundation of Gades (modern Cádiz; the earliest known Phoenician trading post in Spain) to 1110 BC, Utica (Utique) to 1101 BC, and Carthage to 814 BC. The dates appear legendary, and no Phoenician object earlier than the 8th century BC has yet been found in the west. At Carthage some Greek objects have been found, datable to about 750 or slightly later, which comes within two generations of the traditional date. Little can be learned from the romantic legends about the arrival of the Phoenicians at Carthage transmitted by Greco-Roman sources. Though individual voyages doubtless took place earlier, the establishment of permanent posts is unlikely to have taken place before 800 BC, antedating the parallel movement of Greeks to Sicily and southern Italy.

Material evidence of Phoenician occupation in the 8th century BC comes from Utica, and of the 7th or 6th century BC from Hadrumetum (Sūsah, Sousse), Tipasa (east of Cherchell), Siga (Rachgoun), Lixus, and Mogador (Essaouira), the last being the most distant Phoenician settlement so far known. Finds of similar age have been made at Motya (Mozia) in Sicily, Nora (Nurri), Sulcis, and Tharros (San Giovanni di Sinis) in Sardinia, and Cádiz and Almuñécar in Spain. Unlike the Greek settlements, however, those of the Phoenicians long remained politically dependent on their homeland, and only a few were situated where the hinterland had the potential for development. The emergence of Carthage as an independent power, leading to the creation of an empire based on the secure possession of the North African coast, resulted less from the weakening of Tyre, the chief city of Phoenicia, by the Babylonians than from growing pressure from the Greeks in the western Mediterranean; in 580 BC some Greek cities in Sicily attempted to drive the Phoenicians from Motya and Panormus (Palermo) in the west of the island. The Carthaginians feared that if the Greeks won the whole of Sicily they would move on to Sardinia and beyond, isolating the Phoenicians in North Africa. The successful defense of Sicily was followed by attempts to strengthen limited footholds in Sardinia; a fortress at Monte Sirai is the oldest Phoenician military building in the west. The threat from the Greeks receded when Carthage, in alliance with Etruscan cities, checked the Phocaeans off Corsica in about 540 BC and succeeded in excluding the Greeks from contact with southern Spain.

Relations with the Greeks

Carthaginian supremacy. By the 5th century BC, active military participation by Tyre in the west had doubtlessly ceased; from the latter half of the 6th century Tyre was under Persian rule. Carthage thus became the leader of the western Phoenicians and in the 5th century formed an empire of its own, centred on North Africa, which included existing Phoenician settlements, new ones founded by Carthage itself, and a large part of modern Tunisia. Nothing is known of resistance from the indigenous North African population, but it was probably limited owing to the scattered nature of local societies and the lack of state formation. The actual stages of the growth of Carthaginian power are not known, but the process was largely completed by the beginning of the 4th century. The whole of the Cap Bon (Jazirat Sharik) peninsula was occupied early, ensuring Carthage a fertile and secure hinterland. Subsequently, its control extended southwestward as far as a line running roughly from al-Kāf to the coast at Thaenae (now the ruins of Thīnah, or Tina). Penetration occurred south of this line later, Theveste (Tbessa, Tébessa) being occupied in the 3rd century BC. In the Cap Bon peninsula, where the Carthaginians developed a prosperous agriculture, the native population may have been enslaved, while elsewhere they were obliged to pay tribute and furnish troops.

Carthage maintained an iron grip on the entire coast, from the Gulf of Sidra to the Atlantic coast of Morocco, establishing many new settlements to protect its monopoly of trade. These were mostly small places, probably of only a few hundred inhabitants. The Greeks called them emporia, markets where native tribes brought articles to trade, which could also serve as anchorages and watering places. Permanent settlements in modern Libya were few and dated after the attempt of Dorieus to plant a Greek colony there. Though in time fishing and agriculture played a part in their wealth, Leptis Magna with its neighbours Sabratha and Oea (Tripoli) became rich through trans-Saharan trade; Leptis Magna was the terminus of the

Carthaginian settlements

shortest route across the Sahara linking the Mediterranean with the Niger. A Carthaginian named Mago is said to have crossed the desert several times, but doubtless much of the trade (in precious stones and other exotics) came through intermediate tribes. Other stations on the Gulf of Gabes included Zouchis, known for its salted fish and purple dye, Gigthis (Bū Ghirārah), and Tacape (Qābis, Gabès). North of Thaenae was Acholla, traditionally an offshoot of the Phoenician settlement on Malta, Thapsus (Rass Dimas), Leptis Minor, and Hadrumetum, the largest city on the east coast of Tunisia. From Neapolis (Nābul, Nabeul), a road ran direct to Carthage across the base of the Cap Bon peninsula.

West of Carthage there have been changes in the course of the Majardah (Bagradas) River; as a result, Utica, a port in Carthaginian and Roman times, is now some seven miles from the sea. Utica was second only to Carthage in importance among the Phoenician settlements and always maintained at least a nominal independence. Beyond Cape Farina (Ra's Sidi 'Alī al-Makkī) as far as the Strait of Gibraltar, the coast offered a number of anchorages, but few of the stations reached anything like the prosperity of those on the Gulf of Gabes and the east coast of Tunisia. One of the more important was Hippo Diarrhytus (Bizerte, Banzart), whose natural advantages as a port were utilized at an early date; another Hippo, later called Hippo Regius (Bône, modern Annaba), was also probably of Carthaginian origin. Along the same stretch of coast were Rusicade (Philippeville, Skikda) and Collo (Chullu). Still farther west, a number of place-names known from the Roman period betray an earlier Phoenician interest through the incorporation of a Phoenician element, *rus*, meaning "cape"; *e.g.*, Rusuccuru (Dellys) and Rusguniae (Matifou). Tingis (Tingi, Tangier) was already settled in the 5th century BC.

Trade. Ancient sources agree that Carthage had become perhaps the richest city in the world through its trade, yet very few traces of its wealth have been discovered by archaeologists. This is because most of it was in perishables—textiles, unworked metal, foodstuffs, and slaves; its trade in manufactured goods was only a part of the whole. There can be no doubt that the most profitable trade was that inherited from the Phoenicians in the western Mediterranean, in which tin, silver, gold, and iron were obtained in exchange for manufactures and consumer goods of small value. Carthage ruthlessly maintained its monopoly of this trade from the late 6th to the end of the 3rd century BC by sinking intruders and exacting recognition of its position from other states. Its wealth is attested by the vast mercenary armies it was able to maintain with a mintage of gold coins in the 4th century far in excess of that known for other advanced states.

Voyages of exploration

It was apparently in connection with this trade that during the 5th century there occurred two voyages of exploration and trade, evidently of particular importance since reports of them were known to later generations of Greeks and Romans. One was along the Atlantic coast of Morocco, the other northward along the Atlantic coast of Spain. They were led by Hanno and Himilco, respectively, both members of a leading family in Carthage. Hanno's voyage is generally associated with an account in Herodotus, writing about 430 BC, of Carthaginian trade on the Atlantic coast of Morocco. Herodotus describes a system of dumb barter with the coastal peoples, by which the Carthaginians exchanged manufactured goods for gold. It is not known where the exchanges took place; the Río de Oro is a possibility, and it is probable that Hanno's expedition went beyond Cape Verde. Nevertheless, the "gold route" did not survive the fall of Carthage and was not exploited by the Romans. This has led some scholars to argue that the Carthaginians' interest in the Atlantic coast of Morocco was stimulated by the more prosaic attraction of the abundant fish.

Himilco's voyage also was known to the Greeks and Romans. He sailed north along the Atlantic coast of Spain, Portugal, and France and reached the territory of the Oestrymnides, a tribe living in Brittany. The purpose of this voyage was apparently to consolidate control of the trade in tin along the Atlantic coast of Europe. It followed the route used by the Tartessians, a people of southern Spain, in the area where Cádiz had been founded, who knew of Ireland and Britain. This trade was no doubt the latest phase of contact between the various areas of the Atlantic seaboard that went back to late Neolithic times. There is no evidence that Himilco reached Britain, nor indeed has any Phoenician object ever been found on the island, but probably Cornish tin was obtained through the tribes of Brittany. Tin was also obtained from northwestern Spain. It is notable that, at Cádiz, the Carthaginian tombs found at intervals there over the past century have produced nothing earlier than the 5th century, which would indicate that it was not until that date that Cádiz became a large and permanent base for the exploitation of trading opportunities in the west.

Trading contacts with the Greek world had been substantial from the earliest period of Phoenician colonization, in spite of the intermittent wars with the Greeks of Sicily. Pottery from Corinth, Athens, Ionia, Rhodes, and other Greek centres has been found at Carthage, Utica, and many other sites, as well as imports from Phoenicia itself and from Egypt. It is known that Selinus, a Greek city in Sicily, grew wealthy from trade with Carthage, probably in foodstuffs, before Carthage enlarged its Sicilian territory. During the 5th century there appears to have been a decline in imports from the Greek world. One factor that may have inhibited trade was the lack of a Carthaginian coinage before the early 4th century, though most important Greek states had had their own coinages for at least a century before that. Carthaginian merchants, however, did not cease to frequent Greek ports, and a number of them were established at Syracuse in 398. From that date, economic contacts with advanced states seem to have revived, especially after the conquests of Alexander the Great in the eastern Mediterranean created a new market for the cheap Carthaginian manufactured goods. The Carthaginian merchant became a familiar figure in such economic centres of the Greek world as Athens and Delos, so much so that there were Greek comedies in which the central figure was the Carthaginian trader.

Revival of economic contacts

Wars outside Africa. Except in politically backward or thinly populated areas Carthage's foreign policy was nonexpansive. One major departure from this policy was a disaster: in 480 Carthage intervened in intercity struggles among the Greeks of Sicily and suffered a heavy defeat at Himera. After a long period of peace, it went in 410 to the help of Segesta, an ally in Sicily, and turned the war into one of revenge for the earlier defeat. After initial successes, including the destruction of Himera, a treaty confirmed Carthage's control of the west of the island. During the 4th century most of the region's wars were caused by the attempts of various rulers of Syracuse to drive the Carthaginians out of Sicily; three of these (398–392, 382–375, and 368) were with Dionysius the Elder of Syracuse. Most of the time the eastern limit of Carthaginian power in the island was recognized as the Halycus (Platani) River. The only occasion in which Carthage suffered directly (since its armies were largely mercenary) was in 310, when the ruler of Syracuse, Agathocles, under heavy pressure in Sicily, launched a daring invasion of Africa, the first experienced by Carthage. Over a period of three years he caused great devastation in Carthaginian territory in eastern Tunisia but in the end was defeated.

Treatment of subject peoples. Carthage was accused by its enemies in antiquity of oppressing and exacting excessive tribute from its subjects. There were, however, different categories of subject community, the most favoured being the original Phoenician settlements and the colonies of Carthage itself. There is little evidence of opposition among them to Carthaginian control. Similar institutions and laws may be attributed to a common cultural background rather than to an attempt to impose uniformity. Carthage exacted dues on imports and exports and levied troops and probably sailors. Carthaginian subjects of various nationalities in Sicily also received favourable treatment, at least in economic matters. Relatively free trade was allowed until the end of the 5th century, and a number of cities had their own coinage. In the 4th century, some Sicilian Greek states became subject to

Carthage, paying a tribute amounting apparently to one-tenth of their produce. It was the Libyans of the interior who suffered most, though few were reduced to slavery. During the First Punic War, Libyans are said to have had to pay one-half of their crops as tribute, and it is supposed that the normal exaction was a quarter, a burdensome imposition. They also were required to provide troops, and from the early 4th century they formed the largest single element in the Carthaginian army; it is unlikely that they received pay except in booty before the Punic Wars. The Carthaginians are said to have "admired not those governors who treated their subjects with moderation but those who exacted the greatest amount of supplies and treated the inhabitants most ruthlessly." This hostile judgment (by the Greek historian Polybius) was made in connection with the Libyans and a destructive revolt—one of a number known—that followed the first Punic War. In this revolt (241–237 BC), mercenaries, unpaid after the Carthaginian defeat in the First Punic War, revolted and for a while controlled much of Carthage's North African territory. It was fought with great atrocities on both sides, and the Libyans were among the most fervent of the rebels. They even issued coins on which the name Libyan appears (in Greek), which probably indicates a growing ethnic consciousness. Notwithstanding this relationship, Carthaginian civilization had profound effects on the material culture of the Libyans (see below).

Political and military institutions. Hereditary kingship prevailed in Phoenicia down to Hellenistic times, and Greek and Roman sources refer to kingship at Carthage. It appears to have been not hereditary but elective, though in practice one family, the Magonid, dominated in the 6th century. The power of the kingship was diminished during the 5th century, a development that has its parallels in the political evolution of Greek city-states and of Rome. Roman sources directly transcribe only one Carthaginian political term—*sufet*, etymologically the same as the Hebrew *shofet*, generally translated "judge" in the Old Testament but implying much more than merely judicial functions. At some stage, probably in the 4th century, the *sufets* became the political leaders of Carthage and other western Phoenician settlements. Two *sufets* were elected annually by the citizen body, but all were from the wealthy classes. Real power rested with an oligarchy of the wealthiest citizens, who were life members of a council of state and decided all important matters unless there was serious disagreement with the *sufets*. A panel of judges chosen from among its members had obscure but formidable powers of control over all organs of government.

Carthaginian magistrates

During the 6th and 5th centuries, most military commands were held by kings, but later the generalship was apparently dissociated from civil office. Even in the time of the kings, military authority appears to have been conferred upon the kings only for specific campaigns or in emergencies. The generals are said to have been regarded as potential overthrowers of the legal government, but in fact there is no record of any army commander's having attempted a coup d'état.

Up to the 6th century, the armies of Carthage were apparently citizen levies similar to those of all city-states of the early classical period. But Carthage was too small to provide for the defense of widely scattered settlements, and it turned increasingly to mercenaries, officered by Carthaginians, with citizen contingents appearing only occasionally. Libyans were considered particularly suitable for light infantry, the inhabitants of the later Numidia and Mauretania for light cavalry; Iberians and Celtiberians from Spain were used in both capacities. In the 4th century the Carthaginians also hired Gauls, Campanians, and even Greeks. The disadvantages of mercenary armies were more than outweighed by the fact that Carthage could never have stood the losses incurred in a whole series of wars in Sicily and elsewhere. Very little is known about the manning of the Carthaginian fleet; technically, it was not overwhelmingly superior to those of the Greeks, but it was larger and had the benefit of experienced sailors from Carthage's maritime settlements.

The city. The Romans completely destroyed Carthage in 146 BC and a century later built a new city on the site, so that little is known of the physical appearance of the Phoenician city. The ancient artificial harbour—the Cothon—is represented today by two lagoons north of the bay of al-Karm (el-Kram). In the 3rd century BC it had two parts, the outer rectangular part being for merchant shipping, the interior, circular division being reserved for warships; sheds and quays were available for 220 warships. The harbour's small size probably means that it was used chiefly in winter when navigation almost ceased. The city walls were of great strength and 22 miles (35 kilometres) in length; the most vulnerable section, across the isthmus, was more than 40 feet high and 30 feet thick. The citadel on the hill called Byrsa was also fortified. Between Byrsa and the port was the heart of the city: its marketplace, council house, and temples. In appearance it may have been not dissimilar to towns in the eastern Mediterranean or Persian Gulf before the impact of modern civilization, with narrow winding streets and houses up to six stories high. The exterior walls were blank except for a solitary street door, but they enclosed courtyards. A figure of 700,000 for the city population is given by the geographer Strabo, but this probably included the population of the Cap Bon peninsula. A more reasonable figure could be about 400,000, including slaves, a size similar to that of Athens.

Physical appearance of Carthage

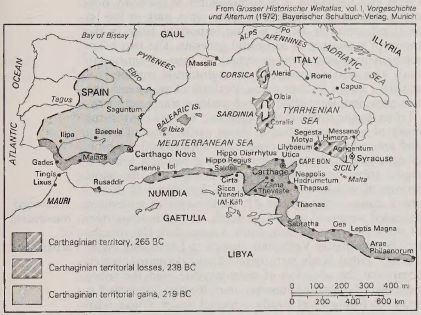
Religion and culture. The Carthaginians were notorious in antiquity for the intensity of their religious beliefs, which they retained to the end of their independence and which in turn influenced the religion of the Libyans. The chief deity was Baal Hammon, the community's divine lord and protector, who was identified by the Greeks with Cronus and by the Romans with Saturn. During the 5th century a goddess named Tanit came to be widely worshiped and represented in art. It is possible that her name is Libyan and that her popularity was connected with the acquisition of land in the interior, as she is associated with symbols of fertility. These two overshadow other deities such as Melqart, principal deity of Tyre, identified with Heracles, and Eshmoun, identified with Asclepius. Human sacrifice was the element in Carthaginian religion most criticized; it persisted in Africa much longer than in Phoenicia, probably into the 3rd century. The child victims were sacrificed to Baal (not to Moloch, an interpretation based on a misunderstanding of the texts) and the burned bones buried in urns under stone markers, or stelae. At Carthage thousands of such urns have been found in the "Sanctuary of Tanit," and similar burials have been discovered at Hadrumetum, Cirta, Motya, Calaris, Nora, and Sulcis. (For illustration, see MIDDLE EASTERN RELIGIONS, ANCIENT: *Religious practices and institutions.*) Carthaginian religion appears to have taught the weakness of human beings in the face of the overwhelming and capricious power of the gods. The great majority of Carthaginian personal names, unlike those of Greece and Rome, were of religious significance—*e.g.*, Hannibal, "Favoured by Baal," or Hamilcar, "Favoured by Melqart."

In comparison with the extent of its power and influence, the artistic and intellectual achievements of Carthage were small. What limited remains of buildings survive—mostly in North Africa and Sardinia—are utilitarian and uninspired. In the minor arts—pottery, jewelry, metalwork, objects in terra-cotta, and the thousands of carvings on stelae—a similar lack of inspiration may be felt. The influence of Phoenician, Egyptian, and Greek artistic traditions can be observed, but they failed to stimulate as they did, for example, in Etruria. There is no evidence that Greek philosophy and literature made much impact, though certainly many Carthaginians in the city's later history knew Greek and there were libraries in the city. One written work is known, a treatise on agriculture by a certain Mago, but this may have been based on Hellenistic models. On the whole, the Carthaginians adhered to traditional modes of thought, which no doubt gave them a sense of solidarity amid more numerous and hostile peoples. Their fanatical patriotism enabled them to offer a more prolonged resistance to Rome than any other power. Their influence on North African history was, in the first place, to bring it into the mainstream of the advancing civilization of the Mediterranean world; more particularly, it introduced

Carthaginian artistic and intellectual achievements

into North Africa advanced techniques leading to agricultural progress, which implied in turn a change by many Libyans from a seminomadic to a stable way of life, and the possibilities of urbanization, which were fully realized in the Roman period.

Carthage and Rome. In the 3rd and 2nd centuries BC, Carthage was weakened and finally destroyed by Rome in the three Punic Wars. Treaties between Carthage and Rome had been made in 508, 348, and 279, and for a long period the two powers had no conflicting interests. But by the 3rd century Rome dominated all southern Italy and thus approached the Carthaginian sphere in Sicily. In 264 Rome accepted the submission of Messana (Messina), though this state had previously had a Carthaginian garrison, partly because of exaggerated fears of a possible Carthaginian threat to Italy and partly because of hopes of gain in Sicily. For Carthage, a Roman foothold in Sicily would upset the traditional balance of power on the island. The ensuing First Punic War, which lasted until 241, was very costly in human life, with losses of tens of thousands being recorded in some naval engagements. Contrary to expectation, the Carthaginian fleet was worsted on several occasions by the newly built Roman; on land the Romans failed to drive the Carthaginians out of Sicily, and a Roman invasion of Tunisia ended in catastrophe. Carthage made peace after a final naval defeat off the Aegates (Egadi) Islands, surrendering its hold on Sicily. Sardinia and Corsica fell to Rome in 238.



Carthaginian Empire.

In response to the defeat, Carthage, under the leadership of Hamilcar Barca and his successors (usually described as the Barcid family), set about establishing a new empire in Spain. The object appears to have been to exploit the mineral wealth directly rather than through intermediaries and to mobilize the manpower of much of Spain into an army that could match that of Rome. Hamilcar and his son-in-law Hasdrubal built up an army of more than 50,000 Spanish infantry and occupied half of the Iberian Peninsula. Finally, in 219, Hannibal, Hamilcar's son, ignored Roman threats designed to prevent the consolidation or extension of the new empire. His invasion of Italy and the crushing defeats he inflicted on the Romans at Lake Trasimene (217) and Cannae (216) were the gravest danger Rome had ever faced. The majority of Rome's allies and subjects in Italy remained loyal, however, and Hannibal found increasing difficulty in getting supplies and reinforcements. After clearing Spain of the Carthaginians (209–206), Scipio Africanus landed near Utica in 204 with a Roman army. In 203 Hannibal was recalled from Italy; but he was defeated by Scipio at the Battle of Zama (in the vicinity of present-day Sāqiyat Sīdī Yūsuf, in Tunisia) in 202. Carthage made peace soon afterward, surrendering its fleet, its overseas possessions, and some of its African territory. During the next 50 years it retained some measure of prosperity, although frequently under pressure from the Numidians under King Masinissa. From 155 irrational fears of a Carthaginian revival were stimulated at Rome by Cato the Elder, and in 149, on flimsy pretexts, the Carthaginians were forced to choose between evacuating their city and settling inland or a doomed resistance. They chose the latter, and, after a three-year siege, the city was destroyed and its site ceremonially cursed by the younger Scipio.

New empire in Spain

Destruction of Carthage

The Greeks in Cyrenaica. The natural contacts of Cyrenaica were northward with Crete and the Aegean world. In the late 12th century BC Mycenaean Greek Sea Peoples landing in Cyrenaica armed the Libyans and with them attempted an unsuccessful invasion of Egypt. Cyrenaica's coast was visited by Cretan fishermen in the 7th century, and the Greeks became aware that it was the only area in North Africa still available for colonization. A severe overpopulation on the small Cyclades island of Thera (Thíra Santorini) led to the foundation of Cyrene (*c.* 630) on a site within easy reach of the sea, well watered, and in the fertile foothills of the Akhḍar Mountains. The founder's name was, or was changed to, Battus, a Libyan word meaning king. For some time friendly relations existed with the local peoples, and there was more intermarriage with non-Greek women than was usual in Greek colonies. Later, when more colonists were attracted by Cyrene's increasing prosperity, hostilities occurred in which the settlers were successful. Cyrene also repulsed an invasion by the Egyptians (570) but in 525 submitted to Persia. Meanwhile, Cyrene had established other Greek cities in the area—Barce (al-Marj), Taucheira (Tūkrah), and Euhesperides (Banghāzī), all of which were independent of their founding city. During the 6th century, Cyrene rivaled the majority of other Greek cities in its wealth, manifested in part by substantial temple building. Prosperity was based on grain, fruit, horses, and, above all, an apparently extinct species of the medicinal plant *Silphium.*

Constitutional changes in Cyrene

The dynasty of Battus ended about 440 BC with the establishment of a democratic constitution like that of Athens, and the general prosperity of Cyrenaica continued through the 4th century in spite of some political troubles. Cyrenaica submitted to Alexander the Great in the late 4th century and subsequently became subject to the Ptolemies of Egypt. The cities, nevertheless, enjoyed a good deal of freedom in running their own affairs. The constitution of Cyrene was elaborated as a fairly liberal oligarchy, with a citizen body of 10,000 and two councils. During the 3rd century a federal constitution for all the Cyrenaican cities was introduced. Apollonia, the port of Cyrene, became a city in its own right; Euhesperides was refounded as Berenice, and a new city, Ptolemais (Ṭulmaythah), was founded, while Barce declined; the term Pentapolis came to be used of the five cities Apollonia, Cyrene, Ptolemais, Taucheira, and Berenice. In 96 BC Ptolemy Apion bequeathed Cyrenaica to Rome, which annexed the royal estates but left the cities free. Disorders led Rome to create a regular province out of Cyrenaica in 74 BC, to which Crete was added seven years later. After Mark Antony temporarily granted the province to his daughter Cleopatra Selene, Augustus reestablished it, together with Crete, as a senatorial province.

The rise and decline of native kingdoms. Between the destruction of Carthage and the establishment of effective Roman control over the Maghrib there was a period that saw a brief flourishing of native kingdoms. Amid the shifting tribal nomenclature used in the sources of various periods, two main groups of relatively sedentary tribes may be distinguished: the Mauri, living between the Atlantic and the Moulouya or perhaps the Chelif rivers, who gave their name to Mauretania; and the Numidae, after whom Numidia was named, in the area to the west of that formerly controlled by Carthage. A third group, the Gaetuli, was a largely nomadic people of the desert and its fringe. The various tribes first emerge into history in the late 3rd century BC, after a period of social evolution resulting from contact with Carthaginian civilization. This is difficult to trace, as Carthaginian products were scarce in the interior of the Maghrib before the 2nd century BC, but the large tumuli at Mzora, Sīdī Sulaymān, Souk el-Gour, and the Medracen, apparently royal tombs of the 4th and 3rd centuries BC, testify to a developing economy

and society. No doubt service in the Carthaginian mercenary armies was a major stimulus to change.

King Masinissa of Numidia

This was most noticeable in Numidia and reached a high point under Masinissa. The son of a chief of the Massyli, a tribe dominating the area between Carthaginian territory and the Ampsaga River (Wadi al-Kabir), he had been brought up at Carthage and was 20 years old at the outbreak of the Second Punic War. At first his tribe was at variance with Carthage, but in 213 BC it became reconciled when its powerful western neighbours, the Masaesyli, under Syphax, deserted Carthage. From 213 to 207 BC Masinissa commanded Numidian cavalry in Spain for the Carthaginians against Rome. On Rome's victory at Ilipa in 206, he returned to Africa where Syphax, now reconciled with Carthage, had occupied some of his tribal territory, including Cirta (Constantine), and his own claims to succession to the chieftainship were disputed. When the Romans landed in Africa in 204, Masinissa rendered them invaluable assistance. Recognized by the Romans as king, he annexed the eastern part of Syphax' kingdom and reigned with success until 148 BC. The Greek geographer Strabo said that he "turned the nomads into a nation of farmers." This is exaggerated, since cereal culture had long been established in parts of Numidia, yet there is no doubt that the area of grain production was much enlarged. This was achieved by deliberate encouragement of Carthaginian civilization. Along with new techniques, Carthaginian language, religion, and art penetrated rapidly inland, and Masinissa's capital, Cirta, took on the aspects of a Carthaginian city; incipient urbanization of a number of Libyan villages is also possible. Masinissa issued copper, bronze, and lead coinage for local use, as did some of the Carthaginian coastal towns under his rule.

On Masinissa's death in 148, his kingdom was divided among his three sons, possibly on the insistence of the Romans, who did not, however, prevent its reunification under Micipsa (148–118 BC). The progress begun under Masinissa continued as refugees from the destruction of Carthage fled to Numidia. Meanwhile, the Romans had formed a province of the area of Tunisia northeast of a line from Thabraca to Thaenae but showed little interest in exploiting its wealth. The attempt by the Roman reformer Gaius Gracchus in 122 BC to found a colony on the site of Carthage failed, though individual colonists who had taken up allotments remained. When Micipsa died, another division of Numidia among three rulers took place, in which Jugurtha (118–105 BC) emerged supreme. He might have been recognized by Rome, but he provoked war when he killed some Italian merchants who were helping a rival to defend Cirta. After some successes due to the incompetence of Roman generals, Jugurtha was surrendered by Bocchus I, king of Mauretania. The kingdom was again reconstituted under other descendants of Masinissa. The boundaries of the Roman province were slightly enlarged in the area of the upper Majardah valley, where veterans of the army of Gaius Marius received lands. During the next 50 years there was further immigration by individual Roman settlers and merchants but no deliberate state action. The last relatively formidable king of Numidia was Juba I (*c.* 60–46 BC), who supported the Pompeian side in the Roman civil war between Pompey and Julius Caesar.

Formation of Africa Nova

The kingdom fell in 46 BC at the Battle of Thapsus. A new province, Africa Nova, was formed from the most developed part of the old Numidian kingdom east of the Ampsaga; it was subsequently (before 27 BC) amalgamated with the original province of Africa by the emperor Augustus. In 33 BC Bocchus II of Mauretania died, bequeathing his kingdom to Rome, but Augustus was unwilling to accept responsibility for so large and relatively backward an area. In 25 BC he installed Juba II, son of Juba I, as king; he ruled until his death about AD 24. He was married to Cleopatra Selene, daughter of Mark Antony and Cleopatra, and under them Iol, renamed Caesarea (Cherchell), and also Volubilis, near Fez (Fès), a secondary capital of the rulers of Mauretania, became centres of late Hellenistic culture. Juba himself was a prolific writer in Greek on a number of subjects, including history and geography. His son Ptolemy succeeded as king but was executed for unknown reasons by the Roman emperor Caligula in AD 40. A brief revolt followed but was easily suppressed, and the kingdom was divided into two provinces, Mauretania Caesariensis, with its capital at Caesarea, and Mauretania Tingitana, with its capital at Tingis (Tangier).

Roman North Africa. *Administration and defense.* For more than a century from its acquisition in 146 BC, the small Roman province of Africa (roughly corresponding to modern Tunisia) was governed from Utica by a minor Roman official, but changes were made by the emperor Augustus, reflecting the growing importance of the area. The governor was thenceforward a proconsul residing at Carthage, after its refounding by Augustus as a Roman Carthage, after its refounding by Augustus as a Roman colony, and responsible for the whole territory from the Ampsaga in the west to the border of Cyrenaica. The proconsul also commanded the army of Africa and was one of the very few provincial governors in command of an army and yet formally responsible to the Senate rather than to the emperor. This anomaly was removed in AD 39 when Gaius entrusted the army to a *legatus Augusti* of praetorian rank. Although the province was not formally divided until 196, the army commander was de facto in charge of the area later known as the province of Numidia and also of the military area in southern Tunisia and along the Libyan Desert. The proconsulship was normally held for only one year; like the proconsulship of Asia, it was reserved for former consuls and ranked high in the administrative hierarchy. In the 1st century it was held by several men who subsequently became emperor—*e.g.*, Galba and Vespasian. The commanders of the army normally held the post for two or three years, and, in the 1st and 2nd centuries AD, it was an important stage in the career of a number of successful generals. The two Mauretanian provinces were governed by men of equestrian rank who also commanded the substantial numbers of auxiliary troops in their areas. In times of emergency the two provinces were often united under a single authority.

Tribes on the fringe of the desert and beyond constituted more of a nuisance than a threat as the area of urban and semiurban settlement gradually approached the limit of cultivable land. A number of minor conflicts with nomadic tribes are recorded in the 1st century, the most serious of which was the revolt of Tacfarinas in southern Tunisia, suppressed in 23. As the area of settlement extended westward as well as south, so the headquarters of the legion moved also: from Ammaedara (Haydarah) to Theveste under Vespasian, thence to Lambaesis under Trajan. Tribal lands were reduced and delimited, which compelled the adoption of sedentary life, and the tribes were placed under the supervision of Roman "prefects." A southern frontier was finally achieved under Trajan with the encirclement of the Aurès and Nemencha mountains and the creation of a line of forts from Vescera (Biskra) to Ad Majores (Besseriani). The mountains were penetrated during the next generation but were never developed or Romanized. During the 2nd century, stretches of continuous wall and ditch—the *fossatum Africae*—in some areas provided further control over movement and also marked the division between the settled and nomadic ways of life. To the southwest of the Aurès a fortified zone completed the frontier defensive system, or limes, which extended for a while as far as Castellum Dimmidi (Messad), the most southerly fort in Roman Algeria yet identified. South of Leptis Magna (Labdah) in Libya, forts on the trans-Saharan route ultimately reached as far as Cydamus (Ghadāmis).

Westward movement of settlement

In the Mauretanias the problem was more difficult, because of the rugged nature of the country and the distances involved. The encirclement of mountainous areas, a policy followed in the Aurès, was again pursued in the Kabylie ranges and the Ouarsenis. The area round Sitifis (Sétif) was successfully settled and developed in the 2nd century, but farther west the impact of Rome was for long limited to coastal towns and the main military roads. The most important of these roads ran from Zarai (Zraïa) to Auzia (Aumale) and then to the valley of the Chelif. Subsequently, the frontier ran south of the Ouarsenis as far as Pomaria (Tlemcen). West of this area, it is doubtful whether a permanent road connected the two Mauretanias, sea communication being the rule. In Tingitana,

Roman control extended as far as a line roughly from Meknès to Rabat, including Volubilis. Evidence attests to periodic discussions between Roman governors and local chieftains outside Roman control, confirming peaceful relations. However, the tribes of the Rif Mountains must have lived in virtual independence, and they were probably responsible for a number of wars recorded in Mauretania under Domitian, Trajan, Antonius Pius (which lasted six years), and others in the 3rd century. They did little or no damage to the urbanized areas and never necessitated a permanent increase in the African garrison. The defense of the North African provinces was far less a problem than that of those on the northern periphery of the empire. For Numidia and the military district in the south of Tunisia and Libya, about 13,000 men sufficed; the Mauretanias had auxiliary units only, totaling some 15,000. This may be contrasted with the position in Britain, where three legions and auxiliaries were required. From the middle of the 2nd century AD, the African garrison was largely recruited locally.

The growth of urban life. The most notable feature of the Roman period in North Africa was the development in Tunisia, northern Algeria, and some parts of Morocco of a flourishing urban civilization. This was due to control of nomadic and pastoral movements, which opened large areas of thinly settled but potentially rich land to consistent exploitation. In addition, there was the incipient urbanization of some parts owing to the Carthaginians and the ambitions of Libyan rulers such as Masinissa and, last, the settlement in Africa of Italian immigrants, who, though relatively few in comparison with the population as a whole, provided the impetus to expansion. Julius Caesar settled many veterans in colonies, mostly coastal towns, and, equally important, established a military adventurer named Publius Sittius along with many Italians at Cirta, beginning the Romanization of Numidia. Caesar planned to refound Carthage, and this was effected by Augustus. The number of his original settlers was 3,000, but the colony grew remarkably quickly because of its favourable geographic position in relation to contact with Rome and Italy. A number of other colonies were founded in the interior of Tunisia and at widely separated places on the Mauretanian coasts. There was also immigration from Italy by private individuals at this time. Colonial foundations of veterans in Mauretania occurred under Claudius (*e.g.*, Tingis, Caesarea, Tipasa). Cuicul (Jamīlah) and Sitifis were founded by Nerva, and Thamugadi and a number of places nearby, in the area north of the Aurès, by Trajan. The army was a potent vehicle in the spread of Roman civilization and played a major part in the urbanization of the frontier regions. On limited evidence, a total of some 80,000 immigrants from Rome and Italy into the Maghrib in this period has been suggested.

Italian settlers

Though at first inferior to the Roman towns, native communities enjoyed the local autonomy that was the hallmark of Roman administration. Between 400 and 500 such communities were recognized, the majority of them villages or small tribal factions. Many, however, advanced in wealth and standing to rival the Roman colonies, acquiring the grant of Roman citizenship, which put the seal of imperial approval on the prosperity, stability, and cultural evolution of developing communities. Naturally, the earliest to show signs of increasing prosperity were the surviving Carthaginian settlements on the coast and places—particularly in the Majardah valley—where the Libyan population had been much influenced by Carthaginian culture and which now also had Italian immigrants. Leptis Magna and Hadrumetum received Roman citizenship and the status of a colony from Trajan, and Thubursicu Numidarum (Khemissa) and Calama (Guelma) probably the rank of municipality. But it was under Hadrian, the first emperor to visit Africa, that the flood tide of such grants occurred; Utica, Bulla Regia (Hammam Derradji), Lares (Lorbeus), Thaenae, and Zama achieved colonial rank, and the process continued throughout the 2nd century. Finally, Septimius Severus, who originated from a rich family of Leptis Magna, and of largely mixed descent, became emperor in AD 193 and showed a great deal of favour to his native land.

In the Maghrib, Roman rule was not superimposed upon established civic aristocracies, as in the Hellenized provinces of Asia Minor, nor upon strongly based tribal aristocracies, as in Celtic Gaul. Roman administration and the development of urban society in general depended, apart from immigrants, on the local leadership of small clan and tribal units and on the activity of individuals. In the 1st century AD there were a few very large estates owned by absentee Roman senators, most of which were subsequently absorbed into the extensive imperial estate in Africa. The later pattern was of landowning on a more moderate—though still substantial—scale by residents, both immigrant and indigenous. Many landowners made their homes in the towns and formed a local municipal leadership. Small independent landowners also existed, but the great majority of the inhabitants were tenant farmers (coloni). A significant portion of these farmers worked on a sharecropping basis and with labour obligations to their landlords. The number of slave workers was probably smaller than in Italy.

Growth of new social elite

Many of the wealthier Africans entered the imperial administration. The first African consul held office in the reign of Vespasian; at the beginning of the 3rd century, men of African origin held one-sixth of all the posts in the equestrian grade of the administration and also constituted the largest group of provincials in the Senate. It is uncertain what proportion were of native Libyan or mixed origin, but in the 2nd century they were certainly the majority.

During the 2nd and early 3rd centuries the wealthy classes in the towns expended vast sums on their communities in gifts of public buildings such as theatres, baths, and temples, as well as statues, public feasts, and distributions of money. This was a general phenomenon throughout the Roman Empire, as members of local elites competed for fame and prestige among their fellow citizens, but it is particularly well attested in Africa.

Economy. The density of the towns in no way implies the predominance of trade or industry; all but a few were residences of both landowners and peasants, and their prosperity depended on agriculture. By the 1st century AD African exports of grain provided two-thirds of the needs of the city of Rome. Some of this, for distribution by the emperors to the urban proletariat, came from the imperial estates and from taxes, but much went on to the open market. An estimate of annual grain production in Roman Africa has been made of more than a million tons, of which 25 percent was exported. Areas of grain production were the Cape Bon peninsula, the Miliana and Majardah valleys, and tracts of relatively level land north of a line from Sitifis to Madauros (M'Daourouch). Cereal crops were the most important in these areas, but fruit, figs, grapes, and beans also were produced.

The production of olive oil became almost as important as cereals by the 2nd century AD, particularly in southern Tunisia and along the northern slopes of the Aurès and Bou Taleb mountains. By the 4th century Africa exported oil to all parts of the empire. Successful cultivation of olives demanded careful management of available water, and the archaeological evidence indicates that much attention was paid to irrigation in the Roman period.

Livestock was an important part of the economy of Roman Africa, though direct evidence is slight. African horses were used in racing and no doubt also in the Roman cavalry. Cattle, sheep, pigs, goats, and mules were also raised. Africa was the major source of the wild animals for shows in Rome and other major cities of the empire, in particular panthers, lions, elephants, and monkeys. Fishing, which had been developed along the coast as far as the Atlantic in the Carthaginian period, continued to flourish. Timber, from the forests along part of the north coast, and marble, the most important North African source being Simitthu (Shimṭū), were also exported.

There were no large-scale industries even by ancient standards in North Africa, except in pottery. By the 4th century, production of amphorae, necessitated by the oil trade, was substantial, and these and other locally produced wares were traded throughout the Mediterranean. Mosaic pavements were extremely popular among the

wealthy throughout North Africa, and well over 2,000 have been discovered, with enormous variations in quality. The majority were made by local craftsmen, though some of the designs originated elsewhere. It is also clear that the building trades were major consumers of both skilled and unskilled labour.

Population increases

Prosperity undoubtedly led to a rise in the population of the Maghrib in the first two centuries AD; in the absence of reliable statistics, population estimates have varied between 4,000,000 and 8,000,000 (the latter being also the population about the beginning of the 20th century). The most recent study proposed about 6,500,000, of whom about 2,500,000 were in present Tunisia. Some 40 percent of the latter (perhaps more) lived in the towns. Of these, Carthage was in a class of its own, reaching at least 250,000. The next largest was Leptis Magna (80,000), followed by Hadrumetum, Thysdrus (el-Djem), Hippo Regius, and Cirta, with between 20,000 and 30,000 each. Many towns in close proximity to each other, especially in the Majardah valley, averaged between 5,000 and 10,000.

The road system in Roman Africa was the most complete of any western province; a total of some 12,500 miles has been supposed. In origin most roads were military but were open to commerce, and a number of minor roads linking towns off the main routes were built by the local communities. The main arteries were Carthage to Theveste; Carthage to Cirta through Sicca Veneria; Theveste to Tacapae through Capsa; Theveste to Lambaesis; Cirta to Sitifis; Cirta to Rusicade; and Cirta to Hippo Regius. Carthage handled by far the greatest volume of overseas official traffic and trade, being the natural port for the wealthiest area of North Africa. Nevertheless, most of the ports originally founded by Phoenicians and Carthaginians expanded during the Roman period; in view of the high costs of land transport, it was natural that agricultural products would go to the nearest port for shipment.

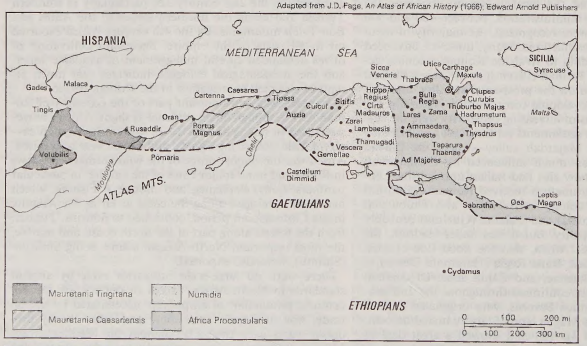
Later Roman Empire. The whole Roman Empire underwent a military and political crisis between the death of Severus Alexander (235) and the accession of Diocletian (284), resulting from serious attacks from outside on the empire's northern and eastern frontiers and from a series of coups d'état and civil wars. Africa suffered less than most parts of the empire, though there was an unsuccessful revolt by landowners in AD 238 against the fiscal policies of the emperor Maximinus Thrax, which ended in widespread pillage. There were tribal revolts in the Mauretanian mountains in 253–254, 260, and 288, and the situation finally brought a visit from the emperor Maximian in 297–298. The revolts had little effect on the urbanized areas, but the towns were injured by economic difficulties and inflation, and building activity almost ceased. There was a return of confidence under Diocletian (284–305), Constantine (312–337), and later emperors. Administrative changes introduced at this time included the division of the province of Africa into three separate provinces: Tripolitania (capital Leptis Magna), covering the western part of Libya; Byzacena, covering southern Tunisia and governed from Hadrumetum; and the northern part of Tunisia, which retained the name Africa. In addition, the eastern part of Mauretania Caesariensis became a separate province (capital Sitifis). In the far west, the Romans gave up much of Mauretania Tingitana, including the important town of Volubilis, apparently because of pressure from the tribe of the Baquates. In the general reorganization of the Roman army by Diocletian and Constantine, the field army (*comitatenses*) in Africa, numbering on paper some 21,000 men, was put under a new commander, the *comes Africae,* independent of the provincial governors. Only the governors of Tripolitania and of Mauretania Caesariensis also had troops at their disposal, but these were second-line soldiers, or *limitanei.* The whole frontier region along the desert and mountain fringes was divided into sectors and garrisoned by *limitanei.* The latter were locally recruited and closely identified with the farming population of their areas. The Tripolitanian Plateau, which was increasingly exposed to attacks by the nomadic Austuriani, is notable for having a large number of fortified farms.

Reforms under Diocletian

Africa, like the rest of the empire, experienced the economic difficulties and governmental pressures that were a feature of the later Roman Empire. The power of the landowners increased at the expense of their tenants and of smaller farmers, both of whom the imperial government sought to bind to the soil in a state of quasi-serfdom. In the cities, the tasks of local government that had earlier been eagerly undertaken by the wealthy became burdensome, and again the imperial government sought to make them compulsory and hereditary, while the councillors themselves sought by any means to enter the imperial administration or professions that provided immunity. The process is well attested in Africa. Nevertheless, the view that the 4th century saw a general decline in urban life throughout the empire must be modified, especially in the case of Africa, where the cities and towns withstood the pressures better than elsewhere and where some towns, Timgad for example, seem to have increased in population. Timgad's growth was doubtlessly due to its relative immunity from damage in civil and external wars and to a solid base of agricultural prosperity.

Christianity and the Donatist controversy. Christianity grew much more rapidly in Africa than in any other western province. It was firmly established in Carthage and other Tunisian towns by the 3rd century and had produced its own local martyrs and an outstanding apologist in Tertullian (*c.* 160–240). During the next 50 years there was a remarkable expansion; more than 80 bishops attended a council at Carthage in 256, some from the distant frontier regions of Numidia. Cyprian, bishop of Carthage from 248 until his martyrdom in 258, was another figure

Adapted from J.D. Fage, *An Atlas of African History* (1958). Edward Arnold Publishers



Roman Africa in the 3rd century AD.

whose writing, like that of Tertullian, was of lasting influence on Latin Christianity. During the next half-century it spread extensively in Numidia (at least 70 bishops known in 312). The reasons for its exceptionally rapid growth are disputed. In northern Tunisia, urban communities provided a similar social and economic environment to that in which Christianity had first spread in Anatolia and Syria, and much the same can be said about smaller communities in which early Christianity can be identified. It has been held that the intermingling of religious currents of Libyan, Carthaginian, and Roman origin tended toward monotheism, but even if this were true, which is debatable, pagan monotheism was not a necessary stage toward the adoption of Christianity for more than a few. It does, however, appear that African Christianity always included a vigorous and fanatical element that must have had its effect in spreading the new religion, even though there is little evidence of positive missionary efforts.

Christians were still a minority at the end of the 3rd century in all levels of society, but they were in a good position to benefit from Constantine's adoption of the religion and his grants of various privileges to the clergy.

Beginning of schism

At this time (AD 313), a division occurred among the African Christians that lasted more than a century. Some Numidian bishops objected to the choice of Caecilian as the new bishop of Carthage, alleging that his ordination had been performed by a bishop who had weakened during Diocletian's persecution of the church and hence was invalid. They consecrated a rival bishop, and, when he died, another named Donatus, who gave his name to the ensuing schism. The churches in numerous communities, especially in Numidia, followed Donatus from the start and claimed that they alone constituted the true church of the martyrs, who were objects of particularly enthusiastic veneration among African Christians. Among Christians outside Africa, however, Caecilian was universally recognized as bishop of Carthage, and the emperor Constantine, when appealed to by the Donatists, followed the decisions of non-African church councils, recognizing Caecilian and his followers as the true church and hence as recipients of imperial favour. Confiscation of Donatist churches led to some deaths, the victims being honoured as martyrs, but in 321 Constantine rejected further pressure and the Donatists continued to increase rapidly in numbers. For the rest of the century they probably made up half of the Christians in North Africa. They were strongest in Numidia and Mauretania Sitifensis, and the antischismatics in the proconsular province; the position in the Mauretanias was more even, but Christianity did not spread rapidly there until the 5th century. In 347 the emperor Constans exiled a number of Donatist bishops and took repressive measures against the *circumcelliones,* seasonal farm workers who were particularly enthusiastic Donatists. But in 362 Julian the Apostate allowed the return of the exiles, who were welcomed with enthusiasm, and the movement proved as strong as ever. Some Donatists appear to have been associated with the revolt of a Mauretanian chieftain, Firmus, and in 377 the first of a series of general laws proscribing Donatism was issued. Nevertheless, these laws were enforced only sporadically, partly because provincial governors and many local magistrates were still pagan and, at a time of growing weakness in the imperial government, were inclined to ignore instructions they found unwelcome. Donatism was further supported by Gildo, brother of Firmus and *comes Africae* 387–397. Then Augustine of Hippo Regius applied his enormous powers of leadership and persuasion in stimulating resolute action, evolving at the same time a theory of the right of orthodox Christian rulers to use force against schismatics and heretics. In 411 an imperial commission summoned a conference at Carthage to establish religious unity; the Donatists had to obey, though the decision against them was a foregone conclusion. The laws that followed their condemnation were more generally enforced and, though there was some resistance, broke the schism as a powerful movement; some communities still existed in the 6th century, however.

Much controversy surrounds the interpretation of the significance of Donatism; an important view considers it in some sense a national or social movement. It is said to have been particularly associated with the rural population of less Romanized areas and with the poorer classes in the towns, whereas orthodox Christianity was the religion of the Romanized upper classes. The identification of the imperial government with these Christians would have intensified the strength of the movement, and the *circumcelliones'* violence, moreover, could be considered a form of incipient peasant revolt. Thus the movement is claimed as analogous to Monophysitism in Egypt and Syria, which produced a vernacular literature and a passive rejection of Greco-Roman culture. The hostility of the Donatists to the existing society was typified by Donatus' remark: "What has the emperor to do with the church?" Against this view it may be said that Donatism in the un-Romanized tribal areas was certainly weak, and the relationship of the sect with Firmus and Gildo was of little importance. In Numidia it was at least as strong in the towns as in the rural areas, and in any case the distinction between the two can be exaggerated. The entire controversy was conducted in Latin, and no vernacular literature was produced; in fact, until the time of Augustine, most of the educated class, of the same social background as Augustine himself and fully imbued with Roman tradition, were Donatists if they were not pagan. It was the reluctance of the landowners to have their peasants disturbed, and the negligence of many provincial governors (both attacked by Augustine), that long protected the Donatists. Lastly, in spite of the remark attributed to Donatus, there is no evidence that the movement attacked the imperial system as a whole, as opposed to individual emperors and officials, and it made full use of its many opportunities to defend itself at law both against the other Christians and against divisions in its own ranks.

Donatism as a national movement

Nevertheless, although it is difficult to sustain the view that Donatism, especially in Numidia, represented in some way a resurgence of local pre-Roman culture, or the speculative, though intriguing, notion that something similar led to the emergence of heretical movements of Islām in the same areas, Donatism certainly appealed to deep-seated traditions of African Christianity. Its fanatical devotion to the memory of martyrs, its doctrinal conservatism and total refusal to compromise on its claim to be the true church while its opponents were contaminated by the stain of weakness in the persecutions, were fully in line with the heroic days of Tertullian and Cyprian.

Extent of Romanization. The question whether Roman civilization in the Maghrib was a superficial phenomenon affecting only a small minority of the population who were economically successful, or whether it had profound effects on a majority, is similarly disputed. A priori the former view may be supported by the fact that, whereas Gaul and Spain emerged from the Dark Ages with a language and religion derived from their Roman past, in the Maghrib both disappeared, arguably because they were superficial. It is not disputed that in the mountainous areas, such as the Aurès, Kabylie, and Atlas, native Libyan language and culture continued little affected by Roman civilization, though the majority appear to have been Christian by the 7th century; nor that Libyan and Carthaginian traditions survived in other areas and affected the modes of acceptance of Roman civilization. As regards language, the late form of Phoenician known as Neo-Punic was still spoken fairly widely in the 4th century—for example, in the hills near Hippo Regius. Inscriptions in the language and script occurred often at the beginning of the Roman period but are very rare after the end of the 1st century AD. An exception may be in Tripolitania, where a form of Neo-Punic was inscribed in Latin script perhaps as late as the 4th century. There was also a Libyan script known solely from funerary stelae and akin to the script of the present Tuareg; it was known in some sense over much of the Maghrib but may not have been used later than the 3rd century. On the other hand, there is no evidence that these languages were ever literary languages, and the inscriptions are negligible in number compared with those in Latin. It may also be observed that the areas in which Libyan inscriptions occur do not correspond with the later areas of Berber dialects. The Latin language unquestion-

Use of Latin language

ably became general through the whole Maghrib, though to a limited extent in the mountains; it is impossible to define any precise social level at which it was unknown. There is a good deal to be said for the view that Christianity, whether Orthodox or Donatist, furthered the use of Latin among elements which up to that time had perhaps still not used it.

The Vandal conquest. The effect of the Donatist controversy on the economy and administration of the African provinces cannot be measured but was certainly profound. At the very moment of the effective victory of the African church, the rest of the Roman Empire was crumbling to ruin. In 406 the Rhine was crossed by Vandals, Alani, Suebi, and others who overran most of Gaul and Spain within the next few years. In 408 Alaric and the Visigoths invaded Italy and in 410 sacked Rome. Although the empire in the west survived for some time longer, the emperors were increasingly at the mercy of their barbarian generals. Meanwhile, large tracts of imperial territory were lost by the settlement of the invading tribes. Africa escaped for a while, though only death prevented Alaric from leading the Goths across the Mediterranean. The retention of Africa became ever more vital to the survival of what was left of imperial authority. In this situation the *comites Africae* were increasingly tempted to intrigue for their own advantage. One of them, Bonifacius, is said to have invited the Vandals, who at the time were occupying Andalusia, to his aid, but it is more likely that the Vandals were attracted to Africa by its wealth and needed no such formal excuse. Led by their king Gaiseric, the whole people, 80,000 in all, crossed into Africa in 429 and in the next year advanced with little opposition to Hippo Regius, which they took after a siege during which St. Augustine died. After defeating the imperial forces near Calama, they overran most of the country, though not all of the fortified cities. An agreement made in 435 allotted Numidia and Mauretania Sitifensis to the Vandals, but in 439 Gaiseric took and pillaged Carthage and the rest of the province of Africa. A further treaty with the imperial government (442) established the Vandals in Africa Proconsularis, Byzacena, Tripolitania, and Numidia as far west as Cirta.

Vandal impact on the economy

Although the Vandals were probably no more deliberately destructive than other German invaders (the notion of "vandalism" stems from the 18th century), their establishment had very adverse effects. The imperial authorities had to reduce the taxes of Mauretania by seven-eighths as a result of their devastation. Over much of northern Tunisia, landowners were expelled and the properties handed over to Vandals. Although the agricultural system remained based on the peasants, the expulsions had a serious effect on the towns with which the landowners had been connected. The Vandals, like other invading tribes except the Franks, were divided from their subjects by their Arian heresy. Although their persecution of Latin Christians was exaggerated by the latter, Vandal kings certainly exercised more pressure than others. This was no doubt in response to the vigour of African Christianity, which kept the loyalty even of those who had little to lose by the substitution of a Vandal for a Roman landlord.

Gaiseric was perhaps the most perceptive barbarian king of the 5th century in realizing the total weakness of the empire. He rejected the policy of formal alliance with it and from 455 used his large merchant fleet to dominate the western Mediterranean. Rome was sacked, the Balearics, Corsica, Sardinia, and part of Sicily were occupied, and the coasts of Dalmatia and Greece were plundered. Although there was no general cessation of trade, this activity accelerated the breakup of the economic unity of the western Mediterranean, already threatened by the creation of the other barbarian kingdoms. Gaiseric's successors were less formidable: Huneric (477–484) launched a general persecution on the Latin church, apparently from genuine religious fanaticism rather than for political reasons, but his successor adopted a milder policy. Under Thrasamund (496–523) there is evidence that many Vandals adopted Roman culture, but the tribe retained its identity until the Byzantine reconquest.

A significant development of the Vandal period was the emergence of independent kingdoms in the mountainous and desert areas, largely of Libyan character. They appeared first in the Mauretanias, where the Roman frontier, already drawn back under Diocletian, receded further under the Vandal kings. By the end of Vandal rule, independent kingdoms existed in the region of Altava (Lamoricière), in the Ouarsenis, and in the Hodna. After 480, towns to the north of the Aurès, such as Thamugadi, Bagai, and Theveste, were sacked by the inhabitants of another kingdom in the Aurès. All the names of the known chieftains are Libyan in character, though the survival of Romanized elements within some of the kingdoms is attested by the fact that epitaphs in Latin continued, by the use of Roman names, and even by the employment of a dating system based on the founding date of the Roman province of Mauretania. Finally, as a harbinger of a serious threat to settled life, whether Roman or Libyan, tribes that had retained a nomadic life on the borders of Cyrenaica and Tripolitania and caused much damage in the 4th century began to push westward and were already a serious threat to the southern parts of Byzacena by the end of Vandal rule.

The Byzantine period. North Africa held an important place in the emperor Justinian's scheme for reuniting the Roman Empire and destroying the Germanic kingdoms. His invasion was undertaken against the advice of his experts (an earlier attempt in 468 had failed disastrously), but his general Belisarius succeeded, though partly through the incompetence of the Vandals. He landed in 533 with only 16,000 men, and within a year the Vandal kingdom was destroyed. A new administrative structure was introduced, headed by a praetorian prefect with six subordinate governors for civil matters and a master of soldiers with four subordinate generals. It required some 12 years, however, to pacify Africa, owing partly to the resistance of the tribes in Mauretania to the reestablishment of an ordered government and partly to lack of support to the army in men and money, leading to frequent mutinies. A remarkable program of fortifications, many of which survive, was rapidly built under Belisarius' successor Solomon. Some were garrison forts in the frontier region, which again seems to have run, at least for a while, south of the Aurès, and then northward from Tubunae to Saldae. But many surviving towns in the interior were also equipped with substantial walls—*e.g.,* Thugga and Vaga (Bājah, Béja). After the death of Justinian (565) there were further difficulties with the Mauretanian tribes (the Mauri), but the most serious damage was done by the nomadic Louata from the Libyan Desert, who on several occasions penetrated far into Tunisia.

Administrative reorganization

Africa shows a number of examples of the massive help given by Justinian in the building, and particularly the decoration, of churches, and in the reestablishment of Christian orthodoxy, though this inevitably brought the persecution of surviving Donatists. Seriously weakened though it had been under the Vandals, some traces of the vigour of the African church remained when it led the opposition of the Western churches to the theological policies of emperors at Constantinople—*e.g.,* those of Justinian himself and also of Heraclius and Constans II immediately before the Arab invasions.

Little is known of the Byzantine period in the Maghrib after the death of Justinian. The power of the military element in the provinces grew, and between 585 and 591 a new official, the exarch, was introduced whose powers were almost viceregal. Economic conditions declined because of the increasing insecurity and also the notorious corruption and extortion of the administration, though whether this was worse in Africa than in other parts of the Byzantine Empire it is impossible to say. It is certain that the population of the towns was only a small proportion of what it had been in the 4th century. The court of Constantinople tended to neglect Africa because of the more immediate dangers on the eastern and Balkan frontiers. Only once in its latest phase was it the scene of an important historical event; in 610 Heraclius, son of the African exarch at the time, sailed from Carthage to Greece in a revolt against the unpopular emperor Phocas and succeeded him the same year. That Africa was still of some impor-

tance to the empire was shown in 619; the Persians had overrun much of the east including Egypt, and only Africa appeared able to provide money and recruits. Heraclius even thought of leaving Constantinople for Carthage but was prevented by popular feeling in the capital.

In view of the lack of evidence for the Byzantine period, and the still greater obscurity surrounding the period of Arab raids and final conquest (643–698) and its immediate aftermath, conclusions on the state of the Maghrib at the end of Byzantine rule are speculative. Much of it was in the hands of tribal groups, among which the level of Roman culture was in many cases no doubt negligible. Even before the Arab attacks began, the picture seems to be one of a continual ebb of Latin civilization and the Latin language from all of the Maghrib except along the coastal fringes of Tunisia, and the development and expansion of larger tribal groupings, some, though not all, of which were Christian. Also, the Byzantine administration was, in a sense, foreign to the Latin population. The military forces sent from Constantinople to stem the invasion were ultimately inadequate, though Arab conquest of the region could not be secure until the capture and destruction of Carthage and the interdiction of reinforcements by sea. The most determined resistance to the Arabs came from nomadic Libyan tribes living in the area around the Aurès Mountains. Destruction in the settled areas in the earlier attacks, which were little more than large-scale raiding expeditions, was certainly immense. It has been held that town life and even an ordered agricultural system almost disappeared at this time, though some scholars believe that a modicum of these survived until the invasions of larger nomadic groups, in particular the Banū Hilāl, in the 11th century. Latin was still in use for Christian epitaphs at en-Ngila in Tripolitania and even at Al-Qayrawān (Kairouan) in the 10th and 11th centuries. However, throughout the Maghrib the conversion to Islām of various population groups rapidly led to the Arabization of most of the region in language and culture, though the modalities of these profound changes remain obscure.

Maghrib on the eve of Arab conquest

The Arab conquest has its part in the widely discussed theory of Henri Pirenne that the essential break between the ancient and medieval European worlds came with the destruction of the unity of the Mediterranean not by the Germanic but by the Arab invasions. The history of the Maghrib is an important element in this debate, for there one can see the complete replacement of a centuries-old political, social, religious, and cultural system by another within a short span of time.

Roman Cyrenaica. Much of the Roman period in Cyrenaica was peaceful. Some Roman immigrants resided there at an early date, and some of the Greeks received Roman citizenship. A famous inscription of 4 BC contains a number of edicts of the emperor Augustus regulating with great fairness the relationship between Roman and non-Roman. The character of its civilization, however, remained entirely Greek. Jews formed a considerable minority group in the province and had their own organizations at Berenice and Cyrene. They took no part in the great revolt of Judaea in AD 66 but in 115 began a formidable rebellion in Cyrene that spread to Egypt. No reason for it is known. It caused great destruction and loss of life, and Hadrian took special measures to reconstruct Cyrene and also sent out some colonists. Peaceful conditions returned, but in 268–269 the Marmaridae, inhabiting the coast between Cyrenaica and Egypt, caused trouble. In the reorganization of the empire by Diocletian, Cyrenaica was separated from Crete and divided into two provinces, Libya Superior, or Pentapolis (capital Ptolemais), and Libya Inferior, or Sicca (capital Paraetonium, Marsā Maṭrūḥ). A regular force was stationed there for the first time under a *dux Libyarum*. At the end of the 4th century, the Austuriani, a nomad tribe that had earlier raided Tripolitania, caused much damage, and Cyrenaica began to suffer from the general decline of security throughout the empire, in this case from desert nomads. A notable phenomenon of the 5th and 6th centuries, as in Tripolitania, is the number of fortified farms, most frequent in the Akhḍar Mountains and south of Boreum (Bū Quraydah) and also apparently in the region of Banghāzī.

Christianity no doubt spread to Cyrenaica from Egypt. In the 3rd century the bishop of Ptolemais was metropolitan, but by the 4th century the powerful bishops of Alexandria consecrated the local bishops. The best known Cyrenaican is Synesius, a citizen of Cyrene of philosophic tastes who was made bishop of Ptolemais in 410 partly because of his ability to obtain help for his province from the imperial authorities. Under Justinian a number of defensive works were constructed as elsewhere in Africa—*e.g.*, Taucheira, Berenice, Antipyrgos (Tobruk), and Boreum. Recent excavations of a series of churches in the province also reveal the expenditure he devoted to their beautification, in what was a province of minor importance. On the eve of the Arab conquest (AD 643) the general condition of Cyrenaica would appear to have been on a par with most of the other eastern provinces of the empire. (B.H.W.)

FROM THE ISLĀMIC CONQUEST TO 1830

After completing the conquest of Egypt in 642 the Arabs started to raid the territory to its west inhabited by the Berbers, which they called Bilad al-Maghrib ("Lands of Sunset"), or simply the Maghrib. In 705 this region became a province of the Muslim empire then ruled from Damascus by the Umayyad caliphs (661–750). The Arab Muslim conquerors left a much more durable impact on the culture of the Maghrib than did the region's conquerors before and after them. By the 11th century the Berbers had become Islāmized and in part also Arabized. Indigenous Christian communities ceased to exist in the region, which before the Arab conquest had constituted an important part of the Christian world. The Islāmization of the Berbers was a consequence of the Arab conquest, although they were neither forcibly converted to Islām nor systematically missionized by their conquerors. Largely because its teachings became an ideology through which the Berbers justified both their rebellion against the caliphs and their support of rulers who rejected caliphal authority, Islām gained wide appeal and spread rapidly among these fiercely independent peoples.

Islāmization of the Berbers

Arab raids to the west of Egypt concentrated at first on the area of Cyrenaica in present-day Libya. Tunisia was raided several times after 647, but no attempt was made to establish Arab rule there before 670. Conflicts among the Muslim leaders, especially after the assassination of the third caliph 'Uthmān in 656, hindered Muslim territorial expansion. Only after the Umayyads had consolidated their authority as a caliphal dynasty in the 660s and had come to view the conquest of the Maghrib in the context of their confrontation with the Byzantine Empire was the systematic conquest of the Maghrib undertaken. 'Uqbah ibn Nāfi' (Sidi Okba) commanded the Arab army that occupied Tunisia in 670. Before his recall in 674 'Uqbah founded the town of Al-Qayrawān (Kairouan), which became the first centre of Arab administration in the Maghrib.

When the conquest of the Maghrib west of Tunisia was initated by 'Uqbah's successor, Abū al-Muhājir Dīnār al-Anṣārī, the Arabs had to fight semisettled Berber communities that had developed some tradition of centralized political authority. In the course of his campaign, Abū al-Muhājir Dīnār prevailed upon the Berber "king" Kusaylah to become Muslim. From his base in Tlemcen, Kusaylah dominated a confederation of the Awrāba tribes living between the western Aurès Mountains and the area of present-day Fès. Since Kusaylah's profession of Islām implied his recognition of caliphal authority, it served as a basis for coexistence between him and the Arabs. However, when 'Uqbah was reinstated as commander of the Arab army in the Maghrib in 681, he insisted on imposing direct Arab rule over the whole region. In 682 he led his troops across Algeria and northern Morocco, reaching the Atlantic Ocean and penetrating south to the areas of Sūs (Sous) and Drâa in southern Morocco. On his way back to Al-Qayrawān, 'Uqbah was attacked near Biskra in present-day Algeria on orders from Kusaylah by Berbers supported by Byzantine contingents. Through his death in this battle and his extended campaign, 'Uqbah became the legendary hero of the Muslim conquest of the Maghrib.

By the 680s the Arabs had gone too far in the conquest

of the Maghrib to be willing to accept defeat at the hands of a Berber leader, albeit one professing Islām. Two large armies had to be sent from Egypt, however, before organized Berber resistance could be suppressed. The first, commanded by Zuhayr ibn Qays al-Balawī, reoccupied Al-Qayrawān, then pursued Kusaylah westward to Mams, where he was defeated and killed. The dates of these operations are uncertain, but they must have occurred before 688 when Zuhayr ibn Qays himself was killed in an attack on Byzantine positions in Cyrenaica. The second Arab army, commanded by Ḥassān ibn an-Nu'mān, was dispatched from Egypt in 693. It faced stiff resistance in the eastern Aurès Mountains from the Jawāra Berbers, who were commanded by a woman whom the Arabs referred to as Kāhinah (al-Kāhina; "the Priestess"). After Kāhinah was defeated in 698, Ibn an-Nu'mān occupied Carthage, the centre of Byzantine administration in Tunisia, and began the construction of the town of Tunis nearby. These successes and Arab naval supremacy in the Mediterranean forced the Byzantines to evacuate their remaining positions on the Maghribī coast. Consequently, under Ibn an-Nu'mān's successor, Mūsā ibn Nuṣayr, the Maghrib was made into a province of the Umayyad Caliphate in 705 known as the *wilāyah* of Ifrīqīyah, thus separating it from the *wilāyah* of Egypt, to which it had been administratively attached until that time.

Khārijī Berber resistance to Arab rule. Political life of the Maghrib in the 8th century was dominated by the contradiction in the position of the Arab rulers who, while posing as the champions of a religion recognizing the equality of all believers, emphasized their ethnic distinctiveness and exercised authority without much regard for Islāmic religious norms. This contradiction surfaced in their relations with the Berbers after the latter became Muslim in large numbers, especially through serving in the Arab army, which is known to have included Berber contingents when it was commanded by Ḥassān ibn an-Nu'mān and his successor Mūsā ibn Nuṣayr. Many Berber warriors participated in the conquest of Spain in 711. Though professing Islām, they were treated as mawālī (clients) of the Arab tribes and consequently had a status inferior to, and received less pay than, the Arab warriors. Furthermore, the Arab ruling class alone reaped the fruits of conquest, as was clearly the case in Spain. The grievances of the warriors highlighted the resentment of Berbers in general, caused by such practices as the levying of human tribute on the Berber tribes, through which the Arab ruling class was provided with slaves, especially female slaves. 'Umar II (717–720) was the only Umayyad caliph who is known to have condemned the levying of human tribute and ordered its discontinuation. He also sent 10 *tābi'un* (disciples of the Prophet Muḥammad's companions) to teach Islām to the Berbers. The enlightened policy of this pious caliph did not survive his short reign, however. Rather it contributed toward confirming the conviction of Muslims in the Maghrib that Islām could not be equated with Umayyad caliphal rule.

Berber grievances against Arab rule

The Muslim Khārijī sect exploited this revolutionary potential in their struggle against Umayyad rule. Khārijī doctrine apparently appealed to the Berbers because it rejected the Arab monopoly on political leadership of the Muslim community, stressed piety and learning as the main qualifications of the head of the community, and sanctioned rebellion against the head when he acted unjustly. In 740 a major Berber rebellion broke out against Arab rule in the region of Tangier. Its first leader was a Berber called Maysara who had come to Al-Qayrawān under the influence of the Ṣufrites (Ṣufriyah), the extremist branch of the Khārijī sect. The Berber rebels achieved an astounding military success against the Arab army. By 742 they had taken control of the whole of Algeria and were threatening Al-Qayrawān. In the meantime, the Ibāḍites (Ibāḍīyah), who constituted the moderate branch of the Khārijī sect, had taken control of Tripolitania by converting the Berber tribes living there, especially the Hawwāra and Nafusa, to their doctrine. Ibāḍite domination in Tripolitania resulted from the activities of *dā'is* sent there from the main centre of the group in Iraq after the Khārijī rebellion there had been suppressed by the Umayyad army in 697.

Political and religious fragmentation

Umayyad caliphal rule in the Maghrib came to an end in 747 when the Fihrids, the descendants of 'Uqbah ibn Nāfi', taking advantage of the preoccupation of the Umayyads with the 'Abbāsid rebellion that led to their downfall, seized power in Ifrīqīyah. The Fihrid dynasty controlled all Tunisia except for the south, which was dominated at the time by the Warfajūma Berber tribe associated with the Ṣufrite Khārijī. Fihrid rule came to an end in 756 when the Warfajūma conquered the north and captured Al-Qayrawān. Immediately thereafter, however, the Ibāḍites in Tripolitania proclaimed one of their religious leaders as imam (the Khārijī equivalent to the Sunnite caliph) and in 758 conquered Tunisia from the Ṣufrites. An Ibāḍite state comprising Tunisia and Tripolitania thus came into being, which lasted until the 'Abbāsids, having consolidated their authority as caliphs in the Middle East, sent an army to the region in 761 to restore caliphal rule in the Maghrib.

The 'Abbāsids could impose their authority only on Tunisia, eastern Algeria, and Tripolitania. Their governors of the reconstituted *wilāyah* of Ifrīqīyah were hampered in the exercise of their authority by their dependence on an army that was recruited predominantly from among the unruly Arabs of the province. A mutiny of the Arab troops against the 'Abbāsid governor in 800 led to the transformation of Ifrīqīyah into an Arab kingdom ruled by the Aghlabid dynasty in the name of the 'Abbāsid caliphs. The founder of the dynasty, Ibrāhīm I ibn al-Aghlab, commanded until then the Arab army in eastern Algeria. After using his troops to restore order in Tunisia, he established himself as ruler of the province. The acquiescence of the caliph, Hārūn ar-Rashīd, to Ibn al-Aghlab's usurpation of authority was linked to the latter's continued recognition of 'Abbāsid suzerainty and payment of tributes to Baghdad.

The Maghrib under Muslim dynasties, 8th–11th centuries. Through their rebellion against caliphal rule in the name of Islām, the Berbers forged religious bonds with other Muslim opponents of the caliphs, and Islāmic political concepts and religious norms gained favour in Berber society. Their rebellion also led to the replacement of rule by the caliphs with four separate Muslim states ruled by dynasties that either nominally recognized caliphal authority, as was the case with the Aghlabids, or totally rejected it, as was the case with the three other states. Only the smallest and most politically insignificant state, the principality of the Banū Midrār in Sijilmāssah (southern Morocco), was ruled by a Berber dynasty. The four states were dependent for their survival on the balance of political forces within the region itself.

Opposition to rule by the caliphs

The Rustamid state of Tāhart. The 'Abbāsid conquest of Ifrīqīyah in 761, which led to the collapse of the Ibāḍite state in Tunisia and Tripolitania, resulted in the migration of important Ibāḍite tribes from Tripolitania and southern Tunisia to western Algeria. There they were led in attacks on 'Abbāsid positions by 'Abd ar-Rahmān ibn Rustam, an Ibāḍite of Persian origin, born and brought up in Tunisia. Ibn Rustam had acquired prominence among the Ibāḍites as governor of Tunisia between 758 and 761. In 776 or 777 he was proclaimed imam by the Ibāḍite tribes of Algeria, and immediately afterward he started construction of his own capital, Tāhart, in the area where the most important Ibāḍite tribes of Algeria were settled. Until the 760s the Berber tribes affiliated with the Ṣufrite branch of Khārijism were the major forces of opposition to caliphal rule in Algeria. After the foundation of the Rustamid state, these tribes became subordinate allies of the Ibāḍites.

The imamate of Tāhart was inherited within the family of 'Abd ar-Rahmān ibn Rustam. This breach of Khārijī doctrine led to a split within the Ibāḍite leadership, which, however, had little effect on the position of the Rustamid imams as leaders of Berber opposition to 'Abbāsid authority. The tribes that recognized the religio-political leadership of and paid tribute to the imams of Tāhart lived in western Algeria, southern Tunisia, and Tripolitania. The imams maintained contacts with them by encouraging visits of their chiefs to Tāhart and by sending emissaries that toured their areas. With the Nafusa of Tripolitania, who had been associated with the Ibāḍite movement in

the Maghrib since the beginning of the 8th century, the Rustamid imams maintained especially close contacts and entrusted important state offices to them. Tāhart became prosperous and developed a cosmopolitan character both by serving as a meeting place for numerous trade caravans connecting the various parts of the Maghrib and by playing an important role itself in Maghribi and trans-Saharan trade. The Rustamids' readiness to live in peace with their neighbours, including the Aghlabids, caused discontent among the Ibāḍite tribes of Tripolitania and southern Tunisia but enabled the Rustamids to retain power until Tāhart was conquered by the Fāṭimids in 909.

The Banū Midrār of Sijilmāssah. As a result of migration after the 740s of Miknāsah Berbers, a group affiliated with the Ṣufrites, from northern Morocco to the oasis of Tafilalt in the south, the principality of the Banū Midrār came into existence. The principality was named after Abū al-Qāsim ibn Wāsūl, nicknamed Midrār, the Miknāsah chief who in 757 founded tha town of Sijilmāssah. Tafilalt had played a role in trans-Saharan trade before the influx and settlement of the Miknāsah. After the establishment of Sijilmāssah, however, it became the foremost centre of trans-Saharan trade in the western Maghrib. At the zenith of its power during the reign of Yasa' ibn Midrār (790–823), the principality controlled the entire region of Drāa in southern Morocco. Nevertheless, the state remained primarily a trading principality, playing almost no role in the political life of the rest of the Maghrib until it too was conquered by the Fāṭimids in 909.

The Idrisids of Fez. The Idrīsid state of Fez (modern Fès) had its origins in the desire of Isḥāq ibn 'Abd al-Ḥamīd, chief of the powerful tribal confederation of the Awrāba, to consolidate his authority in northern Morocco by giving his rule an Islāmic religious character. For that purpose he invited Idrīs ibn 'Abd Allāh, a sharīf (descendant of the Prophet Muḥammad) then living in Tangier, to settle at his seat of government in Walīla (Oulili). Idrīs moved to Walīla in 788 and was recognized imam Idrīs I of the Awrāba the following year, but he was assassinated by agents of the 'Abbāsids in 791. His son, born a few months later and also called Idrīs, was proclaimed imam of the Awrāba in 803, when he was still a young boy. Idrīs II founded the state called, after himself, Idrīsid, with the help of Arab refugees coming from both Spain and Aghlabid territory. By moving the seat of his authority in 809 to Fez, the capital city he had started to build a year earlier, he made clear he was establishing a state that was distinct from the Awrāba confederation. The arrival of more Arabs from Spain and Aghlabid territory in the following two decades gave the Idrisid state a distinctly Arab character.

Although Idrīs I had Shī'ite sympathies, the state founded by his son was in matters of religious doctrine Sunnite. Its rulers, however, identified themselves with Berber rejection of caliphal rule and stressed their own descent from the Prophet as a means of legitimizing their authority. During Idrīs II's reign (809–828) the state included the greater part of present-day Morocco. From the 860s, however, the authority of the Idrisids started to decline, and the tribes of northern Morocco that had previously followed them allied themselves with the Umayyad rulers of Spain. Nevertheless, they continued to rule in Fez until they were deposed by the Fāṭimids in 921. Under the Idrisids, Islāmic urban culture began to make its appearance in Morocco. The foremost urban centre was Fez, which continued to exercise a dominant influence on the religious and cultural as well as the political life of Morocco until the imposition of the French protectorate in 1912.

The Aghlabids. After their usurpation of power in 800, the Aghlabids adapted their government to the requirements of political survival in a land still dominated by an Arab class of large landowners, who also provided the government its regular troops. The urban, ethnically mixed communities resented the domination of the state by the old Arab families and the heavy taxes that they and the peasant communities had to pay. Emphasizing Islāmic religious norms was the means by which these groups articulated their grievances against the state and the Arab ruling class. By the beginning of the 9th century such grievances could be expressed formally when two of the four Sunnite schools of Islāmic religious law, the Hanafite (Hanafīyah) and the Malikite (Mālikiyah), had become established in the Maghrib. The Hanafite school developed in Iraq; as it was recognized by the 'Abbāsid caliphs, it also was adopted by the Aghlabids. Most of the religious scholars in Tunisia, however, adhered to the simpler and stricter teachings of the Malikite school. By teaching the religious law and adominishing the rulers to adhere to its provisions in the administration of justice and in such matters as taxation and the prohibition of alcohol, Malikite scholars have emerged since the 820s as defenders of the rights of the common people against the state.

Schools of Islāmic religious law

Political life in the Aghlabid state reflected the rulers' constant fear of rebellion by their Arab troops and preoccupation with the need to allay the grievances of the religious scholars. They tried to placate the Malikite scholars by appointing many of them to the office of qadi ("judge") and by instituting a program of sacred building construction. The Grand Mosque of Tunis, the Zaytūnah, among others, was built in the Aghlabid period. In order to reduce the threat of Arab troop rebellions, the Aghlabids channeled their energies into conquering Sicily. Initiated in 827, the conquest of Sicily was given a religious character by entrusting the command of the army to the qadi Asad ibn al-Furāt.

The Fāṭimids and Zirids. The grievances that the inhabitants of Ifrīqīyah harboured against Aghlabid rule were transformed into a revolutionary movement by the Ismā'īlites (Ismā'īlīyah), the extremist branch of the Shī'ite sect. From the middle of the 9th century Ismā'īlite leadership, operating from Salamyah in northern Syria, sent out *dā'is* to organize opposition to the 'Abbāsid caliphs. One of these, Ḥusayn ibn Zakariyyā', better known as Abū 'Abd Allāh ash-Shī'ī, operated among the Kutāma of the Little Kabylie region in eastern Algeria from 901. The sedentary Kutāma were pious and unsophisticated Muslim Berbers living in small village communities. Aghlabid rule in the region was represented by fortified garrison posts manned by Arab troops, by whom the Kutāma were constantly harassed. Through patient preaching, Abū 'Abd Allāh molded the Kutāma into a highly motivated and disciplined militant movement. After defeating the Arab troops in the Little Kabylie, he conquered the rest of the Aghlabid territory in Algeria between 904 and 907 and then conquered Tunisia itself. Raqqādah, the fortified residence of the Aghlabids near Al-Qayrawān, was conquered in March 909. The head of the Ismā'īlites in Salamyah, 'Ubayd Allāh Sa'id, made his entry into Raqqādah in January 910.

The state that 'Ubayd Allāh then founded was intended to be completely Shī'ite in character. He styled himself as the imam who, according to Shī'ite doctrine, was the only legitimate head of the Muslim community and the final authority on religious law. The state he founded, known as Fāṭimid (*Ad-Dawla al-Fāṭimiyya*) after the Prophet Muḥammad's daughter Fāṭimah, was viewed as a stepping-stone to the overthrow of the 'Abbāsids. Nevertheless, 'Ubayd Allāh was intent on consolidating Shī'ite rule first in the Maghrib itself. He built a fortified capital, Al-Mahdīyah, on the Tunisian coast and initiated the conquest of the western Maghrib in 917. The Fāṭimids soon brought Idrisid rule in Fez to an end, but after 40 years of campaigning in western Algeria and Morocco they were unable to impose their authority on the powerful Berber tribes living there. The Umayyads of Spain, moreover, occupied the enclaves of Melilla and Sabtah (Ceuta) on the northern coast of Morocco in 927 and 931, respectively, and from there organized tribal resistance to the Fāṭimids. In eastern Algeria, however, the Fāṭimids were loyally supported by Zīrī ibn Manād, chief of the Takalata branch of the Ṣanhājah Confederation, to which the Kutāma Berbers belonged. The parts of the Maghrib that the Fāṭimids controlled therefore consisted only of the former province of Ifrīqīyah, ruled before them by the Aghlabids.

In Ifrīqīyah itself the Arab aristocratic families, previously affiliated with the Hanafite school of law, converted in their entirety to Shī'ism and, consequently, preserved under Fāṭimid rule some of their former privileges. The

Malikite scholars, however, opposed the Fāṭimids, who, accordingly, resorted to repression and had several of them tortured. Differences in ritual and religious law, and the exorbitant system of taxation made necessary by the large army that the Fāṭimids had to maintain, were the main causes of Malikite opposition. Out of desperation, the Malikite leaders of Al-Qayrawān in 944 even supported the rebellion of one of their Khārijī rivals, Abū Yazīd, against the Fāṭimids.

Direct Fāṭimid rule in the Maghrib effectively came to an end in 973, when the Fāṭimid imam, Al-Muʿizz, whose armies had conquered Egypt four years earlier, took up residence in Cairo. As his viceroy in the Maghrib, Al-Muʿizz appointed the Berber chief Buluggin, son of the Fāṭimids' chief ally in Algeria, Zīrī ibn Manād. In the 70 years during which the Zīrids (Banū Zīrī) ruled Ifrīqīyah in the name of the Fāṭimids, they fell progressively under the influence of the Arab Islāmic culture of the region. In this period the Malikite school of Islāmic law reasserted itself in Ifrīqīyah and produced one of its most prominent scholars, Ibn Abī Zayd al-Qayrawānī (d. 996), whose *Risalah* is one of the most widely used and commented on expositions of Malikite law. Malikite riots broke out between October 1016 and March 1017, which led to the killing of a large number of Shīʿites—estimated at some 20,000—and the looting of their property. These developments resulted in the renunciation of Fāṭimid authority by the Zīrids in 1044.

Invasion of Arab tribes

The Fāṭimids reacted to this by unleashing two large nomadic Arab tribes on the Maghrib, the Banū Hilāl and the Banū Sulaym (Sulaim), both of which had until then lived in Upper Egypt. The Zīrids were overwhelmed by the sheer number of the invaders, who are said to have included 50,000 warriors when they crossed into Cyrenaica in 1050. After suffering defeat at their hands in 1052 in southern Tunisia, the Zīrids vacated Al-Qayrawān and retreated to the well-fortified former Fāṭimid capital of Al-Mahdīyyah on the coast. The Banū Hilāl ravaged the Tunisian countryside and then infiltrated into eastern Algeria. Here, they brought to an end the rule of the Banū Hammād, a dynasty related to the Zīrids that had made itself independent of them in 1015. The Arab invasion introduced into the eastern Maghrib unruly tribal groups, who remained a source of political instability in the region until well into the 15th century.

The Maghrib under the Almoravids and the Almohads. The fragmentation of political life in the Maghrib, following both the Arab invasion and a general decline in the authority of the Fāṭimids, was arrested by the Almoravids. These were the founders of the first of two empires that unified the Maghrib under Berber Islāmic rule.

The Almoravid empire came into being through the success of a militant Islāmic movement that was initiated among the Ṣanhājah Confederation of tribes in Mauretania by one of its chiefs in about 1035. Religious reform was a means of cementing the unity of the Ṣanhājah tribes at a time when the control that they previously had on trans-Saharan trade had become threatened, from the south by the Soninke state of Ghana and from the north by the infiltration of Zanātah Berbers into southern Morocco. The movement's leader, ʿAbd Allāh ibn Yāsīn, was a Ṣanhājah religious scholar from southern Morocco. Before joining the Ṣanhājah tribes, Ibn Yāsīn was attached to a centre of religious learning, Dār al-Murābiṭīn, in Sūs (southern Morocco), then headed by a scholar who had studied previously in Al-Qayrawān. Two theories have been proposed to explain the name "Al-Murābiṭūn (Almoravids)," meaning inmates of a ribat (fortified monastery), a term by which Ibn Yāsīn's followers were known. The first is that he founded a ribat somewhere in Mauretania to train his followers. The other relates the name to Dār al-Murābiṭīn in Sūs, suggesting that the Almoravid movement was under the direct influence of this centre of learning. Whatever the case, the Almoravids were strict adherents of the Malikite school of law as it developed in Ifrīqīyah since its introduction to the Maghrib in the 9th century.

The Almoravids began the invasion of Morocco after consolidating their control over Sijilmāssah in 1056. When Ibn Yāsīn was killed in 1059 in an attack on the heretical Barghawāṭa tribal confederation on the Moroccan coast, the military and religious leadership of the Almoravids passed to the chief of the Lamtūnah tribe, Abū Bakr ibn ʿUmar. The latter returned to Mauretania in 1060 to fight against rebels challenging his authority. Command of the Almoravids in southern Morocco was then assumed by Abū Bakr's cousin, Yūsuf ibn Tāshufīn (Tāshfīn), under whose leadership the Almoravids conquered most of the Maghrib and Muslim Spain. By 1082 Almoravid rule extended as far east as Algiers. After the collapse of the Andalusian Umayyads in 1031, Muslim Spain became divided into a number of small Muslim principalities whose rulers were unable to hold out against Christian military advances. Upon request of the Spanish Muslims, the Almoravids sent their army into Spain in 1086. By 1110, four years after Ibn Tāshufīn's death, the Almoravids had become masters of the whole of Muslim Spain. The capital of their expanded empire was Marrakech, which Ibn Tāshufīn had started to build in 1070.

Almoravid conquest of Muslim Spain

In the Almoravid empire the Ṣanhājah tribes of Mauretania constituted a ruling class, distinguished from the rest of the population by the litham (face muffler) that their men wore. The Lamtūnah tribe formed the aristocracy of this ruling class and occupied the empire's important administrative and military posts. Strict adherence to the Malikite version of Islāmic law provided the religious legitimization for the authority of this tribal caste. The *fuqahāʾ* (experts on Islāmic law) supervised both the administration of justice by the qadis and the work of the provincial governors, and they acted as advisers to the rulers. The empire's simple system of government, in which military commanders acted as administrators, was rendered especially stifling by the narrow legalism of the *fuqahāʾ*. Mystical tendencies and new religious ideas reaching the Maghrib from Muslim Spain and the Arab east that the *fuqahāʾ* feared might undermine their authority were fought with the backing of the state.

The Almohad revolt

Out of religious opposition to the Islām of the Almoravid jurists developed the revolutionary movement of the Almohads (Al-Muwaḥḥidūn)—*i.e.,* the adherents of *tawḥīd,* the belief in the oneness and uniqueness of God—and led to the downfall of the Almoravids. The founder of the movement was Muḥammad ibn Tūmart, a Berber belonging to the Maṣmūdah tribe of the High Atlas region of Morocco. After returning from a pilgrimage to Mecca in 1117, he preached in public against equating Islām with the provisions of one of the four schools of Islāmic law, calling for a return to its original sources—namely, the Qurʾān (Koran) and the traditions of the Prophet. He also condemned the literal interpretation of the Qurʾān endorsed by the Almoravid *fuqahāʾ,* on grounds that it undermined *tawḥīd* by misleading the faithful to believe that God had human attributes. Ibn Tūmart fled from Marrakech in 1122 when he realized that he would be put to death if he did not cease in his criticism of the state's official religious dogma. After settling with some people of his tribe in the village of Tinmallal in 1124, he started to organize a religious community of Maṣmūdah tribesmen, who became united not only because of their sense of tribal solidarity but also because of their belief in Ibn Tūmart as the *mahdi* (divinely guided redeemer). After Ibn Tūmart's death in 1130, the movement and the conquest of the Almoravid empire continued under his trusted lieutenant, ʿAbd al-Muʾmin, a Berber from the Qūmiya tribe living in the region of Tlemcen.

Beginning in 1133, ʿAbd al-Muʾmin succeeded in establishing his authority in all the High and Middle Atlas mountains. From about 1139 he invaded northern Morocco and then western Algeria. After becoming master of this region in 1145, he advanced into the main centres of Almoravid authority in Morocco, conquering Fez in 1146 and Marrakech in 1147. Muslim Spain passed under Almohad rule between 1148 and 1172. Prior to completing the conquest of Spain, however, the Almohads had advanced into the eastern Maghrib, where the Normans of Sicily, profiting from Zirid weakness, had occupied several positions on the Tunisian coast. Between 1152 and 1160 the Almohads were able to conquer the whole of the eastern Maghrib, including Tripolitania. For the first

and last time in its history, the entire Maghrib was unified under one central indigenous authority.

Like the Almoravid empire, that of the Almohads was a Berber tribal state, in which the Maṣmūdah tribes, previously united in the community of Tinmallal, constituted the ruling class. Unlike the Almoravids, however, the Almohads did not have a clear religious orientation. They rejected the idea of equating the holy law with any of its established schools, but, for practical reasons, the Almohad judges based their judgments on the provisions of the already established Malikite school. Moreover, the belief of the common people in Ibn Tūmart as the *mahdī* was slowly being superseded by the spread of Ṣūfism (Islāmic mysticism) and the veneration of Ṣūfī holy men. Ṣūfism had a prominent representative during the Almohad period in the person of Shu'ayb Abū Madyan al-Ghawth (d. 1197). At the Almohad court, however, the sciences and philosophy were cultivated. The philosopher Ibn Rushd (Averroës) wrote his famous commentaries on Aristotle when at the court of the Almohad caliph Abū Ya'qūb Yūsuf (1163–84). These diverse developments meant that Almohad doctrine could not unite even the ruling class, whose coherence was undermined still more when 'Abd al-Mu'min appointed his son as heir-apparent in 1154, thus making his family, which did not belong to the Maṣmūdah tribe, the ruling dynasty. Through this act, 'Abd al-Mu'min bypassed Abū Ḥafṣ 'Umar, the Maṣmūdah chief who gave protection to Ibn Tūmart in the High Atlas during his period of exile and whom the other Maṣmūdah chiefs expected to succeed 'Abd al-Mu'min. The opposition of the Maṣmūdah was dealt with by putting a number of their chiefs to death and by giving the Ḥafṣids (*i.e.*, the family of Abū Ḥafṣ 'Umar) a position in the state hierarchy second only to the ruling dynasty. Nevertheless, the ruling family constantly had to contend with the opposition of the Maṣmūdah chiefs.

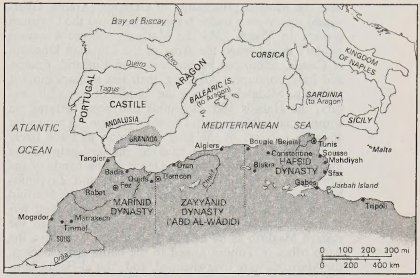
The spread of Ṣūfism

Tension within the ruling class finally led to an open split when the Almohads attempted to reestablish their authority over the eastern Maghrib, after the Banū Ghāniya, the family that last ruled Muslim Spain in the name of the Almoravids and that after 1148 retained control of the Balearic Islands, had taken control there. The Banū Ghāniya invaded eastern Algeria in 1184 and, with local Arab tribal support, brought Almohad authority in the region to an end. In 1203 they took control of Tunisia as well. The Almohad caliph An-Nāṣir (Muḥammad ibn Abī Yūsuf Ya'qūb) restored the empire's authority in the region with several large military campaigns from 1205 to 1207. Before returning to Marrakech, he appointed a Ḥafṣid to govern the reconquered eastern Maghrib. The Ḥafṣids were able to squelch the ongoing rebellion of the Banū Ghāniya in 1227 and to establish control over Ifrīqīyah, thus emerging as virtual rulers of the region. When the Almohad caliph Al-Ma'mun formally renounced the Almohad doctrine in 1229, the Ḥafṣids declared themselves independent of him.

Decline of the Almohads

At the time of the Ḥafṣid secession, the control of the Almohads over western Algeria also had weakened, and they were no longer able to restrain the nomadic Zanātah tribes living in the south from moving with their herds to the rich pasturelands of the north. A group of these Zanātah, the Banū Marīn, advanced through northern Algeria into Morocco during the 1240s. Having captured Fez in 1248, they emerged as rulers of northern Morocco. It was only a matter of time before they brought Almohad rule to an end with the conquest of Marrakech in 1269. In the 1230s another group of Zanātah Berbers, the Banū 'Abd al-Wād, had taken control of the region of Tlemcen in western Algeria. The state they founded there was overrun several times in the 13th and 14th centuries by the Marīnids. Nevertheless, its ruling dynasty, the Banū Zayyān (Zayyānids), was able to maintain its authority in Tlemcen until the beginning of the 16th century.

Political fragmentation and the triumph of Islāmic culture (*c.* 1250–*c.* 1500). After the collapse of Almohad rule, the Maghrib became divided into three Muslim states, each ruled by a Berber dynasty: the Ḥafṣids, whose territory included Tunisia, eastern Algeria, and Tripolitania; the Marīnids, ruling over Morocco; and the Zayyānids,



Last medieval dynasties in North Africa, 13th–14th centuries.
Adapted from J.D. Fage, *An Atlas of African History* (1966); Edward Arnold Publishers

whose capital was in Tlemcen, ruling over most of western Algeria, when this region was not occupied by the Marīnids. Both the rigorist legalistic doctrine of the Almoravids and the more enlightened religious orientation of the Almohads had proved to be unsuitable as foundations for durable political authority. Furthermore, the rulers themselves were unsuitable to act as custodians of the faith. Islāmic culture came of age in the Maghrib only after the rulers gave up attempting to identify their authority with a single religious doctrine and allowed religious life to develop freely through the interplay of religious ideas and social forces in relative independence from the state. The Maghribi rulers subsequently legitimized their authority by cultivating relations of trust and cooperation with the leading religious scholars of the time. Their capital cities became, consequently, the foremost centres of learning in their realms and were adorned not only with exquisite mosques but also with sumptuous madrasahs, residential colleges built and financed by the rulers. The Malikite school of law was again recognized. Its scholars were held in great esteem and granted various privileges by the rulers, but they were not allowed to determine the conduct of government.

Flowering of Islāmic culture

From the 12th century Ṣūfism had spread widely in the Maghrib. Ṣūfi holy men were venerated in both the towns and the countryside. Although in the towns their influence tended to be overshadowed by that of the legal scholars and the organs of the state, in the countryside they constituted the main custodians of Islāmic norms. Often allied with tribal chiefs, and sometimes having their own communities, these religious leaders contributed toward the establishment of order and stability by using their moral authority to uphold religious norms and arbitrate conflicts. They could perform these functions and gain influence over the tribal societies because the rulers' administrative authority extended little beyond their capital cities and garrison towns, and they, as well as the urban scholars, considered tribal society to be of marginal importance. Indeed, the tribes exercised direct influence on political life only when they became involved in conflicts for power within the ruling family or when their warriors took part in wars against a foreign enemy.

Relations between the three Maghribi states were greatly influenced by the pressures that the Christian states of the Iberian Peninsula exerted on them from the middle of the 13th century. The Ḥafṣids claimed to be the heirs of Almohad religious authority, but after the first independent Ḥafṣid ruler, Abū Zakarīyyā' (1228–49), they gave up attempting to substantiate this claim, either by pressing forward the conquest of the western Maghrib or by helping the Muslims of Spain militarily. The Marīnids inherited both the heartland of the former Almohad state in Morocco and its confrontation with the Christians in Spain, but, because of political instability, they were never able to take the initiative in the war against the Christians. Through their military outposts in southern Spain, they merely tried to check attacks on Morocco itself and to

Military pressures from the Iberian Peninsula

help the Muslim principality of Granada (Arabic: Gharnāṭah) survive as a buffer between them and the Christian powers. In March 1344 the Marīnids suffered a serious military defeat when the army of the Christian kingdom of Castile, reinforced by warriors from England, France, and Italy, conquered Algeciras, their last military outpost in Spain. Meanwhile, since the middle of the 13th century, the Ḥafṣids and Zayyānids had been carrying on commercial relations with Christian Aragon. In return for allowing subjects of the king of Aragon to trade freely in their dominions, they received military help in the form of Catalan mercenaries. Defeat at the hands of the Christians, at a time when the Ḥafṣids and Zayyānids had friendly relations with Aragon, prompted the Marīnid sultan Abū al-Ḥasan ʿAlī (1331–51) to invade their territories. Between 1346 and 1347, his army overran the eastern Maghrib as far east as Tripolitania, but when the Arab tribes of Tunisia joined in the battle against them, the Marīnids were overwhelmed, and Abū al-Ḥasan himself had to flee by sea from Tunis. His son and successor, Abū ʿInān, also invaded the eastern Maghrib in 1356–57, but he too had to withdraw from Tunisia because of Arab tribal resistance.

Political life in the Maghrib from the middle of the 14th to the end of the 15th century was dominated by the preoccupation of the ruling dynasties with internecine conflicts, which in the case of the Ḥafṣids was complicated by the domination of many parts of their territories by Arab tribes. These conflicts led to the division of the Ḥafṣid state between 1348 and 1370 into two parts, one ruled from Tunis and the other from Bejaïa (Bougie), with the ruler of each part being supported by a different Arab tribal group. After its reunification in 1370 by Sultan Abū al-ʿAbbās, the Ḥafṣid state enjoyed periods of relative stability interspersed with ones of strife. Political instability did not, however, prevent the development of learning in the towns. The greatest intellectual figure of the Maghrib before the modern period, the historian and sociologist Ibn Khaldūn, was born and educated at this time in Tunis. Conflicts for power within the Zayyānid state enabled the Marīnids to establish indirect control over Tlemcen in the second half of the 14th century, but, being preoccupied with strife within their own dominions, they were not able to realize their long-held ambition of bringing the whole of the Maghrib under their rule.

The Maghrib from about 1500 to 1830. Between 1471 and 1510 the line of confrontation between the Muslims of the Maghrib and the Christians of the Iberian Peninsula shifted from Spain to the Maghrib itself. The Portuguese occupied a number of positions on the Moroccan coast between 1471 and 1505, which included Tangier in the north and Agadir in the south. The Spaniards conquered Granada, the last Muslim stronghold on the peninsula, in 1492, and between 1505 and 1510 they began establishing garrison posts along the Maghribī coast. The most important of these were at Oran (Wahrān) and Bejaïa in Algeria and Tripoli in Libya. The strong religious reaction in the Maghrib to Christian colonial intrusion enabled the Saʿdī dynasty of sharīfs to capture power in Morocco in 1549 and paved the way for the establishment of Ottoman rule later in the rest of the Maghrib.

Spanish and Portuguese outposts in the Maghrib

Morocco under sharīfian dynasties. As a reaction to the Portuguese presence in Agadir, the tribes in southern Morocco were organized by the sharīfian Saʿdī family—with the active support of Ṣūfī leaders—into a militant religious movement directed against both the Portuguese presence and Morocco's own rulers, the Waṭṭāsids. The latter was a branch of the Marīnid dynasty that had usurped power in Fez in 1472 and pursued a policy of coexistence with the Portuguese. After occupying Marrakech in 1525 and consolidating their authority in southern Morocco, the Saʿdīs conquered Agadir in 1541. By 1550 they had forced the Portuguese to evacuate the rest of their positions on the Moroccan coast and conquered the Waṭṭāsid capital of Fez. The Saʿdīs consolidated their rule in Morocco thereafter and, by later defending the territory against Ottoman expansion from Algeria, gave it a national identity distinct from the rest of the Maghrib. Their authority was legitimized by their descent from the Prophet, but the dynasty's mainstay was the support it received from the settled agricultural and commercial communities, as well as the possession and use of firearms by its troops. The dynasty reached the zenith of its power during the reign of Aḥmad al-Manṣūr (1578–1603) who, with the help of Spanish and Turkish mercenaries, built Morocco's first professional army. With this force at his command, al-Manṣūr imposed his will on the whole country, besides defending it against the Turks and, in 1591, conquering the West African state of Songhai (now Mali). However, conflict for power after his death resulted in the division of the country into several principalities that lasted until the country was reunited through another sharīfian family, that of the ʿAlawites.

The ʿAlawites, who rule Morocco to this day, came to power with the help of Arab tribes that had moved into Morocco in large numbers during the Almohad period. The founder of the dynasty, Mawlāy ar-Rashīd, mobilized these tribes against the powerful Berber principality of the Dilāʾiyya that had dominated the Middle Atlas and parts of northern Morocco since the 1640s. Mawlāy ar-Rashīd's half brother, Mawlāy Ismāʿīl, succeeded in reunifying Morocco with the help of a professional army of ʿAbīds (blacks) recruited from the descendants of the many slaves who were brought back to Morocco after the conquest of Songhai. After Mawlāy Ismāʿīl's death, however, conflict over succession between his sons, who are said to have numbered about 500, complicated by the intrigues of the ʿAbīd officers, ushered in a period of chaos and economic decline that lasted nearly 50 years. Following the dynasty's recovery during the reign of Sultan Muḥammad ibn ʿAbd Allāh (1757–90) and continuing under Sultan Mawlāy Sulaymān (1792–1822), Morocco enjoyed a period of relative stability that was disturbed on a large scale only by conflicts between the ruling dynasty and tribes recognizing the authority of Ṣūfī leaders. The economy of Morocco also started to recover in this period, and the state's external trade expanded. The occupation of Algeria by the French after 1830, together with European political and economic infiltration of Morocco thereafter, however, created new challenges with which the state's traditional political system could not adequately cope.

Ottoman rule in the Maghrib. The Ottoman Turks occupied Egypt in 1517. Shortly afterward they became involved in the confrontation between Muslims and Christians in the Maghrib through the exploits of two Muslim privateers, ʿArūj and his brother Khayr ad-Dīn Barbarossa, who occupied Algiers in 1516 and made it a base for operations against the Spaniards. After ʿArūj was killed in 1518 in an attack on Tlemcen, Khayr ad-Dīn offered submission to the Ottoman sultan in return for military help, which subsequently enabled him to gain control over most of the Maghrib.

Barbarossa's submission to Ottoman control

Algeria was the first country of the Maghrib to be ruled by the Ottoman Turks. Administered at first by governors sent from Istanbul, the Ottoman regency of Algiers was transformed into a sort of military republic when the troops stationed there rebelled against the Ottoman governor in 1689 and installed one of their officers as ruler, giving him the title of dey (maternal uncle). The Ottoman troops thus emerged as a ruling caste that periodically renewed itself with fresh recruits from various parts of the Mediterranean region. The deys, chosen from within this caste, governed Algeria independently from the Ottoman government. They retained religious ties to the Ottoman sultan, however, by recognizing him as caliph and by making the Hanafite school of law—the official school of the Ottoman empire—the official school of law in Algeria as well. Piracy provided the ruling caste with its main source of revenue. Generated largely from the money received for ransoming Christian captives and from the price of peace levied on obliging Christian countries, such income remained forthcoming until the middle of the 18th century. Local inhabitants accepted the rule of the deys because the taxes they had to pay them were light and because their own leaders were allowed a large degree of autonomy in managing the affairs of their communities. Furthermore, the deys were careful to cultivate the good will of the influential Ṣūfī personalities in the countryside. From the

middle of the 18th century, the balance of power in the Mediterranean started to turn in favour of the European powers. Thereafter, the revenue that the deys derived from piracy declined. The heavy taxes that they subsequently had to impose on the Algerians led to conflicts with the tribal communities led by Ṣūfī leaders, which ultimately weakened the regime of the deys on the eve of the French invasion of Algeria in 1830.

Ottoman domination in Tunisia

The Ottoman Turks occupied Tunis in 1534 but were forced by Spanish troops to evacuate it the following year. Thereafter, the Ḥafṣids ruled Tunisia under Spanish protection until the Ottoman Turks reconquered the country in 1574. In 1591 the Ottoman troops stationed in Tunis rebelled against the governor sent from Istanbul and established a regime headed by deys chosen by the troops, which was similar to the dey-ruled regime that appeared in Algeria a little later. In Tunisia the regime of the deys was transformed from within through the importance that the bey, the officer responsible for maintaining order in the countryside and for collecting taxes, came to have in it. In 1705 the bey, Ḥusayn ibn ʿAlī, effectively usurped the power of the dey when, with the help of Tunisian tribal warriors, he repulsed the invasion of Tunisia by the army of Algiers. In this way the Ḥusaynid dynasty of beys, which ruled the country until the monarchy was abolished in 1957, came into being. While recognizing the religious authority of the Ottoman sultan as caliph, the Ḥusaynids ruled Tunisia independently from the Ottoman government. They officially adopted the Hanafite school of law but governed the country through local Malikite notables and allowed Malikite religious scholars to manage the religious and legal affairs of their communities, while also bestowing favours on them. In common with other Maghribi states at the time, piracy was an important source of revenue. It was supplemented, however, by trade in the country's products, which the beys controlled through monopolies sold mostly to Jews at high prices.

The Ottoman Turks conquered Tripoli in 1551 from the Knights of St. John of Malta. The Ottoman province that they established was governed from Tripoli and included the whole of present-day Libya. In 1711 the province underwent a change similar to the one that Tunisia had experienced in 1705, when the chief of the cavalry, Aḥmad Karamanlī, usurped power and established his own dynasty. The Karamanlīs ruled Libya until 1835 when, in the wake of a tribal rebellion supported by the British, direct Ottoman rule was reimposed there. From the middle of the 16th century Libya became active in the lucrative trans-Saharan trade that crossed its territory. In the Karamanlī period it also became an important centre of piracy. After Napoleon's occupation of Malta in 1798, Libya was opened to European trade, and it consequently became involved in the rivalry between the British and the French for supremacy both in the Mediterranean region and in West Africa.

At the time when European colonial expansion in the Maghrib began with the French occupation of Algiers in 1830, the region was divided into four political entities. Morocco, ruled by the ʿAlawite dynasty, was a sovereign country. Algeria, Tunisia, and Libya were autonomous states that recognized the religious authority of the Ottoman sultān. The French occupation of Algeria had direct and serious consequences for the authority of the rulers of Tunisia and Morocco and, indirectly, for the authority of the rulers of Libya as well. (J.M.A.-N.)

NORTH AFRICA AFTER 1830

European pressures on the North African regimes

Advent of European colonialism. The French capture of Algiers in 1830, followed by the Ottoman reoccupation of Tripoli in 1835, rudely interrupted the attempts of North Africa's rulers to follow the example of Muḥammad ʿAlī, the pasha of Egypt, and increase their power along European lines. Of the four powers in North Africa at the beginning of the 19th century, only Tunis and Morocco survived as independent states into the second half of the century to encounter the heavy pressures that Europe then brought to bear on the region for free trade and legal reform, measures originally leveled against the Ottoman Empire and Egypt. Between the death of Tunisia's ambitious reformer, Aḥmad Bey, in 1855 and the dismissal of its talented, reform-minded prime minister, Khayr ad-Dīn, in 1877, Tunis responded to these pressures with the ʿAhd al-Amān, or Fundamental Pact, in 1856 and the short-lived constitution of 1860, the first in the Arab world. The Fundamental Pact guaranteed the equality before the law of all subjects—Muslim, Christian, and Jew—while the constitution provided for a consultative assembly and the administration of justice. The constitution was suspended in 1864, but its chief proponent, Khayr ad-Dīn, came to power in 1869 as president of the International Financial Commission, a group appointed to handle the country's foreign debt, and as prime minister in 1873. At Khayr ad-Dīn's departure in 1877, Tunisia was internally strong but very weak internationally.

The sultan of Morocco, by contrast, was trapped between the European demands for free trade, conceded in 1856, and an unruly tribal population resistant to the imposition of central government. Although defeated by France at the battle of Isly in 1844 and by Spain at Tetuan (Tétouan) in 1860, Morocco was nevertheless able to rely on the support of Great Britain in its dealings with Europe. As a result, although Morocco's immigrant Europeans in this period conducted themselves with impunity under the protection of their consuls, the sultans Muḥammad and Hassan, who ruled Morocco from 1859 to 1894, maintained the country's independence and gradually extended a network of caids (*qāʾids*) or district governors, into the far south of the country. At the beginning of the 20th century—with the fall of Tunisia to French control in 1881—Morocco was the sole exception to colonial rule in North Africa.

France's conquest of Algeria

In 1835 Libya reverted to the status of a provincial backwater of the Ottoman Empire. The French meanwhile took almost 20 years to complete their conquest of the former Turkish territory of Algiers—from the bey of Constantine in the east and from the Arab hero Abdelkader (ʿAbd al-Qādir) in the west—and another 20 years to replace the army with a civilian administration, following the fall of the French Second Empire in 1870. The incorporation of Algeria into metropolitan France was a triumph for the territory's European settlers, achieved at the expense of the native Muslim population, who were denied political rights and were administratively repressed and economically deprived. Immigration from France, Italy, and Spain brought the Europeans in Algeria to about a sixth of the total population in 1900, a proportion that subsequently fell to about a tenth at the outbreak of the Algerian Revolution in 1954. Most Europeans remained in the cities, of which the two largest, Algiers and Oran, had European majorities. The economy of Algeria came to rest on the large-scale production of wine and wheat for export to France, while the majority of the country's Muslims grew ever more impoverished. The injustices of the system were widely condemned in France, and attempts were made by the French to avoid the same mistakes in colonizing Tunisia and Morocco.

A French protectorate was eventually imposed on Tunisia in 1881–83, after the British withdrew their objections to French expansion in North Africa at the Congress of Berlin in 1878. The French preserved the administration of the bey of Tunis, although under French supervision, an indirect form of rule they later applied to Morocco as well. The Moroccan protectorate itself was established only in 1912, after the conclusion of the Entente Cordiale between France and Britain in 1904, a treaty that settled a number of hostilities between the two countries, and the cession of the Cameroons to Germany in 1911. Both acts together left France free to divide the country with Spain, which took over the Rif Mountains in the north and the border region with the Spanish Sahara in the south. Pacification of the Moroccan interior was achieved with a minimum of force by French Field Marshal Louis-Hubert-Gonzalve Lyautey until his efforts were interrupted by the Rif War, waged by the Moroccan nationalist Abd el-Krim (Muḥammad ibn ʿAbd al-Karīm al-Khaṭṭābī) and his forces between 1921 and 1926, an event that delayed total pacification of the country until 1934. Libya was similarly invaded by Italy in 1911, but the prolonged resistance of the Sanūsiyah brotherhood in Cyrenaica denied the Ital-

Guerrilla resistance to colonialism

ian Fascists control of the country until 1931, when they captured and executed the brilliant Sanūsī guerrilla leader ʿUmar al-Mukhtār. By 1939, however, the colonization of Morocco, Tunisia, and Libya by French and Italian settlers was well advanced.

Nationalist movements. World War II brought major changes to North Africa, promoting the cause of national independence. A reaction to years of colonialism had set in that was erupting into strong nationalist tendencies in each of the four countries of the region. The Sanūsī leader Sīdī Muḥammad Idrīs al-Mahdī as-Sanūsī, exiled in Cairo during the war, was restored to power in Cyrenaica by the British and became King Idris I of a united Libya in 1951. Tunisian nationalism formally emerged with the influential Young Tunisians in 1907. It developed further with the founding of the Destour ("Constitution") Party in 1920 and the Neo-Destour Party under Habib Bourguiba in 1934. In Morocco the strong nationalist movement of the 1930s culminated in the foundation of the Independence (Istiqlāl) Party in 1943. In Algeria the French refusal of demands by the reform-minded Young Algerians for French citizenship cleared the way for the radical separatist movement of Messali Hadj Sheik Abd al-Hamid and the Arab Islāmic nationalist movement of Ben Badis. After the war the French were on the defensive, conceding independence to Tunisia and Morocco in 1956 in order to concentrate their efforts on Algeria, where a full-scale rebellion led by the National Liberation Front (FLN) broke out in 1954. This prolonged and costly "savage war of peace" led to Algerian independence in 1962 and, afterward, to the mass exodus of Algeria's European population.

The discovery of oil in Libya in the 1950s presaged further transformations there. The Libyan monarchy was overthrown by a military coup in 1969 and replaced by the popular republicanism of Colonel Muammar al-Qaddafi, whose adventurous Arab nationalism, which he has espoused since coming to power, has fluctuated in intensity with the price of oil. Oil also came to dominate the economy of Algeria, where agriculture was neglected in favour of a program of industrialization based upon the country's huge oil and gas reserves. This policy, however, has been disappointing, and popular disillusionment has called into question the legitimacy of the one-party presidential regime of the FLN in alliance with the army, which has governed Algeria since independence. In Tunisia, the pro-Western Bourguiba survived as president until 1987 when he was deposed by his prime minister, Zine el-Abidine Ben Ali, after having discredited his regime by his inflexible autocracy. Tunisia's heavy economic reliance on tourism since the mid-1960s, moreover, has been a questionable and precarious substitute for an emphasis on agricultural exports to the European Community (EC). Like Tunisia, Morocco has almost no oil, but it does possess greater reserves of phosphates and a more prosperous agriculture. The Moroccan monarchy of kings Muḥammad and Hassan has dominated the country since independence. Although allowing for a variety of parties in the legislature and considerable freedom of speech in the press and media, the monarchy has retained firm control of the government. In 1976 Morocco annexed part of the former Spanish territory of Western Sahara, after which it became involved in a guerrilla war with Polisario, an indigenous nationalist organization based in Algeria. The war became a major obstacle to North African unity, which is regarded as the region's best answer to its exclusion from the EC. Underlying all the political and economic problems of the region is the rapid population growth in Morocco, Algeria, and Tunisia since the 1950s, which threatens to destabilize the conservative regimes in all three countries. (M.Br.)

Western Sahara

THE COUNTRIES OF NORTH AFRICA

Algeria

Algeria is an independent republic in the Maghrib. Its official name is Al-Jumhūriyah al-Jazāʾirīyah ad-Dīmuqrāṭiyah ash-Shaʿbīyah (Democratic and Popular Republic of Algeria). With an area of 919,595 square miles (2,381,741 square kilometres), it is the second largest country in Africa and the 11th largest country in the world. Nearly nine-tenths of the national territory, however, consist of six Saharan *wilāyāt* (*départements* or provinces) in the south.

PHYSICAL AND HUMAN GEOGRAPHY

The country is bounded to the east by Tunisia and Libya; to the south by Niger, Mali, and Mauritania; to the west by Morocco and Western Sahara; and to the north by the Mediterranean Sea.

Algeria is a country of vastness; the Mediterranean to the north separates it from Europe but at the same time opens a thousand doors to it, while in the south the Sahara links it to Africa. History, language, customs, and Islām make it an integral part of the Arab world. Algeria's struggle for liberation, which lasted from 1954 to 1962, has gained it a significant place among the "nonaligned" nations. For the first two decades of independence, Algeria was firmly part of the socialist Third World. During the 1980s its economy was increasingly opened up to privatization and liberalization measures, and multiparty democracy commenced in 1989.

The land. *Relief.* Most of the population of Algeria lives in the northern part of the country—the Tell—which is the richer and the better-watered sector. The remainder of the country, the Saharan region, is uninhabited desert, with the exception of several oases. The Saharan region conceals rich mineral resources and, above all, oil and gas. Each of the country's two physical regions results from a different geologic evolution. The main features of structure and relief have been produced by the collision of the African and Eurasian tectonic plates. This has formed the geologically young and crumpled mountain chains in the north, with the solid and ancient platform of basement rock, horizontal and uniform, forming the south. The first of these areas is the mountainous Atlas region, consisting of two large mountain chains that run roughly parallel from east to west and that are separated by high plateaus. The second region consists of the Sahara desert.

From north to south there are five different zones, all running from east to west. The first zone is formed by intermittent coastal folded massifs; the second is formed by the coastal plains that separate and extend south of the coastal massifs; the third zone consists of the chain of the Tell Atlas (Atlas Tellien) mountains; the fourth zone consists of the High Plateaus (Hauts Plateaux); and the fifth consists of another chain of mountains, the Saharan Atlas (Atlas Saharien).

The north

The coastal ridges and massifs are indented with numerous bays and are often separated from each other by plains—such as the plains of Oran and Annaba—that extend inland. In the same way, the Tell Atlas is not continuous. In the west it forms two distinct ranges separated by interior plains. Thus the plains of Maghnia separate the Tlemcen Mountains to the south from the Trara Mountains to the northwest. Similarly the plains of Sidi Bel Abbes and Mascara are nestled between hill ranges to the north and south. The Dahra Massif forms a long range extending from the mouth of the Chelif river in the west to Mount Chenoua in the east; it is separated from the Ouarsenis Massif to the south by the plains of the Chelif valley.

The relief as a whole, therefore, does not constitute a barrier to communications in the western Tell. However, this is not the case in the central Tell, where the Blida Atlas merges with the Titteri Mountains and the mountainous block of the Great Kabylie joins with the Biban and Hodna mountains to make north-south communications more difficult. Only the valley of the Wadi Soummam permits communication with the port of Bejaïa.

Mountain barriers

Farther east, from Bejaïa to Annaba, one mountain bar-

rier follows another to separate the Plains of Constantine from the sea. The lands south of the plains are dominated by the Hodna, Aurès, and Nemencha mountains. The plains themselves, which have long been used for growing cereals, have a distinct local topography and do not present the same features as the Algero-Oranian High Plateaus, which extend westward from the Hodna Mountains into Morocco. The latter are broken by sebkhas (lake beds encrusted with salt) and are much less favourable to agriculture because of their lower rainfall.

To the south of the Algero-Oranian High Plateaus and the Plains of Constantine runs the second mountain chain, the Saharan Atlas, which is formed of a series of ranges trending southwest to northeast. These decline in altitude from the west where Mount Aissa attains an elevation of 7,336 feet (2,235 metres) in the Ksour Mountains to lower summits in the Amour and Oulad Naïl mountains. Higher summits are again found in the Aurès Mountains, where the highest peak in northern Algeria, Mount Chelia (7,638 feet), is located.

The south

The Algerian Sahara may be divided roughly into two depressions of different altitude, separated from one another by a central north-south rise called the M'zab (Mzab). Each zone is covered by a vast sheet of sand dunes called an erg. The Great Eastern Erg (Grand Erg Oriental), which has an average altitude of 1,300 to 2,000 feet, and the Great Western Erg (Grand Erg Occidental) decline in elevation northward from the foot of the Ahaggar (Hoggar) Mountains to below sea level in places south of the Aurès Mountains. The Ahaggar Mountains in the southern Sahara rise to majestic summits, the highest, Mount Tahat, reaching 9,573 feet in altitude.

Only the northern Tell ranges, lying along a tectonic plate boundary, experience much seismic activity. Severe earthquakes there have twice destroyed the town of Chlef (El-Asnam), in 1954 and 1980. An earthquake in 1989 did much damage in the zone between the Chenoua massif and Algiers.

Drainage. Most of the rivers of the Tell Atlas are short and undergo large variations in flow. The largest river is the Chelif, which rises in the High Plateau. It crosses the Tell Atlas and flows through an east-west trough to reach the sea east of Mostaganem. The Chelif is so intensively exploited for irrigation and drinking water that it has ceased to flow in its lower reaches during the summer months. South of the Tell Atlas only ephemeral rivers (wadis) are found, and much surface runoff ends in saline chotts within inland depressions. Several Sharan watercourses, in particular those flowing off the Ahaggar uplands, occupy valleys formed largely during past pluvial periods in the Pleistocene Epoch (1,600,000 to 10,000 years ago). Some southward-flowing wadis feed the water tables beneath the Saharan surface, and desert oases occur in locations where the water, under hydrostatic pressure, rises to the surface in artesian wells or springs.

Soils. With its wide variations of relief and geology, Algeria has a diverse mixture of soils. Recent vegetation clearance and erosion have limited the area of fertile brown soils to those uplands where evergreen oak forests are still found. Mediterranean red soils occupy the lower altitudes in much of the northern Tell, while farther south increasing aridity results in immature soils that have undergone little chemical weathering or organic matter accumulation. In the desert areas soil development is further impeded by strong and nearly constant wind erosion. An ambitious project since the 1970s has sought to create a "green barrier" against Saharan encroachment northward by reforesting a narrow strip up to 12 miles in width and some 1,000 miles in length.

Climate. Climate, more than relief, is the country's major geographic factor. The amount of rainfall, and above all its distribution through the year, as well as the timing and magnitude of the sirocco, a dry, desiccating wind that emanates seasonally from the Sahara (often with gale force), constitute the principal elements upon which agriculture and many other activities depend.

Algeria's coastal zone and northern mountains have a typical Mediterranean climate, with warm dry summers and mild rainy winters. Algiers, for example, has afternoon temperatures in July of 83° F (28° C), which drop to about 70° F (21° C) at night, while in January daily temperatures range between 59° and 49° F (15° and 9° C). Eighty percent of the city's 30 inches (760 millimetres) of annual precipitation falls between October and March, and July and August are usually rainless. Total annual rainfall increases along the coast as one proceeds from west to east but diminishes rapidly from the coast southward into the interior. The greatest amount of rainfall is experienced in the mountainous regions of the eastern littoral, which are directly exposed to the humid winds that blow inland from the Mediterranean. From a point about 50 miles west of Algiers to the Tunisian frontier, annual rainfall exceeds 23 inches, and in certain places—for example in the Great Kabylie, Little Kabylie, and Edough regions—reaches about 40 inches. West of this location, however, a considerable part of the Chelif Plains, and the plains of the littoral and the region immediately to the south of it in the vicinity of Oran, are insufficiently watered, receiving less than 23 inches. As soon as one crosses the Atlas ranges to the south, however, rainfall diminishes rapidly, except in the Aurès and in a section of the Amour Mountains, which still receive about 16 inches.

Mediterranean climate

This east-west boundary roughly separates the two principal agricultural zones of the country. In the first, dry farming is generally possible and commercially profitable. Fine forests and an abundant vegetation also are found. In the second zone the cultivation of cereal crops is possible only with irrigation. Instead, pastoral activities are predominant, and the forests disappear.

Algeria's relief, which parallels the coastline, limits the southward penetration of the Mediterranean climate. The plains and hills in the region immediately to the south of the coastal mountains still receive sufficient rainfall but have a much drier atmosphere, and temperatures show



Travelers passing through a valley of the Aurès Mountains in northern Algeria.
Victor Englebert

more variation in range. The High Plateau, on the other hand, is characterized by great daily and annual extremes of temperature, hot summers and cold winters, and insufficient rainfall. Summer temperatures are typically above 100° F (38° C) in the afternoon and drop to about 50° F (10° C) at night. In winter the daily range is from about 60° F (16° C) during the day to about 28° F (– 2° C) at night. Annual rainfall varies between 4 and 16 inches.

On the southern border of the Saharan Atlas, the Sahara proper begins. The demarcation coincides with a diminution of the rainfall to less than four inches a year. The landscape and the type of plant life differ greatly from those in the north. Life and activity are limited to a few privileged locations. Daily and annual temperature ranges are even more extreme than on the High Plateau, and the rains, more than in the north, are marked by their great irregularity. Three years may pass without rainfall in the Tademaït region, and as many as five years on the Ahaggar Plateau.

Plant and animal life. Natural vegetation patterns generally follow the country's north-south climatic gradient, with accompanying altitudinal variations in the highland areas. All vegetation in Algeria, where some seasonal aridity occurs everywhere, is characteristically drought-resistant. Forests cover only about 2 percent of the entire land area and are found primarily in the less-accessible mountain regions, where remnants of evergreen forests remain on the moister slopes. Dominated by holm oak, cork oak, conifers, and juniper, the forests today have only limited patches of valuable cedar. Much of the entire Tell region in the north was once covered with woodland, but most of this has been replaced by a poor maquis scrubland consisting of evergreen hard-leaved shrubs and low trees. Often aromatic, maquis shrubs include laurel, rosemary, and thyme. On limestone and poorer soils, however, maquis degenerates into garigue, a low-growing shrub association of gorse, lavender, and sage.

Maquis scrubland

Farther south, increasing aridity reduces the vegetation to a discontinuous type of steppe (treeless plains) dominated by esparto grass. A richer association containing Barbary fig and date palm is still found along the wadis, however. In the desert proper, plant life is very dispersed and consists of tufts of several kinds of grass, various robust species that need almost no water such as drinn and cramcram, several shrubs (which are always stunted and are sometimes spiny), ethels, acacia, and jujube trees, as well as some more varied species that are found in the beds of wadis with underground water or in mountainous regions.

The animal life of the northern mountains includes wild mouflons, Barbary deer, wild boars, and Barbary apes. A multitude of migratory birds pass through the country, including storks and flamingos. In the Sahara gazelles, fennecs, hyenas, and jackals can be found together with many smaller mammals, such as gerbils and desert hare. Insect life is abundant and is most spectacularly manifested in the region's periodic outbreaks of massive locust swarms. Scorpions are common in the arid and semiarid regions.

Settlement patterns. Algeria's population density is highest in the plains and coastal mountains of the northern Tell region. This coincides with the areas of higher, more reliable rainfall. Density declines southward so that much of the southern High Plateau and Saharan Atlas regions are very sparsely populated, while farther south large stretches of the Sahara are virtually uninhabited. Traditionally, rural settlement in Algeria consisted of widely scattered hamlets and isolated dwellings, with nomads in parts of the Sahara and its fringes. Concentrated village settlements were sometimes found at oases and in certain upland regions, such as in the Aurès Mountains and in the Great Kabylie region, the latter being a Berber stronghold renowned for its hilltop villages and traditional way of life.

Rural settlement patterns

French settlers coming to Algeria in the latter half of the 19th century built several hundred "villages of colonization" in the countryside. Often geometric in layout, these settlements replicated French villages and house designs and often provided important service centres in areas of dispersed rural settlement.

The Algerian War of Independence (1954–62) destroyed nearly 8,000 villages and hamlets and displaced some three million people. Many of the displaced were relocated to several thousand new resettlement centres, while others were moved to towns. Most of these centres continued to exist after the war, becoming regular villages as they acquired service functions. In the 1970s another wave of rural settlement was engendered by the government's agrarian reform program, as about 400 "socialist villages" were constructed. By the 1980s, however, this program was abandoned in favour of promoting privately funded settlement efforts.

Urbanization increased greatly under French rule as service centres were created in rural areas and European suburbs and new public buildings were added to the larger cities. Port and industrial activities also accelerated the development of certain coastal towns, such as Annaba (Bône), Skikda (Philippeville), and Mostaganem. During and after the War of Independence, rural exodus to many towns changed them from mainly European settlements to overcrowded Algerian cities. The departure of some one million Europeans after the war made many dwellings available but, because of the subsequent rapid urban growth rate (and even with considerable new construction), did little to alleviate overcrowding in the cities. In the late 20th century, one-half of the population lived in urban areas, of which the largest were located along the coast.

The people. *Ethnic composition.* Some 80 percent of the country's population consider themselves to be ethnically Arab, though most Algerians are descendents of ancient Berber groups who mixed with various invading peoples from the Arab Middle East, southern Europe, and sub-Saharan Africa. Arab invasions in the 8th and 11th centuries brought only limited numbers of new people to the region but resulted in the extensive Arabization and Islāmization of the indigenous Berber population. About 20 percent of Algerians now consider themselves to be Berber, of whom the Kabyle Berbers, occupying the mountainous area east of Algiers, form the largest group. Other Berber groups are the Shawia (Chaouïa), who live primarily in the Aurès Mountains; the M'zabites, a sedentary group descended from the 19th-century Ibāḍite followers of ʿAbd ar-Raḥman ibn Rustam, who inhabit the northern edge of the desert; and the Tuareg nomads of the Saharan Ahaggar region. Nearly all the European settlers, mainly French, Italian, and Maltese nationals, who formed a sizable minority in the colonial period, have departed.

Linguistic composition. Arabic is the first language of the majority of the population and is understood by most others. It is also the country's official language. Berber, in several geographic dialects, is spoken by Algeria's ethnic Berbers, though most Berbers also tend to be bilingual in Arabic.

Algeria's official policy of "Arabization" since independence, which aims to promote indigenous Arabic and Islāmic cultural values throughout society, has resulted in the replacement of French by Arabic as the national medium and, in particular, as the primary language of instruction in primary and secondary schools. Arabization has met with strong resistance among some Berber groups, who fear domination by the Arabic-speaking majority.

Official policy of "Arabization"

Religions. Most Algerians, both Arab and Berber, are Sunnite Muslims of the Malikite (Māliki) sect. A source of unity and cultural identity, Islām provides valuable links with the wider Islāmic world as well. In the struggle against French rule, Islām became an integral part of Algerian nationalism. A distinctive North African aspect of the religion, stemming from pre-Islāmic Berber practices, is the important role played by marabouts, or saintly individuals who possessed special spiritual powers. Venerated locally as mystics and teachers, marabouts gave rise to brotherhoods with their own rituals and rites and were of particular appeal to rural folk who lacked the education to assimilate Qur'ānic teachings directly. Because of the disdain for established authority that maraboutism engendered, Islāmic reformers and state bodies have historically sought to restrict its growth and influence.

While the independent Algerian government has confirmed the country's Islāmic heritage, its policies have often encouraged secular developments. In reaction, Islāmic fundamentalism has been increasing in strength since the

late 1970s. Muslim radicals have periodically clashed with left-wing students and emancipated womens' groups, while fundamentalist imams (prayer leaders) have gained control of many of the country's major mosques.

Demographic trends. Algeria's annual rate of population growth has been high—often above 3 percent—throughout much of the latter half of the 20th century, but by the late 1980s there were signs of demographic transition as growth overall, and birth rates in particular, began to decline. With a youthful population in which one-half are 18 years of age or younger and improved infant mortality rates, however, death rates have also declined and partly offset the effects of the lower birth rates. Most fertility decline has occurred in the cities, where the government's limited family planning program is focused. Life expectancy is about 65 years for men and 67 years for women.

Emigration of Algerians to Europe, once a viable alternative for the country's unemployed, has declined in the late 20th century as France has restricted further immigration, but decades of such migration have left a large Algerian community scattered throughout many of the cities of France, Belgium, and other western European countries. In the desert region, the effects of drought and government policies promoting sedentarization have acted to reduce Saharan nomadism sharply in the 20th century. A growing number of Algeria's famed Tuareg nomads, for example, now lead sedentary lives around oases such as Djanet and Tamanghasset (Tamanrasset), while others cling irresolutely to a precarious and ever more obviously fading way of life.

Decline of nomadism

The economy. Algeria's economy is dominated by its export trade in oil and natural gas. Until 1962 the economy was largely rural-based and complementary to that of France. Since independence, however, production of oil and especially natural gas has come into its own, and industrialization has proceeded rapidly. A series of nationalizations and national plans transformed Algeria into a centrally planned economy with a state socialist system, but, with efforts to privatize parts of the economy taking place in the 1980s, its socialist orientation has been modified somewhat. Standards of living have risen to those of an intermediately developed country, but lower levels of self-sufficiency in food production and an increasingly serious international debt problem pose major obstacles to continued rapid development.

Resources. Extensive deposits of sulfur-free light crude oil were discovered in the Algerian Sahara in the mid-1950s. Production began in 1958, concentrated in three main fields: Hassi Messaoud in the northeastern part of the Sahara, Zarzaitine-Edjeleh along the Libyan border, and El-Borma on the Tunisian border. Reserves in the late 20th century were estimated to be more than nine billion barrels.

Oil and natural gas

Deposits of natural gas were first discovered at Hassi R'Mel in 1956, and since then discoveries have also been made at several other fields. With proven reserves of some 106 trillion cubic feet (3 trillion cubic metres), Algeria ranks seventh in the world in terms of total gas reserves. The gas has a methane content of almost 85 percent and also contains ethane, propane, and helium. Gas liquefaction plants at Arzew and Skikda and a trans-Mediterranean pipeline to Italy via Tunisia permit exports of Algerian gas.

Extensive deposits of high-grade iron ore are worked at Ouenza, and major deposits of medium-grade ore exist at Gara Djebilet near Tindouf.

Deposits of nonferrous metal ores are smaller and more scattered. These include sizable deposits of zinc and lead at El-Abed near Tlemcen and of mercury ore at Azzaba. Intensive prospecting for minerals in the Ahaggar Mountains has been carried out, and traces of tin, nickel, cobalt, chrome, and uranium have been found. Development of the Ahaggar uranium deposits began in the early 1980s.

Phosphate deposits of relatively inferior grade are mined south of Tébessa at Djebel Onk. Sizable kaolin deposits at Djebel Debbagh and large reserves of marble and onyx have been found.

Agriculture. Algeria's intensively cultivated land is largely restricted to the coastal plains and valleys that were colonized by French settlers who established vineyards, orchards, citrus groves, and market gardens. The best farms were located in the well-watered fertile plains around Bejaïa and Annaba in the east, in the Mitidja Plain south of Algiers, and beyond Oran from Sidi Bel Abbes to Tlemcen. The Médéa and Mascara plateaus are also rich vineyard areas. In the drier High Plateau, notably around Constantine, and in the Sersou Plateau to the west, cereals are grown. Also in the west there is an extensive area of esparto grass growing naturally on the region's steppe plains.

Because of aridity, however, more than four-fifths of the country's surface area is uncultivable, and most of the remaining agricultural land is suitable only for pasture. The rest is tilled or devoted to vineyards and orchards. Winter grains (wheat, barley, and oats) are grown on the largest area of arable land. Cotton, tobacco, olives, and dates are important, and sorghum, millet, corn (maize), rye, rice, and truck vegetable crops are also grown. The climate is ill-suited to extensive stock raising, but there are some scattered herds of cattle, goats, and sheep.

Irregular rainfall has long been a threat to agriculture and has also limited hydroelectric development. Dam construction and irrigation projects have added some stability to crop production, but Algeria's meagre water resources are under increasing pressure from urban-industrial demands as well as from the country's growing agricultural needs. At independence Algeria possessed some 20 sizable dams, and an active construction program nearly doubled that number by the late 1980s, adding substantially to the country's total irrigated acreage.

Water resources

Since independence agriculture has been the neglected sector of Algeria's economy, suffering from underinvestment, poor organization, and successive restructuring. As a result, cereal production has undergone large annual fluctuations, orchard and industrial crops have largely stagnated, and viticulture has declined markedly. Wine production, once the mainstay of colonial agriculture and exports, is now low, a tenth of its 1950s levels, and is increasingly deemed culturally inappropriate. Only market gardening and livestock production have shown significant growth. As a result, Algeria has changed from being a food-exporting nation in the 1950s to having a serious food dependency in the late 20th century, as up to 75 percent of food needs are imported.

Forestry and fishing. Algeria's limited forested area has relegated forestry to a position of only minor importance in the country's economy. Furthermore, as the forested area has decreased rapidly since the 1950s, adding to the country's serious problem of soil erosion, government efforts have been aimed at preserving and expanding the remaining forested area. Some cork from the cork oak forests in the higher elevations of the Tell Atlas is processed domestically, however.

The fishing industry is largely underdeveloped, landing only about one-half of its estimated potential catch. Refrigeration and canning facilities, necessary for transporting the catch inland, are limited. The government has given the industry increasing attention in its recent development plans, however.

Industry. The country's main mining centres are at Ouenza and Djebel Onk near the eastern border with Tunisia and at El-Abed in the west. Nearly all of the country's substantial output of high-grade iron ore from the opencut works at Ouenza is used to supply Algeria's own steel industry. Similarly, about one-third of Djebel Onk's phosphate production supplies the Annaba fertilizer complex, while the remainder is exported. El-Abed is Algeria's largest zinc and lead mine, producing most of the nation's output of zinc and lead.

Before independence the manufacturing sector was mainly confined to food processing, textiles, cigarettes, and clothing. Since 1967, however, the main emphasis has been put on heavy industry. The state steel corporation, for example, completed its large El-Hadjar steelworks complex at Annaba in the early 1970s and has constructed a zinc electrolysis plant near the El-Abed mine at Ghazaouet. Much of the steel produced for domestic consump-

Steel production

tion is allocated for machine tools, tractors, agricultural equipment, buses, trucks, and automobiles. Paralleling the Annaba steel complex is the vast Skikda petrochemical works, which includes a gas liquefaction plant, an ethylene factory, liquid petroleum gas separation facilities, a plastics factory, and a benzene refinery. Other gas liquefaction plants are at Bejaïa and Arzew, the latter also being the site of a nitrogenous fertilizer factory, an oil refinery, and a liquid petroleum gas separation plant. A complex at Sétif is composed of methanol and plastics factories, while a further major project in the heavy industry sector is the phosphate fertilizer factory at Annaba.

Most of these industrial developments were by large state-run companies. In the 1980s these were restructured into smaller state-run units and encouraged to pursue joint ventures with private concerns. Also in the 1980s, more emphasis was placed on lighter manufacturing projects.

Following the discovery of oil in the mid-1950s, the main prospecting and producing companies were two French groups, CFP-A (Compagnie Française des Pétroles-Algérie) and ERAP (Entreprise de Recherches et d'Activités Pétrolières). They were later followed by some of the international oil companies. In the late 1960s and early 1970s all French and international oil companies operating in Algeria were nationalized and amalgamated into the state-owned Algerian oil concern, Sonatrach (Société Nationale de Transport et de Commercialisation des Hydrocarbures), which had been set up in 1963–64. Sonatrach extended its activities into exploitation and production on its own account with some success. Much of this development was accomplished with Soviet assistance and more recently by setting up a series of joint service companies with American specialist help.

Pipelines

Four pipelines transport oil from the oil fields to the Mediterranean. The Trans-Mediterranean natural gas pipeline from Tunisia to Sicily and Naples was completed in 1981, boosting substantially the sales of Algerian natural gas to Europe. Exports of natural gas promise to be more important for the economy than sales of oil.

Finance and trade. The Banque d'Algérie, an independent central bank established in 1963, issues the Algerian dinar, the national currency. The government restructured the commercial banking system in the mid-1980s, increasing the number of state-owned commercial banks in the country. The state also opened the financial market to private banks, including some foreign ones, in the 1990s. A law enacted in 1995 lifted government price controls on a variety of commodities. Price subsidies on various basic products have been gradually phased out, in line with Algeria's restructuring agreements with the International Monetary Fund.

Virtually all of Algeria's foreign exchange earnings are derived from the export of petroleum and natural gas products, both of which are refined domestically at an increasing rate. Other exports include phosphates, vegetables, dates, tobacco, and leather goods. The major imports are capital goods and semifinished products, consisting mostly of industrial equipment and consumer goods, followed closely by foodstuffs. About two-thirds of all trade is with countries of the European Union, followed by the United States.

Algerian trade with France dropped from four-fifths of the total trade in 1961 to about one-fifth in the late 20th century. French imports of Algerian agricultural products, especially wine, were severely restricted after independence. Algerians in France formerly remitted substantial sums of money annually to relatives in Algeria; this was partly responsible for Algeria's healthy balance-of-payments position. By the mid-1990s, however, the annual balance of payments was often negative, and Algeria had a high level of external debt.

Transportation. Fast and frequent rail service was established between Oran, Algiers, and Constantine by the late 20th century. The main rail line parallels the coast and extends from the Moroccan to the Tunisian border. Several standard-gauge lines branch from the main line to port cities and to some interior towns, and a few narrow-gauge lines cross the High Plateau to the Algerian Sahara. Two trans-Saharan roads have been built: one paved route from El-Goléa to Tamanghasset and then south to Niger, the other from El-Goléa to Adrar and then on to Mali. A state bus company and several private companies provide reliable intercity bus services.

The principal ports are Algiers, Oran, Annaba, Bejaïa, Bettioua, Mostaganem, and Ténès, in addition to the primarily petroleum and natural gas ports at Arzew and Skikda. Algeria's merchant fleet has grown into a major world shipping line. Administered by the Algerian National Navigation Company, the fleet includes more than 150 vessels, including oil tankers and specialized liquid natural gas tankers. Air Algérie, the state airline, operates flights to many foreign countries and provides daily domestic flights between the country's major cities and towns. There are international airports at Algiers, Annaba, Constantine, Oran, Tlemcen, and Ghardaïa.

Administration and social conditions. *Government.* Algeria was dominated for the first three decades following independence by the National Liberation Front (Front de Libération Nationale; FLN), until 1989 the sole legal political party. New electoral laws passed in that year made the country a multiparty state. The newest constitution, adopted in 1996, provides for a strong executive branch headed by a president, who may be elected, by universal suffrage, for two five-year terms. The president, who is chief of state, appoints numerous state officials, including a wide range of civilian and military leaders, provincial governors, and the prime minister, who acts as head of the government. The prime minister nominates a government for the president's approval, thus completing the executive, and presents a program to the lower house of the nation's bicameral legislature for ratification.

Constitution of 1996

Once the government is in place, the head of government presents draft legislation, which is debated first in the country's lower house, the National People's Assembly (Majlis al-Sha'bī al-Waṭanī), composed of 380 deputies elected for five-year terms by universal adult suffrage. Debate then passes to the upper house, the Council of the Nation (Majlis al-Ummah), consisting of 144 members serving six-year terms, one-third of whom are appointed by the president. The remaining two-thirds are elected indirectly by a secret ballot of local and district legislatures. The legislature meets twice per year, each session lasting no less than four months. It is empowered to draft and ratify legislation on a wide variety of issues, including matters of civil and criminal law, personal status, state finance, and the exploitation of natural resources.

The constitution of 1996 also established a Constitutional Council (Majlis Dustūrī) to oversee elections and referenda, rule on issues of the constitutionality of treaties, negotiations, and amendments, and, when called on by the president, issue opinions on the constitutionality of laws. The Council is appointed jointly by the executive, legislative, and judicial branches.

Below the national level the country is divided into 48 *wilāyāt* (provinces), each with its own elected assembly (Assemblée Populaire de Wilaya; APW), executive council, and governor. The provinces are in turn divided into 227 *dā'irāt* (administrative districts) and then into more than 1,500 *baladīyāt* (communes), each one having its own assembly (Assemblée Populaire Communale) to run local affairs.

Justice. The judiciary consists of three levels. At the first level is the tribunal, to which civil and commercial litigation is submitted and which takes action in penal cases of the first instance. At the second level is the provincial court, which consists of a three-judge panel that hears all cases and functions as a court of appeal for the tribunals and for the administrative jurisdictions of the first instance. At the third and highest level is the Supreme Court, which is the final court of appeal and of appeals against the decisions of the lower courts. In 1975 the Court of State Security, composed of magistrates and high-ranking army officers, was created to handle cases involving state security. The Council of State acts as an administrative equivalent to the Supreme Court, hearing cases not ordinarily reviewed by that body; and the Tribunal of Conflicts was instituted to regulate any jurisdictional disputes that might arise between the other two high courts.

Arabization of learning

Education. Particular attention has been given to replacing French with Arabic as the language of instruction and emphasizing scientific and technical studies. Education in Arabic is officially compulsory for all children between 6 and 15 years of age, and most children of primary-school age and half of all secondary-school-age children are enrolled. Girls and children residing in rural areas have remained underrepresented in the classroom, although much progress for both groups has been made since independence. The literacy rate is about three-fourths for men but less than half for women. The educational system has experienced much difficulty trying to accommodate the increasing number of school-age children. The scarcity of qualified Arabic teachers has been ameliorated by the recruitment of teachers from other Arab countries. Arabic replaced French as the language of instruction at all institutes of higher learning in 2000. Berber discontent over the policy of Arabization, however, has prompted the government to restore Berber language and literature studies at a number of universities. The major institutions include Islāmic universities in Algiers and Constantine, several regional university centres, and a number of technical colleges.

Health and welfare. Because of the country's relatively young population and pressing medical needs, the health care system is oriented toward preventive medicine rather than treatment. Instead of building expensive hospitals, Algeria emphasizes smaller clinics and health centres and maintains a comprehensive vaccination program. Medical care, including medication, is provided by the state without charge, although those earning middle and higher incomes pay a part of their medical fees on a proportional scale. There is an increasing trend toward private health care. In an effort to extend health care to everyone, the government requires all newly qualified physicians, dentists, and pharmacists to work in public health for at least five years. Most medical personnel and facilities, however, remain concentrated in the north, especially in the large cities. Remote mountain locations and much of the Sahara are nearly devoid of modern facilities. Tuberculosis, hepatitis, measles, typhoid fever, cholera, and dysentery are the principal health problems, often brought about by inadequate sanitation facilities and lack of safe drinking water.

Housing. Algeria's chronic housing shortage contributed to health problems throughout much of the latter half of the 20th century. Continuous rural-urban migration and unchecked population growth allowed urban shantytowns to proliferate. The government, whose spending priorities had been focused largely on heavy industry since independence, did little to relieve the housing shortage until the mid-1980s. At that time, however, development plans began emphasizing investment in social infrastructure and services. More construction of affordable government-subsidized housing units has since taken place, including a large prefabricated housing construction program to tackle the most urgent housing needs. Foreign companies—including some from Yugoslavia—were increasingly granted large construction contracts. Algeria also benefited from soft loans throughout the 1990s from the World Bank, the European Union, and other Arab countries to promote its construction sector. State companies were privatized, and joint ventures with European and American companies finally began to address some of the country's housing needs.

Cultural life. Algerian culture and society were profoundly affected by 130 years of colonial rule, by the bitter independence struggle, and by the subsequent broad mobilization policies of postindependence regimes. A transient, nearly rootless society has emerged, whose cultural continuity has been deeply undermined. Seemingly, only deep religious faith and belief in the nation's populist ideology have prevented complete social disintegration. There has been a contradiction, however, between the government's various populist policies, which have called for the radical modernization of society as well as the cultivation of the country's Arab-Islāmic heritage and traditional family structure. Although Algeria's cities have become centres for this cultural confrontation, even in remote areas of the countryside the state has taken roles traditionally filled by the extended family or clan. Algerians have thus been caught between a tradition that no longer commands their total loyalty and a modernism that is attractive yet fails to satisfy their psychological and spiritual needs.

Role of religion

Daily life. Despite efforts to modernize Algerian society, the pull of traditional values remains strong. Whether in the city or countryside, the daily life of the average Algerian is permeated with the atmosphere of Islām, which has become identified with the concept of an autonomous Algerian people and of resistance to what many Algerians perceive as a continued Western imperialism. Practiced largely as a set of social prescriptions and ethical attitudes, Islām in Algeria has more characteristically been identified with supporting traditional values than serving a revolutionary ideology.

Algerians enjoy association football (soccer), handball, volleyball, and athletics. Algerian athletes have participated in the Olympic Games since 1964. They have won medals in boxing, but their major success has been in the area of long-distance running. Noureddine Morceli won the men's 1,500-metre event at the 1996 Summer Olympics and has held numerous world running records. Another runner, Hassiba Boulmerka, won several world championships and a gold medal in the women's 1,500-metre run at the 1992 Summer Games, becoming the first African or Arab woman to win an Olympic track-and-field event.

Algerian cuisine, like that of most North African countries, is heavily influenced by Arab, Berber, Turkish, and French culinary traditions. Couscous, a semolina-based pasta customarily served with a meat and vegetable stew, is the traditional staple. Mutton, lamb, and poultry are still the meat dishes of choice; favourite desserts rely heavily on native-grown figs, dates, and almonds and locally produced honey; and couscous and unleavened breads complete virtually every meal. As is the case in the Middle East, strong, sweet Turkish-style coffee is the beverage of choice at social gatherings, and mint tea is a favourite.

The arts. Various types of music are native to Algeria. One of the most popular, originating in the western part of the country, is *raï* (from Arabic *raʾy*), which combines varying instrumentation with simple poetic lyrics. Both men and women are very free to express themselves in this style. One especially popular Algerian singer of *raï*, Khaled, has exported this music to Europe and the United States, but he and other popular musicians have been targets of Islāmic extremists. *Wahrani* (the music of Oran), another style, blends *raï* with classical Algerian music of the Arab-Andalusian tradition.

Literature

Algeria has produced many important writers. Some, such as Albert Camus and Jean Sénac, are French, although their work was influenced by the many years they spent in Algeria. The writing of Henri Kréa reflects the two worlds he inhabited as the son of a French father and an Algerian mother. 'Abd al-Hamid Benhadugah is the father of modern Arabic literature in Algeria, while Jean Amrouche is considered the foremost poet of the first generation of North African writers who wrote in French. The work of Mouloud Feraoun reflects Berber life. Mohammed Dib, Malek Haddad, Mourad Bourboune, Rachid Boudjedra, and Assia Djebar have all written about contemporary life in Algeria, with Djebar reflecting on this from a woman's perspective.

Press and broadcasting. Daily newspapers are published in both Arabic and French in Algiers, Oran, and Constantine. Several weeklies and a host of magazines are also published in the country. The number and range of newspapers increased during the 1990s, despite frequent violent attacks directed against journalists by Islāmic extremists. Radiodiffusion Télévision Algérienne operates as a broadcasting institution under the Ministry of Information and Culture. Its three radio channels offer programming in Arabic, Kabyle, and, on its international channel, a mixture of French, English, and Spanish. The television network—with two channels—transmits to most of the country. The number of satellite dishes has increased, and many Algerians are now able to receive European stations.

(A.K.Ch./K.Su.)

For statistical data on the land and people of Algeria,

see the *Britannica World Data* section in the BRITANNICA BOOK OF THE YEAR.

HISTORY

Algerian history before Ottoman rule reveals a country of which the western part was often closely associated with Morocco and the eastern part with Tunisia. Few extensive or long-lived Muslim dynasties originated or were based in Algeria. Geographically, Algeria is a difficult country to rule, with the Tell and Saharan Atlas mountain chains impeding easy north-south communication and the few good natural harbours having access to limited hinterlands. That a significant minority of Algerians were native Berber speakers (and many remain so to this day) indicates the greater resistance to Arabization in Algeria as contrasted with neighbouring Tunisia, not to mention Libya and Egypt. Nor was Ottoman Algeria in the early years of the 19th century nearly so developed in its "nationalization" of politics and government as Tunisia.

Never an easy country to rule or to hold together, Algeria is today very much a nation-state. Much of the present-day sense of nationhood is the result of Algeria's history since 1830. Apologists for French rule in Algeria were wont to assert that France made Algeria. They were, at best, half right. It was the dialectic of colonial confrontation between the two communities on opposite sides of the Mediterranean that fostered Algerian nationalism. Modern Algeria must be viewed in light of its century and a half of colonial rule and confrontation with the West to be understood.

The 19th century. It is customary to begin the story of the French conquest of Algeria in April 1827 when the dey of Algiers angrily struck the French consul with a fly whisk. Three years later the French conquest of Algeria began. In those intervening years, the French government had attempted several tactics to establish control over the region: they tried unsuccessfully to induce Muḥammad ʿAlī, the pasha of Egypt, to send his army against the Deylik (Muḥammad ʿAlī was willing but only provided he kept full control of Algeria), and they instituted a naval blockade against Algeria that was ultimately found to be ineffective. Finally, in early 1830, they decided to invade the country.

The government of the dey, temporizing in the traditional way of confronting European demands and trusting that intervention from other European powers or from Istanbul might save the day, proved no match for the French army that landed on July 5, 1830—Ḥusayn, the last dey of Algiers, surrendered. He and other top officials accepted the French offer of exile. Their departure marked the end of a three-century-long period of Algerian history as an autonomous province of the Ottoman Empire. Only one important Ottoman Algerian leader, Aḥmad Bey, managed to hold out a few years longer, but he ruled from Constantine, an interior city far removed from Algiers and the sea, which France easily controlled.

The French invasion

The French government had decided to invade in the belief that a quick victory abroad might earn it sufficient popularity at home to win the coming elections. Instead, only days after the French victory in Algeria, the July Revolution in France forced the reactionary King Charles X from the throne and ushered in the rule of Louis-Philippe as king of France.

In Algeria a period of vacillation ensued. Although those who achieved the July Revolution in France had cynically dismissed the campaign in Algeria as foreign adventurism to cover oppression at home, they were reluctant to simply withdraw. Various alternatives were considered, including an early ill-fated plan to establish princes of the Tunisian beylical family in parts of Algeria as rulers under French patronage. Efforts to rule through local clients proved equally ineffective, the French realizing too late that such an option might have been better achieved by recruiting the officers of the defeated dey. Another idea was to hold only coastal areas that could be secured easily and economically by French naval power. These first few years of colonial rule were characterized as well by numerous changes of French command. Even in these early years of French indecisiveness a number of French settlers began to arrive. They would soon constitute an ever-growing interest group bent on seeing that France remained in Algeria.

Algerian resistance

There also were efforts to reach settlements with the two principal resistance leaders who emerged after 1830, Aḥmad Bey in Constantine and a native tribal and Ṣūfī brotherhood leader, Abdelkader (ʿAbd al-Qādir ibn Muḥyi ad-Dīn), in western Algeria. Aḥmad Bey repulsed a French attempt on Constantine in 1836, but was driven from the city the following year. The French signed two different agreements with Abdelkader (1834 and 1837), but after the French moved through territory claimed by him later, he countered with a major attack in 1839, driving the French back to Algiers and the coast.

France decided thereafter on all-out war. Led by General (later Marshal) Thomas-Robert Bugeaud, the campaign of conquest eventually brought one-third of the total French army strength (more than 100,000 men) to Algeria and lasted until Abdelkader, using hit-and-run tactics of tribal combat, was forced to surrender in 1847. Earlier Abdelkader, seeking refuge and recruits in Morocco, had forced a reluctant Sultan Abd ar-Rahman to take a stand against French incursions. This resulted in the disastrous defeat of Moroccan forces at the Battle of Isly in 1844.

Abdelkader, exiled to France, was later permitted to settle with his family in Damascus, Syria, where he and his followers saved the lives of many Christians during the 1860 massacres there. Respected even by his opponents, Abdelkader became, and has remained, the personification of Algerian national resistance to foreign domination.

(L.C.Br.)

Abdelkader's defeat marked the end of what might be called resistance on a national scale, but smaller operations continued, such as the occupation of the Saharan oases (Zaatcha in 1849, Nara in 1850, and Ouargla in 1852). The eastern Kabylie region was subdued only in 1857, while the final great Kabylie rising of Muḥammad al-Moqrānī was suppressed in 1871. The Saharan regions of Touat and Gourara, theretofore Moroccan spheres of influence, were occupied in 1900; the Tindouf area, previously regarded as Moroccan rather than Algerian, was only attached to the latter region after the French occupation of the Anti-Atlas in 1934.

Pattern of French rule

French Algeria. The manner in which French rule was established in Algeria during the years 1830–47 laid the groundwork for a pattern of rule that French Algeria would thereafter maintain in its essentials. It was characterized by a tradition of violence and mutual incomprehension between rulers and ruled, by the relative absence of well-established native interlocutors between the French rulers and the great mass of the population, and by an ever-growing French settler population (the colons) demanding the privileges of a ruling minority in the name of French democracy. That Algeria eventually became juridically a part of France added to the power of the colons, who sent delegates to the French parliament. From the late 19th century until the end of French rule, the settlers accounted for roughly 10 percent of the total population.

Settler domination of Algeria was not, however, secured until the fall of Napoleon III in 1870 and the rise of the Third Republic in France. Until then, Algeria remained largely under military administration. The governor-general of Algeria (a title first given to Bugeaud in 1845, replacing the earlier title "governor-general of the French possessions in Africa") was almost invariably a military officer until the 1880s, and most Algerians—but not the settlers—were subject to rule by military officers organized in the famous Arab Bureaus (Bureaux Arabes), whose members (officers with an intimate knowledge of local affairs and of the language of the people), having no direct financial interest in the colony, often sympathized with the outlook of the people they administered rather than with the demands of the European colonists. The seeming paradox of French Algeria was that despotic and military rule offered the native Algerians a better situation than did civilian and democratic government.

A large-scale confiscation of cultivable land, following the crushing of resistance, made colonization possible. Settler colonization was of mixed European origin (mainly Spanish in and around Oran; French, Italian, and Maltese

European-Muslim relations

in the centre and east). For long the presence of the non-French settlers was officially regarded with alarm; but, with time, the influence of French education, of the Muslim environment, and of the Algerian climate created in the non-French a European-Algerian, subnational sentiment. This would probably have resulted, in time, in a movement to create an independent state if Algeria had been situated farther away from Paris and if the settlers had not feared the potential strength of the Muslim majority.

On the overthrow of Louis-Philippe's regime in 1848, the settlers succeeded in having the territory declared French and the three former Turkish provinces converted into departments on the French model, while colonization was developed with renewed energy. On the establishment of the French Second Empire in 1852, responsibility for Algeria was at first transferred from Algiers to a minister in Paris. Soon, however, the emperor reversed this disposition. While expressing the hope that an increased number of settlers would forever keep Algeria French, he also declared that France's first duty was to the three million Arabs. With considerable accuracy he declared that Algeria was "not a French province but an Arab country, a European colony, and a French camp."

This attitude aroused certain hopes in Arab minds, but they were destroyed by the emperor's downfall in 1870. The French defeat in the Franco-German War gave impetus to the last great Kabylie rising (1871) under Muḥammad al-Moqrānī. Its suppression by French forces was followed by the sequestration of another 11 million acres (4.5 million hectares) of land and the imposition of an indemnity of 36.5 million francs; these measures together provided land for refugees from Alsace and capital with which to exploit the land.

During the 50 years that followed, the European population felt free to establish political, economic, and social domination over the country and its native inhabitants. At the same time, new communications, the installation of hospitals and medical services, and modern education—dispensed to a very limited extent and in French to the Muslims, while generally available to the Europeans—created a minority of better-off Algerians.

For Algerians, service in the army and in the factories of France during World War I was another eye-opening experience. When peace returned, some 70,000 Algerians remained in France, and by living with extreme economy they were able to support many thousands of their relations in Algeria.

Three rival tendencies

Nationalist movement. The development of Algerian nationalism can be described in terms of three separate tendencies. First, there was the small group of Algerians who had gained access to French education and earned their living in the modernized French sector. Many of this group, called "assimilationists," were prepared to consider permanent union with France, provided the rights of Frenchmen were extended to native Algerians. Such was the case with the loosely organized "Young Algerians" in the period before World War I, or even to a considerable extent with Khaled Ben Hachemi ("Emir Khaled"), the grandson of Abdelkader, in the 1920s, or with Ferhat Abbas, who later became first premier of the Provisional Government of the Republic of Algeria, as late as the 1930s. All of this group were prepared to accept gradualist, reformist tactics, eschewing illegal actions. They were the Algerian equivalents of the political class who led their countries to independence in most former European colonial territories. They had no such chance in Algeria, for their roots in Algerian society were too shallow and the colons of French Algeria resisted even small reformist measures that might have led, however slowly, to piecemeal liberation.

The second tendency was a Muslim reformist group inspired by the religious Salafiya movement founded earlier in Egypt by Sheikh Muḥammad ʿAbduh. Organized in 1931 as the Association of Algerian Muslim Ulama (AUMA) under the leadership of Sheikh Abd al-Hamid ben Badis, this group was not a political party as such. As religious reformers primarily, they were instead important in engendering among the masses of Algerians a strong sense of Muslim Algerian nationality. They also stymied any possible effort on the part of the assimilationist tendency to move toward more accommodating positions with France in the hope of gaining some concessions.

The third tendency was more proletarian and radical in orientation. It took organizational form among Algerian workers in France in the 1920s under the leadership of Messali Hadj, later gaining wide support in Algeria as well. Preaching a nationalism without nuance, Messali Hadj brought a message that was bound to appeal to Algerians who fully realized their deprivation vis-à-vis the minority French community. Messali Hadj's message, or for that matter the more muted message of Ben Badis, could have been resisted by the gradualist reformers, led since the early 1930s by Ferhat Abbas, only if they had been able to show that step-by-step decolonization was possible. This they were never able to demonstrate. Several efforts to liberalize the treatment of native Algerians promoted by French reformist groups in collaboration with the Algerian reformists both before and after World War I, during the 1930s, and after World War II all proved to be too little and too late.

Failure of reformism

At the time of the Popular Front government in France (1936–37), for example, the Blum-Viollette proposal (so named for the French premier and the former governor-general of Algeria) would have provided for a very small number of Algerians to obtain full French citizenship without being obliged to relinquish their right to be judged by Muslim law on matters of personal status (*e.g.*, marriage, inheritance, divorce, and child custody). This had long been the sticking point shrewdly exploited by the settler population. To all but a few Algerians, abandoning the right to have personal status judged by Muslim law was tantamount to apostasy. Blum-Viollette was thus a potential breakthrough. The small number of Algerians (including the educated, veterans of French military service, and other narrowly defined groups) brought into full French citizenship could then have been gradually increased in later years. Colon opposition to the measure was so fierce that the project was never even brought to a vote in the French Chamber of Deputies. The characteristics of colonial rule in Algeria virtually ruled out any nationalist option other than one based on organized violence. The group that inherited this mission, the National Liberation Front (FLN), not surprisingly grew out of Messali Hadj's organization, later absorbing many adherents of the other two nationalist tendencies. (L.C.Br.)

World War II and the independence movement. World War II brought with it the collapse of France and, in 1942, the Anglo-American occupation of North Africa. The occupation forces were to some extent automatically agents of emancipation, while broadcasts in Arabic both from Allied and Axis stations began to compete, with promises of a brave new world for formerly subject peoples. The effect was heightened by the promise of the emancipation of Syria and Lebanon, given in June 1941 by the Free French and backed by the British authorities in the Middle East.

The Algerian Manifesto

In December 1942 the former assimilationist leader Ferhat Abbas drafted an Algerian Manifesto for presentation to the Allied as well as to French authorities, seeking recognition of the political autonomy of Algeria as a sovereign nation. In December 1943 General Charles de Gaulle declared that, because of loyalty shown, France was under an obligation to the Muslims of North Africa, and in March 1944 French citizenship was extended to certain categories of Muslims. This was by then, however, far from enough to satisfy Muslim opinion. A display of Algerian nationalist flags at Sétif in May 1945 led to an unorganized rising, in which 84 European settlers were massacred. The suppression that followed was indiscriminate, and it resulted, according to a French committee of inquiry, in not fewer than 1,800 deaths.

On Sept. 20, 1947, a statute of Algeria was finally voted by the French Assembly, defining the country as "a group of departments endowed with a civic personality, financial autonomy, and a special organization." The statute created an Algerian Assembly of 120 deputies, elected in equal numbers by two electoral colleges—one composed of 370,000 Europeans and 60,000 assimilated Muslims

and the other of 1,300,000 Muslims. After lengthy debates the statute was passed by a small majority, with 15 Muslim members abstaining. Muslims were at last to be considered as full French citizens with the right to keep their personal Qur'ânic status and were granted the right to work in France without further formalities. The military territories of the south were to be abolished, and Arabic was to be taught in schools at all levels.

Unfortunately, the implementation of this law was poor and the subsequent elections were "managed" by the administration, while most of the reforms laid down by the statute remained a dead letter. In spite of this, Algeria remained quiet. The principal change had been the fact that some 350,000 Algerian workers—five times as many as in the post-World War I period—were able to establish themselves in France and remit money to Algeria.

The Algerian War. Signs of the approaching storm, however, were only too apparent. In 1950 the French police discovered that a robbery of the Oran post office had been the work of the nationalist Special Organization (OS), an offshoot of the party led by Messali Hadj, which had taken the name of the Movement for the Triumph of Democratic Liberties (MTLD). The leader in the robbery was Ahmed Ben Bella, who had been highly commended during the fighting in Italy with the Free French. In 1952 Ferhat Abbas, when tried for a trivial offense, was defended by three lawyers—one Muslim, one Christian, and one Jewish; they combined to deliver an impressive attack on the administration. About the same time, Ahmed Mezerna, acting head of the MTLD, took the unprecedented step of personally seeking support in Egypt. The head of the Association of Algerian Muslim Ulama toured the Arab East and secured scholarships from the Arab governments for Algerians who wished to pursue their studies in Arabic.

The storm burst on the night of Oct. 31, 1954. It was organized by a few young men who, dissatisfied with Messali Hadj's leadership, had decided that justice for Algeria could only be realized by open rebellion. The movement took the title of the National Liberation Front (FLN) and issued a leaflet stating that its aim was the restoration of a sovereign Algerian state. It advocated social democracy within an Islâmic framework and citizenship for any resident in Algeria, with the same rights and duties as other citizens. A preamble recognized that Algeria had fallen behind the other Arab states in emancipating itself socially and nationally, but it claimed that this could be remedied by a difficult and prolonged struggle. Two weapons would be used—guerrilla warfare at home and diplomatic activity abroad, particularly at the United Nations, where the support of the Arab countries and other states would be invaluable. The FLN military objective was to make the position of the administration untenable by sudden raids, ambushes, and sabotage.

The National Liberation Front

Though the first outbreak, which occurred in the region of Batna and the Aurès, was ineffective militarily, it led to the arrest of some 2,000 members of the MTLD, who had not in fact been in favour of open rebellion. In mid-February 1955 Jacques Soustelle arrived in Algiers as governor-general; in June he announced a new plan, which, however, was once again to prove too little and too late. On August 20 a new rising at Ain Abid and at the mine of Al-Alia near Philippeville (now Skikda) degenerated into another massacre of Europeans, followed by summary executions of Muslims. In January 1956 the electoral victory of the Republican Front in France and the premiership of Guy Mollet led to the appointment of the moderate and experienced General Georges Catroux as governor-general. When Mollet personally visited Algiers, however, to prepare the way for the new governor-general, he was bombarded with tomatoes by the European populace. Yielding to this pressure, he allowed Catroux to withdraw and named in his place the pugnacious Socialist Robert Lacoste as resident minister. Lacoste's policy was described as pacification, but was in fact forcible suppression.

French forces sent to Algeria

A French army of 500,000 men was sent to Algeria to counter the control that the rebels had managed to establish in the more out-of-the-way portions of the country while collecting money for their cause and taking reprisals against fellow Muslims who would not cooperate with them. By May the rebels had won over the majority of previously noncommitted political leaders, and Ferhat Abbas and Tawfiq al-Madani, of the Association of Algerian Muslim Ulama, had joined FLN leaders in Cairo.

Externally, the major event of 1956 was the French decision to grant full independence to Morocco and Tunisia and to concentrate on retaining "French Algeria." The rulers of the newly independent states—the Moroccan sultan and Premier Habib Bourguiba of Tunisia—hoping also to find an acceptable solution to the Algerian problem, prepared to hold a meeting in Tunis with five principal Algerian leaders who had been guests of the sultan in Rabat. French intelligence officers, however, managed to divert to Algiers the plane chartered by the Moroccan government to fly the Algerians to Tunis. The Algerian leaders were then arrested and confined in prison in France for the next six years. Far from decapitating the rising, this act provoked an outbreak in Meknès that cost the lives of 40 French settlers before the newly independent Moroccan government could restore order.

In the next year, 1957, the rebels attempted to paralyze the administration of Algiers by terrorism. This was defeated by French parachute troops, who used torture to extract information. The French also cut Algeria off from independent Tunisia and Morocco by barbed wire fences, illuminated at night by searchlights; this separated the resistance bands within Algeria from some 30,000 Algerian armed forces who occupied positions between the fortified fences and the actual frontiers of Tunisia and Morocco, from which they drew supplies. These troops had the advantage of a friendly people and government as a base; they could not, however, penetrate into Algeria proper but could only harass the French line.

Provoked by these assaults, the French air force in February 1958 bombed the Tunisian frontier village of Sâqiyat Sîdi Yûsuf, killing a number of civilians, including children from the local school. This led to an Anglo-American mediation mission, which negotiated the withdrawal of French troops from various districts of Tunisia and their concentration in the naval base of Bizerte (Banzart).

A meeting—the Maghrib Unity Congress—was held in Tangier from April 27 to 30 under the auspices of the Moroccan and Tunisian nationalist parties and the Algerian FLN. It recommended the establishment of an Algerian government in exile and of a permanent secretariat to promote Maghrib unity. The latter proposition had little permanent result, but a government—the Provisional Government of the Algerian Republic (GPRA)—was set up on September 19.

By then, however, conditions had been radically changed by events of May 13, 1958; these began as a typical settler rising—thousands of European Algerians sacked the offices of the governor-general and, with the tacit approval of the army officers, called for the integration of Algeria with France and for the return of de Gaulle to power. The Muslims were clearly taken aback, but soon there was a relatively friendly mixing of Muslim demonstrators with the Europeans and a general hope of better times to come. In the crisis caused by this rising, de Gaulle returned to power in France.

Changes under de Gaulle

On June 4 de Gaulle visited Algiers amid scenes of great enthusiasm. He gave no clear indication, however, that he shared the settlers' enthusiasm for integration, which, in their minds, meant the submergence of the native Algerians in an enlarged France. All Muslims, however, were now granted the full rights of French citizenship, and on October 30 de Gaulle announced in Constantine a plan to provide adequate schools and medical services for the Muslim population, to create employment for the vastly increasing Muslim masses, and to introduce Muslims into the higher ranks of the public services.

In September 1959, de Gaulle, in anticipation of the opening of the United Nations General Assembly, declared publicly that the Algerians had the right to determine their own future. From this time it gradually became clear that he was prepared to go even to the length of granting independence if peace could not be secured on any other terms. The agitation of the Europeans now became extreme.

On Jan. 24, 1960, a fresh settler rising collapsed after nine days from lack of military support. A year later, however, as the prospect of negotiations with the GPRA became more probable, there was another rising, this time organized by four generals, of whom two—Raoul Salan and Maurice Challe—had previously been commanders in chief in Algeria. De Gaulle remained unshaken, and the rising, lacking substantial support from the army, collapsed after only three days.

In May 1961, negotiations were opened in France with representatives of the GPRA. This body had by now long been recognized by the Arab and communist states, from which it received aid, though it had never been able to establish itself on Algerian soil. Negotiations were broken off in July, after which the veteran Ferhat Abbas was replaced as premier by the much younger Ben Youssef Ben Khedda. Settler opposition was meanwhile organized by a body calling itself the Secret Army Organization (OAS), which began to employ terrorism as brutal as that sometimes used by the rebels.

Independence for Algeria

On March 8, 1962, negotiations were resumed, and on the 18th agreement was finally reached. Algeria would thenceforth be independent, provided only that a referendum, to be held in Algeria by a provisional government, confirmed the desire for it. In case of approval, French aid would continue; Europeans could depart, remain as foreigners, or take Algerian citizenship, as they preferred. This announcement produced a violent outburst of terrorism and attempted resistance by the OAS; but in May the terror subsided as its futility became obvious. On July 1, 1962, the referendum in Algeria recorded some 6,000,000 votes in favour and only 16,000 against. After three days of unbounded Muslim rejoicing, the GPRA entered Algiers in triumph, while the departure of the Europeans assumed mass proportions.

Meanwhile, however, the GPRA was itself torn by dissensions, and its authority was challenged by Colonel Houari Boumedienne, who commanded the Algerian army on the Tunisian side. In this he was supported, after some hesitation, by Ben Bella, now released from captivity in France, and by Muḥammad Khidr, secretary general of the FLN. It was not until three months later that the small-scale civil war that ensued was finally settled by the recognition of Ben Bella as premier, Boumedienne as chief of staff, and Khidr as head of the party organization.

Independent Algeria (from 1962). The Europeans who abandoned the country included the overwhelming majority of senior administrators and managerial and technical experts. The chief exception was a group of some 10,000 French schoolteachers who remained, with great courage, often in very isolated posts.

During the six previous years some 10,000 French troops and officers and possibly as many as 250,000 Muslims had lost their lives in the fighting; scores of villages had been destroyed, and 2,000,000 peasants had been moved to new sites. Nevertheless, many public services such as the post office and the railways continued to work remarkably well. On farms and in factories, however, management had largely vanished. Production fell, while unemployment and underemployment reached extreme levels.

Ben Bella's personal style of government and his reckless promises of support for revolutionary movements were not conducive to orderly administration. On the other hand, the revenue from the extensive oil and natural gas fields that had recently been discovered and exploited in the Sahara was of very great assistance.

A serious problem was presented in April 1963 by the resignation of Muḥammad Khidr and by his subsequent departure abroad, taking with him the funds of the FLN. He was later assassinated in Madrid. Little by little, the gradual elimination of other dissident leaders appeared to leave control securely in the hands of Ben Bella and the army under Boumedienne. What appeared to be Ben Bella's plans for a complete political takeover, removing Boumedienne and his supporters, were foiled on June 19, 1965, when Boumedienne and the army moved first. Ben Bella's erratic political style and poor administrative record made his removal acceptable to Algerians, but the Boumedienne regime began with little popular support.

Boumedienne's coup

In the following years Boumedienne moved undramatically but effectively to consolidate his power, with army loyalty remaining the basic element. Efforts to reorganize the FLN met with some success. The cautious and deliberate Boumedienne approach was seen in constitutional developments; communal elections were held in 1967, provincial (*wilāyah*) elections in 1969. Elections for the National Assembly, however, did not take place until 1977. In the previous November, a new constitution had been adopted following wide public debate and referenda.

On Dec. 27, 1978, Boumedienne died. Colonel Chadli Bendjedid, nominated by the FLN to succeed him, was confirmed as president in a referendum in February 1979. The release of Ben Bella later that year from house arrest indicated that the new president felt confident in his authority and served as a symbol that, 17 years after independence, many old disputes were no longer relevant.

Independent Algeria was committed to a socialist, centrally directed economy and society. The mass exodus of the French at the time of independence left the new government with vast abandoned lands. These and the remaining French estates (all French land being nationalized by 1963) were turned into state farms run by workers' committees. In 1971 Boumedienne had inaugurated an agrarian reform aimed at breaking up larger Algerian-owned farms and creating small holdings organized into cooperatives. Subsequent steps continued to break up large holdings and redistribute land to landless peasants.

Agrarian reform

Economic plans stressed developing a state-run industrial core, and Algeria's important oil and gas industry came to be controlled by a government company, Sonatrach. Algeria's economic difficulties were eased by the export of oil and gas as well as by the remittances from the nearly 850,000 Algerians living abroad (mostly in France). In 1976 Algeria signed a trade agreement with the European Community (EC); yet unemployment and underemployment have remained major problems.

In October 1988 serious riots in Algiers, Annaba, and Oran (leaving an unofficially estimated 500 dead) rocked the regime. Bendjedid, reelected for his third five-year term as president in December 1988, moved to liberalize the system and challenge the FLN political monopoly. The new constitution, approved in February 1988, initiated political plurality and dropped all references to socialism. In the 1990 local elections the Muslim fundamentalist Islāmic Salvation Front (Front Islamique du Salut; FIS), led by Abbasi al-Madani, captured clear majorities in the provincial and municipal councils, winning roughly double the number of seats taken by the FLN. The first round of balloting for the National Assembly, held in December 1991, produced an even more striking victory for the FIS, which won 188 seats, just 28 short of a simple majority and 99 short of the two-thirds majority needed to amend the constitution. There seemed little doubt that the FIS would achieve a majority in the second balloting scheduled for Jan. 15, 1992. Instead, the Algerian government and army intervened on January 12 to cancel the elections, President Bendjedid having resigned the previous day. Mohammed Boudiaf, a former FLN dissident, was sworn in as president of a ruling Supreme State Council. Boudiaf was assassinated five months later on June 29 by an alleged FIS gunman while giving a speech in Annaba, as dissension between fundamentalists and the government continued unabated.

In the realm of foreign relations, Algeria's policy is revolutionary in word but pragmatic in deed. Immediately after independence Algeria was a haven for Third World guerrilla and revolutionary movements, but this has largely passed. Algerian spokesmen continue to press for strong positions on the Palestine problem, decolonization in Africa, and economic ties between the developed and underdeveloped worlds, but at the same time the government has supported commercial ventures with private American companies. In addition, the Algerian government played a major role in mediating the release, in January 1981, of U.S. hostages held in Iran.

Relations with Morocco

With neighbouring Morocco, relations have not been smooth. A short border war that broke out in the autumn of 1963 (the area in dispute being rich in iron-ore deposits)

was brought to a halt through intervention of the Organization of African Unity. The rapprochement achieved in 1969–70 later broke down again over Morocco's efforts to absorb Western Sahara (formerly Spanish Sahara). Algeria supported the Popular Front for the Liberation of Saguia el Hamra and Río de Oro (Polisario Front) in resisting Morocco. Then in May 1987 Bendjedid and Morocco's King Hassan met to resolve differences. Subsequent progress toward a possible resolution of the Western Sahara issue has eased tensions between the two states significantly, and diplomatic relations were restored in 1988. (N.B./L.C.Br.)

Fighting between government forces and Islāmic extremist groups continued unabated through the 1990s under successive government-backed administrations, with civilians often being randomly targeted for vicious attacks by both sides. In April 1999 Abdelaziz Bouteflika, the former foreign minister under Boumedienne, ran for president unopposed, as other candidates withdrew following rumours that the elections were rigged. Bouteflika assured the international community that the elections were legitimate and vowed to work with other political parties. More violence ensued, however, and the number of killed, missing, and injured continued to rise. From the mid-1990s the government and various Islāmic groups attempted several times to clear up political differences between them and end the violence, but at the outset of the 21st century the civil war continued to rage and had by then claimed the lives of some 100,000 civilians and numerous political figures. (Ed.)

For later developments in the history of Algeria, see the BRITANNICA BOOK OF THE YEAR.

Libya

The Socialist People's Libyan Arab Jamahiriya (in Arabic, Al-Jamāhīrīyah al-ʿArabīyah al-Lībīyah ash-Shaʿbīyah al-Ishtirākīyah) is an independent socialist state of North Africa. It is bounded by the Mediterranean Sea on the north, Egypt on the east, The Sudan on the southeast, Niger and Chad on the south, and Tunisia and Algeria on the west. Largely composed of the Sahara, it covers an area of 678,400 square miles (1,757,000 square kilometres) and is one-fourth the size of the conterminous United States and almost twice the size of Egypt. The population is concentrated along the coast, where the de facto capital, Tripoli (Ṭarābulus), and Banghāzī (Benghazi), the de jure capital, are located.

PHYSICAL AND HUMAN GEOGRAPHY

Before the discovery of oil in the 1950s, Libya was poor in natural resources and severely limited by the climatic conditions of the Sahara. The country was almost entirely dependent upon foreign aid and the import of commodities necessary for the maintenance of its economy. Petroleum dramatically changed this situation, and Libya became one of the richest countries of the Middle East and Africa. The government controls the economy and has attempted to develop agriculture and industry with the wealth derived from its huge oil revenues. It has also established a welfare state, which provides medical care and education.

The land. *Relief.* Libya is underlain by basement rocks of Precambrian age (from 3.8? billion to 540 million years ago) that are mantled with marine and wind-borne deposits. The major physical features are the Nafūsah Plateau and the Al-Jifārah (Gefara) Plain in the northwest, the Akhḍar Mountains in the northeast, and the Saharan plateau occupying much of the rest of the country.

The Al-Jifārah Plain covers about 10,000 square miles of Libya's northwestern corner. It rises from sea level to about 1,000 feet (300 metres) at the foothills of the Nafūsah Plateau. Composed of sand dunes, salt marshes, and steppe, the plain contains most of Libya's population and its largest city—Tripoli. The Nafūsah Plateau is a limestone massif that stretches for about 212 miles (340 kilometres) from Miṣrātah on the Gulf of Sidra to the Tunisian border at Nālūt. West of Tarhūnah it rises steeply from the Al-Jifārah Plain, reaching altitudes between 2,000 and 3,000 feet.

In the country's northeastern corner, the Akhḍar Mountains stretch for about 100 miles along the coast between Al-Marj and Darnah. The limestone mountains rise steeply from the coast to about 2,000 feet and then stretch about 20 miles inland, attaining their highest altitudes of about 3,000 feet.

The desert and the plateaus

The Saharan plateau covers some 90 percent of Libya and is itself about one-half covered by sand deserts, making it truly a desert land. Al-Ḥarūj al-Aswad is a hilly basaltic plateau in central Libya. Covered with angular stone fragments and boulders, it rises to about 2,600 feet and is crowned by volcanic peaks. The Al-Ḥamrāʾ Plateau lies south of the Nafūsah Plateau. It contains bare rock outcrops and rises to 2,700 feet. An arm of the Tibesti Mountains stretches northward from the main massif in Chad. In the Fezzan region of the southwest a series of long depressions and basins contain wadis (dry riverbeds) and oasis settlements. Mobile sand dunes that reach heights of 300 feet are found in the Fezzan's Marzūq desert and in the Libyan Desert of the east, which extends across the border into Egypt. The country's highest elevations are at Bikkū Bittī peak (Picco Bette), rising to 7,500 feet (2,286 metres) on the Libya-Chad border, and at Mount Al-ʿUwaynāt, with an elevation of 6,345 feet (1,934 metres) on the Libya-Sudan-Egypt border.

Drainage. There are no perennial rivers in Libya. The numerous wadis that drain the uplands are filled by flash floods during the rains and quickly dry up or are reduced to a trickle. The largest wadi systems are the Wadi Zamzam and Wadi Bayy al-Kabīr, both of which reach the western coast of the Gulf of Sidra. Other large wadis drain the interior basins of Surt, Zalṭan, and the Fezzan. There is also, however, extensive underground water. Numerous oases are watered by wells and springs, and artesian wells tap large deep fossil aquifers in the Fezzan and southeastern Libya. Along the coastal strip there are several salt flats, or sebkhas, formed by the ponding and evaporation of water behind coastal dunes. Principal salt flats are those of Tāwurghāʾ, Zuwārah, and the Banghāzī Plain.

Soils. The gray-brown soils of the Al-Jifārah Plain and the Nafūsah Plateau are fertile, although they have become saline from overirrigation. In the east, the soils of the Barce plain—which stretches between the Akhḍar Mountains and the sea—are light and fertile. Rich alluvial soils are found in the coastal deltas and valleys of large wadis. The rest of the country is covered by wind-eroded sand or stony desert. The soils in these areas are poorly developed and contain little organic material. On the margins of the Sahara, the soils are seriously depleted from cultivation and overgrazing.

Climate. The climate over most of the country is that of the hot, arid Sahara, but it is moderated along the coastal littoral by the Mediterranean Sea. The Saharan influence is stronger in summer. From October to March, prevailing westerly winds bring cyclonic storms and rains across northern Libya. A narrow band of semiarid steppe extends inland from the Mediterranean climate of the Al-Jifārah Plain, the Nafūsah Plateau, and the Akhḍar Mountains. The desert climate of the Sahara reaches the coast in the Surt Desert along the southern fringes of the Gulf of Sidra. Periodic droughts, often lasting several years, are common in the steppe and desert climates.

Mediterranean climate is characterized by a cool rainy winter season and a hot dry summer. The warmest months are July and August, when Banghāzī and Tripoli, in the Mediterranean zone, experience average monthly temperatures of 72° to 85° F (22° to 29° C) and 62° to 86° F (17° to 30° C), respectively. The coolest months are January and February; Banghāzī has winter monthly temperatures of 50° to 63° F (10° to 17° C), and Tripoli has 47° to 61° F (8° to 16° C). Al-ʿAzīzīyah on the Al-Jifārah Plain has recorded the world's highest shade temperature, about 136° F (58° C). Banghāzī receives an annual average rainfall of 10 inches (250 millimetres), and Tripoli receives 15 inches.

The amount of annual precipitation declines, and its variability increases, inland from the coast. Most of the rainfall occurs in only a few days between November and January. Steppe climate has less than four inches of rainfall annually, and Saharan desert climate has less than one inch. In the Sahara, 200 consecutive rainless days in a year have been recorded in many areas, and the world's

highest degree of aridity occurs at Sabhā, which averages only 0.4 inch of rainfall annually. The average January temperature at Sabhā is 52° F (11° C), and in July it is 88° F (31° C). Large daily ranges about these averages occur, however. The dry climate is exacerbated by the *ghibli*, a hot, arid wind that blows from the south several times a year, affecting the entire country. It is preceded by a short lull in the prevailing winds, which is followed by the full force of the *ghibli*. The wind carries large quantities of sand dust, which turns the sky red and reduces visibility to less than 60 feet. The heat of the wind is increased by a rapid drop of relative humidity, which can fall from 80 to 10 percent within hours.

The effect of the *ghibli* wind

Plant and animal life. In years of good rainfall the coastal plains are covered with herbaceous vegetation and annual grasses; the most noticeable plants are the asphodel (an herb of the lily family) and jubule. The northern area of the Akhḍar Mountains—where the influence of the Mediterranean is most apparent—supports low and relatively dense forest (or maquis) of juniper and lentisc. Annual plants are abundant and include species such as brome grass, canary grass, bluegrass, and rye grass. The forest becomes more scattered and stunted south of the mountain crest, and annual plants are less frequent. The Nafūsah Plateau has less plant life, and the natural vegetation of grassland lies between barren hills.

In the semiarid steppes vegetation is sparse; isolated drought-resistant plants grow in generally barren pockets. The species most commonly found are saltwort (a plant used in making soda ash) and spurge flax (a shrubby plant), while goosefoot, wormwood, and asphodel also are widespread. Annual grasses grow in the rainy season, and leguminous plants appear in years of good rainfall. Although rainfall is extremely low in the true desert zone and the vegetation cover is scant, some of the plants of the semiarid region penetrate into the occasional wadi valley, and date palms are grown in the southern oases.

Wild animals include desert rodents, such as the desert hare and the jerboa; hyenas; foxes, such as the fennec and the red fox; jackals; skunks; gazelles; and wildcats. The poisonous adder and krait are among the reptiles that inhabit the scattered oases and water holes. Native birds include the wild ringdove, the partridge, the lark, and the prairie hen. Eagles, hawks, and vultures are common.

Settlement patterns. Libya is divided into three regions—the western region (formerly Tripolitania province), the eastern region (formerly Cyrenaica province), and the southern region (formerly Fezzan province). Two-thirds of the population lives in the western region, the majority in Tripoli and other cities along the coast and on the Nafūsah Plateau. About 20 percent of the people live in the eastern region, primarily in Banghāzi and other coastal cities. The remainder of the population is concentrated in oasis towns in the southern region.

Libya's three regions

The vast majority of the rural population lives in coastal oases and is engaged in farming based on irrigation; plots of land are generally held in individual ownership and are often small. On the Nafūsah Plateau, where water is less readily available, a sophisticated agrarian system based on olive- and fruit-tree cultivation and associated livestock raising has evolved. In the eastern region, however, the traditional economy was based on nomadic and seminomadic pastoralism. Arable farming has largely been an adjunct of the pastoral system, with shifting dry-land cultivation rarely entailing sedentary farming. Land ownership is no longer exclusively tribal, but the system of tenancy contrasts sharply with that of ownership in the west. In southern Libya, isolated irrigated farming at the oases represents a third traditional economic system.

The most common mode of life in rural Libya is sedentary cultivation. In the traditional oases most farmers rely on irrigation, and water is raised from shallow wells either by the animal-powered *dalū* (a goatskin bag drawn by rope over a pulley) or, increasingly, by electric or diesel pumps. Landholdings in the oases are small and fragmented; the average five to seven acres (two to three hectares) per farm are generally divided into three or four separate units. On the coastal lowlands farmers normally live on their land and often have rights to graze stock and undertake shifting grain cultivation on communally held land. In both the east and the west, Arab farmers occupy large, formerly European estates, in which individual units range from 12 to 600 acres (5 to 250 hectares).

Pastoral nomadism is practiced in the arid and semiarid regions, particularly in the Akhḍar Mountains and surrounding steppe lands in the eastern region. Nomadic groups subsist primarily on their herds of sheep, goats, and camels, but also participate in the shifting cultivation of cereals. The Bedouins move south as soon as pasture appears in the fall and remain there until the ephemeral grasslands die and necessitate the return to the northern hill lands.

The village was originally an institution alien to Libya's tribal organization. Since the first Turkish occupation in the 16th century, towns and villages were developed by occupying powers mainly as military posts or administrative centres. Many village sites have been occupied for centuries; smaller settlements often began as collecting centres for the nomadic tribes during their summer residence in the oases or hill pastures. Berbers in the west, however, are thought to have retained a more or less continuous thread of settlement in their fortified nucleated villages in the western Nafūsah Plateau. In the southern oases, the villages served both as defense posts for the scattered communities and as watering and provisioning points on the trans-Saharan caravan routes. Modern development has led to the expansion of villages into towns and has fostered internal migration of the rural population from the land to the centres of settlement.

Urban settlement

The two main cities are Tripoli and Banghāzi. They contain more than one-third of the country's entire urban population and about one-fourth of the total population. Tripoli, with a metropolitan population of more than one million people, is the de facto political capital and the most important economic centre. Banghāzi, with half a million people, is the primary city in the eastern region. The modern cities have developed around the old city centres (medinas) with satellite towns and villages in surrounding oases. Shantytowns housing recent rural-to-urban migrants are also found near the two cities, and, although low-income housing is under construction, these areas present problems of sanitation and water supply.

Besides Tripoli and Banghāzi, there are 12 large towns. In the west Gharyān, Al-Khums, Miṣrātah, Tājūrā', Sūq al-Jum'ah, Janzūr, and Az-Zāwiyah are the major centres. In the east Ajdābiyā, Al-Marj, Al-Baydā', Darnah, and Tobruk (Ṭubruq) are of the same rank. These cities are primarily regional administrative and commercial centres with some light industry. Several have petroleum refineries and petrochemical industries.

The people. *Ethnic composition.* Almost all Libyans speak Arabic, the country's official language, and adhere to the Sunnite branch of Islām. They claim descent from the Bedouin Arab tribes of the Banū Hilāl and the Banū Sulaym, who invaded the Maghrib in the 11th century. In the eastern region the influence of the Sanūsīyah, a 19th-century militant Islāmic brotherhood, remains strong. Most of the Jewish and Italian minorities, long established in Tripolitania (the western region), left the country after the government seized their properties in 1970. Small numbers of Roman Catholic and Coptic Christians remain. The government's embrace of Arab nationalism has reduced Western influences, although English is still widely used as a second language in international business and politics. Nearly one-fifth of Libya's total population in the late 20th century was composed of foreign workers temporarily residing in the country. The tribe (*qabīlah*) was for long the basis of the social order in Libya, and eight out of every nine persons once resided in tribal domains.

The Berbers were the major original inhabitants of Libya. The main groups were the Luata, the Nefusa, and the Adassa. The Berbers lived in coastal oases and practiced sedentary agriculture. Most of them have been assimilated into Arab society except in the Nafūsah Plateau region, Awjilah, Hūn, Socra, and Zuwārah. The Berbers speak their own Hamitic language but have adopted the Arabic alphabet. Many are bilingual in Berber and Arabic; most are Muslims.

Origins of the Arab population

The Arab invasions began in the 7th century. The initial Arab incursions were essentially military and had little effect upon the composition of the population. The Banū Hilāl invasion of 1049 and succeeding attacks of the Banū Sulaym later in the 11th century, however, brought migrations of large pastoral nomadic tribes from the eastern Arabian peninsula.

The Banū Sulaym were composed of four main groups—the Banū Hebib, the 'Awf, the Debbab, and the Zegb. The Hebib settled in Cyrenaica, while the others went into Tripolitania. After the establishment of tribal groups, Libya underwent a period of disorder and tribal feuding, which was augmented by the incursion of other Arab adventurers from Egypt. Toward the close of the period of anarchy, the Debbab group took control of much of Tripolitania. By the 20th century about 97 percent of Libya's inhabitants were Arabic-speaking Muslims of mixed Arab and Berber descent.

Several other social groups exist alongside the tribal unit. They are the sharīfs (holy tribes), who came originally from the Fezzan; the marabouts (dervishes who are credited with supernatural powers), who infiltrated from Saguia el Hamra in what is now Western Sahara; and the Koulouglis, who are descended from the Janissaries (elite Turkish soldiers) and the Berber and Christian slave women with whom they interbred.

The sharīfs claim direct descent from the Prophet Muḥammad. Their alleged blood relationship with the Prophet gives them a powerful standing in Muslim society, where they are looked upon as holy men with divine powers of foresight. Extensive tracts of land are found under sharif control in all the oases of western Libya. Marabout tribes are descended from holy men who also claimed relation to Muḥammad. They founded their religious devotions upon an ascetic life manifested in their existence as hermits. In areas where their teachings and way of life made them acceptable to the local inhabitants, they settled and founded tribes pledged to the pure way of life.

Minority population groups

The Koulouglis have served since Turkish times as a secretarial class in several areas and are often concentrated in and around villages and towns. They speak Arabic and practice Islām.

The trans-Saharan slave trade, which continued during Turkish times, introduced black Africans and their cultures into many of the tribes, especially in the Fezzan and in Tripolitania. Their languages are those of the central Sahara and the eastern Sudan; most also speak Arabic and have adopted Islām.

Small groups of Tuareg tribespeople are found in the southwest, especially at the Ghadāmis and Ghāt oases. Traditionally nomadic, they are gradually assuming a sedentary life-style. Isolated Teda (Tubu) communities of the southeast are slowly gravitating toward the north and the Al-Kufrah oasis in search of employment.

Demographic trends. Libya has one of the highest rates of population growth in Africa, averaging more than 3 percent annually for much of the second half of the 20th century. The huge influx of foreign workers into the country since the 1960s accounts for part of this rapid growth, but Libya's annual rate of natural increase (birth rate minus death rate) has also been one of the highest averages in Africa for much of the late 20th century. Death rates have declined to near the world average, but birth rates remain high. Almost one-half of the population is 15 years of age or less despite high rates of infant mortality—the highest in North Africa—portending continued high birth rates and rapid growth well into the 21st century.

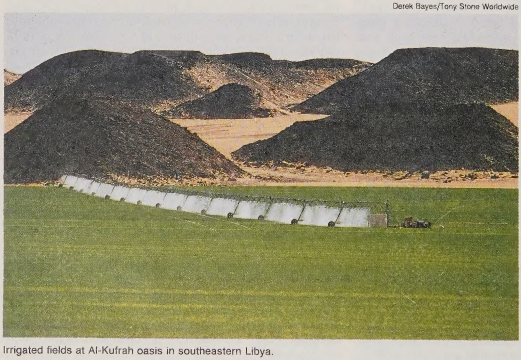
The economy. Oil revenues are Libya's main source of income. During the 1980s, oil accounted for two-thirds of the national income and nearly 99 percent of export earnings, although it employed less than 10 percent of the labour force. The government exerts strong control over the economy. The petroleum industry was nationalized in the 1970s; state trade unions and industrial organizations run most other industries and utilities. To reduce the country's heavy dependence on oil, economic policy has emphasized agricultural and industrial development. Declining oil revenues during the 1980s, however, led to frequent revisions and delays in planned developments. In 1988, domestic reforms liberalized economic policy and encouraged private enterprise.

Libya's per capita income is the highest in Africa, but its population is relatively small. A shortage of labour has led to a large number of foreign workers—mostly from other North African countries, western Africa, and the Middle East—in agriculture and industry. Since the mid-1980s, however, Libya has attempted to reduce the number of foreign workers because of the huge drain that their remittances to their respective countries has caused on Libya's reserves of foreign exchange.

Resources. Petroleum is Libya's most important mineral resource. First discovered in 1956 near the Algerian border, it has since been located mainly in the Surt Basin. The major oil fields are Zaltan, Āmāl, and Intiṣār A in the vicinity of Banghāzī; the Dahra field is located near Miṣrātah, and the Sarir field is near Darnah. Deposits have been located near Ghadāmis on the western border, Murzuq in the southwest, and the Al-Kufrah oasis in the southeast. Exploration for new deposits has concentrated on the western region and offshore, where a large field was discovered northwest of Tripoli in 1988. Libya's proven oil reserves represent almost half of Africa's, or about 2 percent of the world's. Libyan crude oil is low in sulfur content and therefore causes less corrosion and less pollution than most crude oils. The deposits are associated with natural gas.

The first pipeline was constructed from the Zaltan field to Marsā al-Burayqah in 1961. Since then additional lines

Derek Bayes/Tony Stone Worldwide



Irrigated fields at Al-Kufrah oasis in southeastern Libya.

have been built from Dahra to As-Sidrah and to Ra's al-Unūf, and other pipelines connect the Tobruk field to Marsā al-Ḥarīqah and the Intiṣār A field to Az-Zuwaytīnah. Refineries are located at Az-Zāwiyah, Miṣrātah, Ra's al-Unūf, and Tobruk. A natural-gas pipeline runs parallel to the oil pipeline from Zaltan. The gas liquefaction plant at Marsā al-Burayqah is the world's largest.

Libya is usually among the world's dozen largest producers of oil. Sales to Europe were enhanced by the closure of the Suez Canal between 1967 and 1975. During the 1980s, however, production and revenues declined because of an increased supply of oil on the world market. Libya has concluded barter agreements with some European and African countries to exchange petroleum for goods and services. Only a small percentage of the Libyan labour force is employed by the oil industry, along with a few thousand foreign workers.

Other mineral resources are limited. There are important deposits of natron (hydrated sodium carbonate) in the Fezzan and of potash in the Surt Desert near Marādah. The iron ore deposits at Shāṭī', although low in iron content, supply the iron-steel complex at Miṣrātah. Marine salt is produced in Tripolitania, where there are also small deposits of gypsum, manganese, and lignite coal. Sulfur has been found in the Surt Desert, and there are scattered deposits of chalk, limestone, and marble that are quarried for the growing construction trade.

The arid climate supports few biological resources except for the grasslands of the Akhḍar Mountains and the Nafūsah Plateau, which are valuable for grazing. There are no hydroelectric resources, and oil represents the only domestic means of producing electricity thermally.

Agriculture, forestry, and fishing. Agriculture is limited by the environment and by shortages of labour. Only about 1 percent of the total land area is cultivated, mostly on the Al-Jifārah and Barce plains, and about one-tenth of that is irrigated. An additional 8 percent of the land is in pasture. Agricultural development by land reclamation and irrigation is a government priority. The largest projects are at the Al-Kufrah oasis, Tāwurghā', and Sarir, on the Al-Jifārah Plain, and in the Akhḍar Mountains. The Great Man Made River project, under construction during the late 20th century, is the most ambitious. Pipelines will carry water from wells in the southern Sahara to Tripoli, Surt, Banghāzi, Tobruk, and the Al-Kufrah oasis.

Cereals are the major crops throughout the country. Barley is the chief cereal grown because it adapts well to different climates and soils. Wheat is grown primarily on the eastern and western plateaus, and sorghum is raised in the Fezzan. Olive plantations were introduced by the Italians on the Al-Jifārah Plain and on the Nafūsah Plateau, and there are smaller olive groves in the east. Orchards of almonds, citrus fruit, apricots, and figs occur on small and large farms and on small, crowded plots in the oases. Dates are the principal crop of the southern oases. Grapes, broad beans, and peanuts also are grown. Tobacco is raised in Tripolitania.

Animal husbandry is important in Cyrenaica, where the herds are raised on communal grazing lands. Livestock includes sheep, goats, cattle, camels, horses, mules, and donkeys. Animals are raised for their milk, meat, and hides or for their services as a means of transportation. Cattle often serve as draft animals. A small amount of milk is produced commercially, and commercial poultry farms are developing around the larger cities.

Less than 1 percent of the land is in forests. Before the 1950s the only wooded area in Libya was the region of scrub brush in the Akhḍar Mountains. Since then, the government has launched a massive afforestation program. Between 1957 and 1964, 27 million acacia, eucalyptus, cypress, cedar, and pine trees were planted in Tripolitania.

There is little demand in Libya for fish, and most fishing is carried out off the Tripolitanian coast by Libyan, Tunisian, Greek, and Maltese fishermen. The catch includes tuna, sardines, and red mullet. Sponge beds are also important. The sponges are harvested mainly by Greeks who are licensed by the Libyan government.

Industry. Industrial development is limited. Most factories are located in Tripoli and Banghāzi and are managed by Arabs. The industrial work force is small: many of the factories employ fewer than 100 persons. A majority of the factories are engaged in the manufacture of processed food, beverages, cement, leather goods, and textiles. The government has monopolies for the processing of tobacco, salt, and esparto grass. There are also oil-related industries, which produce steel drums, tanks, and pipe fittings; and petrochemical plants are located near refineries.

The production of electricity for public consumption is a government monopoly. There are also private plants, such as the 25,000-kilowatt facility built by an oil company at Marsā al-Burayqah. The total installed capacity, all thermal plants powered by oil, grew more than sevenfold during the 1970s.

Finance and trade. Financial services are headed by the Central Bank of Libya, which supervises the banking system, regulates credit and interest policies, and promotes the transformation of foreign banks into Libyan institutions. The Libyan Arab Foreign Bank has made some investments, primarily in Italy.

Since 1963 Libya has usually enjoyed a favourable balance of trade. Almost all its exports are represented by crude petroleum, but agricultural products and hides and skins also are exported. Imports consist of equipment for the oil and construction industries, farm machinery, consumer goods, and agricultural products. Most of the country's imports are purchased from Italy, Germany, the United Kingdom, France, and Japan. Exports, almost all petroleum, usually go to Italy, Germany, Spain, France, Greece, and Turkey. Foreign trade

Transportation. The main road is the 1,100-mile national coastal highway between the borders of Tunisia and Egypt. The Sabhā road runs from the coastal highway at Al-Qaddāḥiyah south and southwest to Ghāt near the Algerian border. Other national roads run from Tripoli to Ghāt and Sabhā and from Ajdābiyā to Al-Kufrah. About half the roads are paved. The two railroads that served Tripoli and Banghāzi were closed in the late 1960s.

Tripoli is the main port, and Tripoli and Banghāzi together handle most of the country's maritime trade. Tripoli handles the bulk of the imports, particularly those associated with the oil industry and the booming trade in consumer goods. Tobruk is the third most important port.

Petroleum is shipped from As-Sidrah, Marsā al-Burayqah, Tobruk, and Az-Zuwaytīnah. Miṣrātah, Zuwārah, and Al-Khums have been developed as fishing ports. Libya's merchant fleet is modest, and most oil is shipped in foreign vessels.

International airports include those at Tripoli and at Baninah, outside of Banghāzi. Domestic airfields include those at Sabhā, Al-Bayḍā', Ghadāmis, and Ghāt. The Libyan Arab Airlines and foreign airlines operate domestic flights and services to countries in the Middle East and North Africa and to several nations in Europe. There are also domestic flights operated by the oil companies.

Administration and social conditions. *Government.* In September 1969 the monarchy of Idris I was overthrown and the constitution suspended in a military coup d'état. In 1977 the 12-member Revolutionary Command Council formed after the coup was replaced by the General Secretariat of the General People's Congress (GPC) with Colonel Muammar al-Qaddafi as secretary-general. He resigned the post in 1979 but remained in effect ruler of the country and head of the revolution. A General People's Committee has replaced the original revolutionary cabinet, the Council of Ministers; each of the committee's members is the secretary of a department. In 1988 all but 2 of the 19 secretariats were moved from Tripoli, most of them to Surt. The General People's Congress serves as a parliament.

The country is divided into 25 *baladīyāt* (municipalities), which in turn are subdivided into zones. The citizens of each zone are members of the Basic Popular Congress (BPC), each headed by an appointed revolutionary or leadership committee. Citizens are also members of the Arab Socialist Union (ASU), the mass political organization and only legal political party. In the late 1980s, sweeping domestic reforms replaced the army and police forces with the Jamahiri Guards.

Justice. The judicial system consists of the Supreme Court, located in Tripoli, with five chambers of five justices each; it is the final court of appeal. The regional courts of appeal, located in Tripoli, Banghāzī, and Sabhā, each with three justices, hear appeals from the courts of first instance and the summary courts, the basic judicial unit, each with one justice per court. Separate religious courts were abolished in 1973, and all judicial courts base their rulings on Libyan law, founded on the basis of the Sharī'ah (Islāmic law). In 1989 the People's Courts, which try political detainees, and the People's Prosecution Bureau replaced the revolutionary courts.

Education. Public education is free and primary education is compulsory for both boys and girls. Arabic is the language of instruction at all levels. The school system is composed of a six-year primary level, a three-year intermediate and vocational level, and a three-year secondary and advanced vocational level. There are also Qur'ānic schools, which are financed by the government. About three-fourths of the adult population is literate. In order to increase the literacy rate the government has also sponsored an adult educational program.

Higher education is offered by the state institutions of the University of Libya, subdivided in 1973 into Al-Fateh University (Tripoli) and Garyounis University (Banghāzi). Advanced religious training is obtained at a branch of the university at Al-Bayḍā'. Libyan students also study abroad in Egypt, Europe, and the United States.

Health and welfare. The chief health problems are typhoid, leishmaniasis, rabies, meningitis, and schistosomiasis (a parasitic infestation of the liver or intestines). The incidence of malaria has declined, but gastroenteritis and tetanus remain major diseases.

Medical and hospital care and medicines are free. Most care is available in hospitals and at outpatient or specialized-care facilities or clinics.

Schools for medicine and dentistry opened in the 1970s, but the rapid expansion of facilities necessitated the continued hiring of expatriate staff. The number of medical personnel has been increased sharply. Some graduate medical students study abroad.

The National Social Insurance Institute operates social security programs. Workers covered by government insurance programs receive medical examinations and treatment, maternity benefits, and dental care. There are also old-age pensions and payments for incapacity or death as a result of work-related accidents.

Welfare programs

Cultural life. Cultural differences between the provinces are important. The population of the west is far more cosmopolitan than that of the east and includes a higher proportion of people with Berber, Sudanese African, and Turkish origins. Cyrenaica was profoundly affected by the teachings of the 19th-century Sanūsiyah, an Islāmic brotherhood, which had little influence in the west and south.

Since the 1969 coup, life-styles have been strongly influenced by the revolutionary government's restructuring of national and local government and its efforts to reduce the influence of traditional tribes. The government has also brought women out of traditional seclusion and into the mainstream of the revolutionary socialist society.

Libyan culture centres on folk art and traditions, which are highly influenced by Islām. The traditional arts of weaving, embroidery, metal engraving, and leatherwork rarely depict people or animals because of the Islāmic prohibition against such representation. The dominant geometric and arabesque designs are best presented in the stucco and tiles of the Karamanli and Gurgi mosques of Tripoli. Surviving traditions are represented by festivals, horse races, and folk dances.

Nonreligious literature has developed largely since the 1960s; it is nationalistic in character but reveals Egyptian influences. The arts are supported by the government through the Ministry of Information, the Ministry of Education and National Guidance, and the Al-Fikr Society, a group of intellectuals and professionals.

Cultural institutions

Libraries include the Government Library and the Archives in Tripoli, the Public Library in Banghāzī, and the university libraries. The Department of Antiquities is responsible for the Archaeological Museum, the Leptis Magna Museum of Antiquities, the Natural History Museum, and the Sabratha Museum of Antiquities, all in the western region, and the archaeological sites of Ptolemais and Appolonia in the eastern region. The Sabhā Museum contains exhibits of ancient remains of the former Fezzan region.

The government controls broadcasting and the press. Newspapers and periodicals are published by the Jamahiriya News Agency (JANA), government secretariats, the Press Service, and trade unions. JANA publishes a daily newspaper, *Al-Fajr al-Jadīd* ("New Dawn"), in Tripoli. Radio broadcasts from Tripoli and Banghāzī are in Arabic and English; the national television service broadcasts in Arabic, with limited hours in English, Italian, and French. Three publishers of general and academic books are located in Tripoli. (Mu.B./G.L.F.)

For statistical data on the land and people of Libya, see the *Britannica World Data* section in the BRITANNICA BOOK OF THE YEAR.

HISTORY

The present borders of Libya contain a huge territory the size of the U.S. states of Texas, Oklahoma, Louisiana, and Mississippi combined. Largely desert with some limited potential for urban and sedentary life in its northwestern and northeastern corners, Libya has never been populous nor a power centre. Like its neighbour Algeria, Libya's very name is a neologism, created by the conquering Italians early in the 20th century. Like Algeria, much of Libya's earlier history—not only in the Islāmic period but even before—reveals that both the western and eastern provinces were more closely linked with neighbouring territory, with Tunisia and Egypt respectively. Even during most of the Ottoman times the country was divided into two parts, one linked to Tripoli in the west and the other to Banghāzī in the east.

Libya thus owes its present unity as a state less to earlier history or geographic constants than to several recent factors: the unifying effect of the Sanūsiyah movement since the 19th century; Italian colonialism from 1911 until after World War II; an early independence by default, since the great powers could agree on no other solution; and the discovery of oil in commerical quantities in the late 1950s. Yet, the Sanūsīyah is based largely in the eastern region of Cyrenaica and has never really penetrated the more populous western region of Tripolitania. Italian colonization was brief and brutal. Moreover, most of the hard-earned gains in infrastructure implanted in the colonial period were destroyed by contending armies during World War II. Sudden oil wealth has been both a boon and a curse as changes to the political and social fabric, as well as to the economy, have accelerated. This difficult legacy of disparate elements and forces helps to explain the unique character of modern Libya. (L.C.Br.)

Ottoman rule. Part of the Ottoman Empire from the early 16th century, Libya experienced autonomous rule (similar to that in Ottoman Algeria and Tunisia) under the Karamanli dynasty from 1711 to 1835. In the latter year the Ottomans took advantage of a dispute over the succession and local disorder to reestablish direct administration. For the next 77 years the area was administered by officials from Istanbul and shared in the limited modernization common to the rest of the empire. In Libya the most significant event of the period was the creation (1837) of the Sanūsiyah (Sennusiyah), an Islāmic order, or fraternity, that preached a puritanical form of Islām, giving the people instruction and material assistance and so creating in them an added sense of unity. The first Sanūsī *zāwiyah,* or lodge, in Libya was established in 1843 near the ruins of Cyrene in eastern Cyrenaica. The order spread principally in that province but also found adherents in the south. The Grand Sanūsī, as the founder came to be called, moved his headquarters to the oasis of Jaghbūb near the Egyptian frontier, and in 1895 his son and successor, Sidī Muḥammad Idrīs al-Mahdī, transferred it farther south into the Sahara to the oasis of Al-Kufrah. Though the Ottomans welcomed the order's opposition to the spread of French influence northward from Chad and Tibesti, they regarded with suspicion the political in-

The Sanūsiyah

fluence it exerted within Cyrenaica. In 1908 the Young Turk revolution gave a new impulse to reform; in 1911, however, the Italians, with banking and other interests in the country, launched an invasion of Libya.

The Ottomans sued for peace in 1912, but Italy found it more difficult to subdue the local population. Resistance to the Italian occupation continued throughout World War I. After the war Italy considered coming to terms with nationalist forces in Tripolitania and with the Sanūsīyah, who were strong in Cyrenaica. These negotiations foundered, however, and the arrival of a strong governor, Giuseppe Volpi, in Libya and a Fascist government in Italy (1922) inaugurated an Italian policy of thorough colonization. The coastal areas of Tripolitania were subdued by 1923, but in Cyrenaica Sanūsī resistance, led by 'Umar al-Mukhtār, was maintained until his capture and execution in 1931.

Italian colonization. In the 1920s and '30s the Italian government expended large sums for developing towns, roads, and agricultural colonies for Italian settlers. The most ambitious effort was the program of Italian immigration called "demographic colonization," launched by Benito Mussolini in 1935. As a result of these efforts, some 150,000 Italian settlers were established in Libya (about 18 percent of that country's total population) by the outbreak of World War II.

These colonizing efforts and the resulting economic development of Libya were largely destroyed during the North Africa campaigns of 1941–43. Cyrenaica changed hands three times, and by the end of 1942 all of the Italian settlers had been withdrawn. Cyrenaica largely reverted to pastoralism. Somewhat more of the economic and administrative development achieved by Italy survived in Tripolitania; however, Libya by 1945 was impoverished, underpopulated, and also divided into regions—Tripolitania and Cyrenaica—of differing political, economic, and religious traditions.

Libyan independence

Independence. The future of Libya gave rise to long discussions after the war. In view of the contribution to the fighting made by a volunteer Sanūsī force, the British foreign minister pledged in 1942 that the Sanūsis would not again be subjected to Italian rule. During the discussions, which lasted four years, suggestions included an Italian trusteeship, a United Nations trusteeship, a Soviet mandate for Tripolitania, and various compromises. Finally, in November 1949, the UN General Assembly voted that Libya should become a united and independent kingdom no later than Jan. 1, 1952.

A constitution creating a federal state with a separate parliament for each province was drawn up, and the pro-British head of the Sanūsīyah, Sidi Muḥammad Idrīs al-Mahdī as-Sanūsī, was chosen king by a national assembly in 1950. On Dec. 24, 1951, King Idrīs I declared the country independent. Political parties were prohibited, and the king's authority was fundamental. Though not themselves Sanūsīs, the Tripolitanians accepted the monarchy largely in order to profit by the British promise that the Sanūsis would not again be subjected to Italian rule. King Idrīs showed a marked preference for living in Cyrenaica, where he built a new capital on the site of the Sanūsī *zāwiyah* at Al-Bayḍā'. Though Libya joined the Arab League in 1953 and in 1956 refused British troops permission to land for the Suez Canal expedition, during that time the government in general adopted a pro-Western point of view in international affairs.

The discovery of oil. In 1959 Libya changed abruptly from a pauper state, dependent on international aid and the rent from U.S. and British air bases, to an oil-rich monarchy. The discovery of major petroleum deposits in both Tripolitania and Cyrenaica assured the country of income on a vast scale. Soon after the discovery there was an enormous expansion of all government services and also of construction projects, and a corresponding rise in the economic standard and the cost of living.

On Sept. 1, 1969, a group of young army officers led by Colonel Muammar al-Qaddafi deposed the king and made Libya a republic. The new regime, passionately pan-Arab, broke the monarchy's close ties to Britain and the United States and also began an assertive policy that led to higher oil prices and to 51 percent Libyan participation in oil company activities and in some cases to outright nationalization.

Plans for Arab unity

Qaddafi's regime. Equally assertive in plans for Arab unity, Libya obtained at least the formal beginnings of unity with Egypt, The Sudan, and Tunisia, but these and other such plans failed as differences arose among the governments concerned. Qaddafi's Libya maintained a strong interventionist orientation on the Palestine issue and in support of other guerrilla and revolutionary organizations in Africa and the Middle East, all of which provoked considerable antipathy from the established governments that were threatened by such groups. In July–August 1977 hostilities broke out between Libya and Egypt, and as a result many Egyptians working in Libya were obliged to return home. Indeed, in spite of expressed concern for Arab unity, the regime's relations with most Arab countries were poor. Qaddafi signed a treaty of union with Morocco's King Hassan II in August 1984, but Hassan abrogated the treaty in August 1986.

The regime, under Qaddafi's ideological guidance, continued to introduce innovations. On March 2, 1977, the General People's Congress declared that Libya was to be known as the People's Socialist Libyan Arab Jamahiriya (the latter term is a neologism meaning "government through the masses"). By 1981, however, a drop on the world market in the demand and price for oil was beginning to hamper Qaddafi's efforts to play a strong regional role. Ambitious efforts to radically change Libya's economy and society slowed, and there were signs of domestic discontent. Libyan opposition movements launched sporadic attacks against Qaddafi and his military supporters but met with arrest and execution. (N.B./L.C.Br.)

Libya's relationship with the United States, which had been an important trading partner, deteriorated in the early 1980s as the U.S. government increasingly protested Qaddafi's support of Palestinian Arab terrorists. An escalating series of retaliatory trade restrictions and military skirmishes culminated in a U.S. bombing raid of Tripoli and Banghāzī in April 1986. U.S. claims that Libya was producing chemical warfare materials have been another source of tension since 1988. Libya has sought throughout the 1970s and '80s to dominate neighbouring Chad or at least to control the mineral-rich Aozou strip situated near the disputed border of the two states. These efforts have produced intermittent warfare in Chad and confrontation with both France and the United States. In 1987 Libyan forces were humiliatingly bested by the more mobile troops of Chad. Diplomatic ties with Chad were restored in October 1988. Libya denied involvement in a December 1990 coup in Chad. (L.C.Br.)

For later developments in the history of Libya, see the BRITANNICA BOOK OF THE YEAR.

Morocco

Morocco (official name Kingdom of Morocco, Arabic: Al-Mamlakah al-Maghribīyah), is situated in northwestern Africa directly across the narrow Strait of Gibraltar from Spain. It is the only African country with coastal exposure to both the Atlantic Ocean and the Mediterranean Sea. Because of its lack of natural harbours, its rugged mountainous interior, and its distance throughout its history from imperial centres in the east, Morocco remained relatively isolated until the early 20th century. This enabled it to preserve a proud traditional character, which is a rich blend of Berber, Arab-Islāmic, and African cultures. Those traits have been joined by a more recent infusion of European cultural elements—a legacy of the colonial period (1912–56) when Morocco was a protectorate of France and Spain. Morocco gained independence in 1956 and has been a constitutional monarchy since 1962. Soon after independence, the Moroccan government began to press a historical claim to the Spanish Sahara (now Western Sahara) directly to its south. In 1975, when Spain withdrew from this region, Morocco annexed the northern half and then added the remainder in 1979—despite protests over the annexations from the international community and from nationalist groups inside the territory.

With the Western Sahara's 97,344 square miles (252,120 square kilometres), Morocco occupies a total area of 274,461 square miles (710,850 square kilometres). Key sectors of the Moroccan economy include agriculture, mining, tourism, and light manufacturing.

Casablanca is Morocco's largest city, primary seaport, and commercial and industrial hub. Rabat is the capital and second largest city.

PHYSICAL AND HUMAN GEOGRAPHY

The land. *Relief.* Most of Morocco lies at high altitudes; the average elevation above sea level is about 2,600 feet (800 metres). Two chains of mountains, one, called the Rif, along the northern coast and the other, the Atlas, in the centre, divide eastern Morocco from Atlantic Morocco. These two parts of the country are connected by the narrow Taza Gap in the northeast as well as by roads that follow older traditional routes. The Atlas and Rif mountains were formed during the Tertiary Period (66.4 to 1.6 million years ago) by the folding and uplifting of sediment that had accumulated in the Tethys Sea, which, at that time, bordered the northern coast of the continent of Africa.

The Rif Mountains are geologically part of the cordilleras (mountain chains) reaching southward from the Iberian Peninsula of Europe, from which Africa was separated only after the Tertiary. The crescent-shaped range rises abruptly from a narrow Mediterranean coastal plain. Most of the limestone peaks in the Rif Mountains surpass 4,900 feet and rise to 8,058 feet (2,456 metres) at Mount Tidirhine.

The Atlas Mountains

The Atlas Mountains comprise three distinct chains. The High Atlas (Haut Atlas), 460 miles (740 kilometres) long, begins as small hills at the edge of the Atlantic, rises rapidly to more than 6,500 feet, and reaches its highest point at Mount Toubkal, which is 13,665 feet (4,165 metres) in elevation. The Middle Atlas (Moyen Atlas) trends away from the High Atlas in a northerly direction, rising to 10,958 feet (3,340 metres) at its crest. The Anti-Atlas extends southwestward from the High Atlas to the Atlantic.

(A.La./W.D.Sw.)

East of the Rif and Atlas mountains is the Moulouya basin, a semiarid lowland created by the eroding force of the Moulouya River. Farther east are the High Plateaus (Hauts Plateaux) of eastern Morocco, extensions of landforms in neighbouring Algeria, which lie roughly between 3,900 and 4,250 feet in elevation. The arid regions to the south and southeast of the Atlas are known collectively as the Sahara, the Arabic word for "deserts." The narrow transitional band is referred to as the pre-Sahara.

Atlantic Morocco consists of plains formed of relatively fine sediments and plateaus of coarser deposits. The Sebou basin, which lies in the northwest between the Rif Mountains and a line running roughly from Rabat to Fès, is a vast alluvial plain. Its agricultural heart is known as the Rharb Plain. South of the Rabat-Fès line, between the Atlas and the Atlantic Ocean, are a series of high plains known collectively as the Moroccan Plateau. These include the Saïs Plain near Fès and Meknès, the Tadla Plain to the northeast of Marrakech, the Haouz Plain west of Marrakech, and the broad Chaouïa, Doukkala, and Abda plains south of Casablanca. Between the High Atlas and Anti-Atlas ranges is the Sous valley, formed by the river of the same name. Morocco's coastline is regular and has few natural harbours. Before modern ports were constructed, sandbars and rocky reefs offshore made navigation difficult.

Drainage. Morocco's mountains capture significant amounts of rain and snow on their windward slopes from storms coming in off the North Atlantic and give rise to numerous perennial watercourses. Indeed, the country has the most extensive stream network in North Africa. Most streams arise either on the western slopes of the Atlas Mountains or on the southern slopes of the Rif Mountains and flow westward into the Atlantic Ocean. The Sebou is approximately 280 miles long and has the largest volume of any Moroccan river. With its tributaries, it accounts for roughly 45 percent of Morocco's surface water resources. The Oum er-Rbia is Morocco's longest river, approximately 345 miles in length. The Moulouya is the only major river flowing into the Mediterranean Sea; it originates on the eastern slopes of the Middle Atlas approximately 320 miles from its mouth, which lies near the Algerian frontier. The northern slopes of the Rif are drained by several short streams that also empty into the Mediterranean. Several minor streams originate on the dry eastern slopes of the High Atlas and flow into the Sahara: the Guir, the Rheris, the Ziz, the Dadès, and the Drâa. Although their volume is small, they have cut impressive gorges. Since the 1930s Morocco's streams have progressively been dammed for irrigation, hydroelectricity, and flood control.

Traditional soil names

Soils. A traditional classification system is usually used to characterize Morocco's major soil types. A dark clay-marl soil known as *tirs* is found on the Chaouïa, Doukkala, and Abda plains. It produces good yields of wheat and barley when precipitation is sufficient and can retain enough moisture to support summer pasture. Another major soil type is *hamri*, a light reddish siliceous soil found throughout the Saïs Plain surrounding Meknès and Fès. It supports productive vineyards and can also produce good cereal yields; it has poor moisture retention, however. *Dhess* is the main soil type of the Sebou basin. A silt-rich alluvial soil, it provides the foundation for much of Morocco's modern irrigated agriculture. Other major soil types, less suitable for agriculture, are *rmel*, a sandy soil found in the Mamora Forest region east of Rabat and along much of the northern coast, and *haroucha*, a rocky soil found throughout Morocco's semiarid regions.

Climate. Most of Morocco north of the Western Sahara, particularly along the coasts, experiences a typical Mediterranean climate, with mild wet winters and hot dry summers. The rainy season generally extends from October to April. Torrential downpours occasionally produce devastating floods, but overall several factors act to reduce the country's rainfall. Morocco is on the southern margins of the mid-latitude tract of frontal storm systems that regularly traverse the North Atlantic. As a result, rainfall levels are relatively low and gradually decrease from north to south. High-pressure ridges, moreover, periodically develop offshore during the rainy season, shifting storms to the north. If these ridges persist for extended periods, drought results. The cold Canary Current off the western shores also induces atmospheric stability and further decreases the potential for precipitation.

In the broad coastal lowlands, average annual rainfall diminishes progressively from about 32 inches (800 millimetres) on the northern Rharb Plain to less than 8 inches in the Sous valley. Farther south, beyond the Anti-Atlas, semiarid conditions quickly fade into desert. Elevation strongly influences this prevailing pattern, however, with significantly higher amounts of precipitation occurring in the mountains. The central Rif, for example, receives more than 80 inches of precipitation annually, and even the High Atlas, much farther south, receives some 30 inches. Above approximately 6,500 feet, snow is common, and the snowpack lingers in the highest elevations until late spring or early summer. Morocco's mountains create a significant rain shadow—directly east of the mountains, in the lee of the prevailing winds, desert conditions begin abruptly.

In the lowlands near the coast, summer heat is reduced by cool onshore breezes. Average daily summer temperatures in the coastal cities range from 64° to 82° F (18° to 28° C). In the interior, however, daily highs frequently exceed 95° F (35° C). In late spring or summer, the *chergui*—a hot dusty wind from the Sahara—can sweep over the mountains into the lowlands, penetrating even to coastal cities. Temperatures rise dramatically, often exceeding 105° F (41° C). If crops have not been harvested, damage can be extensive from the hot desiccating effects of the *chergui*. In winter, the marine influence again moderates temperatures in the coastal regions. Average daily winter temperatures range from 46° to 63° F (8° to 17° C). Away from the coast, temperatures drop significantly—occasionally below the freezing point.

The *chergui*, a local wind

Plant and animal life. Outside the desert areas, the vegetation of Morocco resembles that of the Iberian Peninsula. In the more humid mountainous areas, there are still

extensive forests, with cork oak, evergreen oak, and deciduous oak on the lower slopes and fir and cedar at higher elevations, particularly in the Middle Atlas. In drier mountain areas open forests of thuya, juniper, and Aleppo and maritime pine are common. East of Rabat is the extensive cork oak Mamora Forest. Eucalyptus, originally from Australia, was introduced by French authorities during the colonial period for reforestation. Since independence, the Moroccan government has established several large plantations of this tree surrounding the Mamora Forest. In the rugged highlands south of Essaouira, vast open forests of argan (Morocco ironwood) are found. This tree, which is unique to southwestern Morocco, has a hard fruit that produces a prized cooking oil.

In Morocco, as is common throughout the western Mediterranean region, centuries of human activity have considerably altered the natural vegetation. On many lower mountain slopes, cutting, grazing, and burning have produced an often dense cover of maquis, or scrub growth, characterized by various associations of wild olive, mastic tree, kermes oak, arbutus, heather, myrtle, artemisia, cytisus, broom, and rosemary. In the arid interior plains, the dwarf palm, jujube tree, esparto grass, and Barbary fig (introduced from the Americas by way of Spain in the 16th century) cover vast areas. East of the mountains, desert begins abruptly and there is little vegetation. The date palm was introduced to Morocco at a very early period and is extensively cultivated in the desert oases.

Demise of large game animals

Large game has been progressively eliminated in Morocco since Roman times, when lions and elephants were still abundant. Both have long since disappeared. The gazelle is still seen occasionally in the south, as are the mouflon (a wild sheep) and fennec (a type of fox) in the Atlas region. With government protection, the macaco (a type of monkey, often called the Barbary ape) now flourishes in the forests of the Middle Atlas. However, the richest fauna in Morocco today is the birdlife. Large migratory birds that sojourn in Morocco include the stork, which picturesquely builds its nests on city ramparts and mosque rooftops, and the flamingo, pelican, and cattle egret.

Settlement patterns. Settlement patterns in Morocco correspond loosely to the three major environmental zones: the coastal plains and plateaus, the highland areas of the Rif and Atlas mountains, and the desert south of the Atlas.

The coastal plains and plateaus contain three-fourths of the country's population, including most of its cities, and virtually all of its modern commercial agriculture. This is the Arabic-speaking part of Morocco. It has been the home of settled farmers and seminomadic tribes for many centuries. Most of the rural population in this region lives in villages of single-story cubical adobe or tamped-earth houses. The main form of agriculture is rain-fed cereal production, with wheat and barley as the main winter crops. This is supplemented by stock raising and summer gardens producing pulses (legumes) and fresh vegetables.

The highland areas of the Rif and Atlas contain about a fifth of the Moroccan population and are the bastion of Berber culture. Villages have a distinctive defensive aspect and are commonly perched on hillsides or hilltops. Dwellings are tightly clustered, are often multistoried, and are built of stone, adobe, or tamped earth. Level land is rare, and terraces are constructed to create arable fields along the nearby valley walls. The main subsistence crops are barley as a winter crop and corn (maize) and fresh vegetables as summer crops. Many villages specialize in cash cropping of a nut or fruit well-adapted to the local microclimate, such as olives, almonds, walnuts, figs, apples, cherries, apricots, or plums. Stock raising of sheep or goats often supplements village agriculture. Some groups practice transhumance, migrating with their flocks or herds to summer pastures at higher elevations or winter pastures at lower elevations, living in dark-coloured *khaymas* (tents) woven of goat hair.

The pre-Saharan and Saharan areas south of the Atlas contain less than 5 percent of Morocco's population. A large proportion of the population is of mixed black African descent, and many groups speak Berber. Virtually all settlement is in oases. Most oases are created artificially either by diversion of water from streams or by importation of water from often distant mountains via underground tunnels (*qanāts*). Dates are the main crop, grown as both a subsistence and a cash crop. In the date palm understory, alfalfa, corn, wheat, and barley, as well as fresh vegetables and other crops, are grown. Much settlement in this region is in highly distinctive fortresslike *ksour* (castles) made of adobe. Formerly, nomadic camel herding was an important economic activity in the Saharan zone. However, government policies, desert warfare, multiyear droughts, and other extenuating factors have caused this way of life to disappear almost completely.

Oasis settlements



Date palms and cultivated fields at the village of Tinrhir on the southern slopes of the High Atlas Mountains in the pre-Saharan region of Morocco.
© Robert Holmes

Although approximately half the Moroccan population lives in urban areas, most Moroccan cities retain at least some of their traditional character and charm. During the period of the French protectorate, colonial authorities purposely attempted to preserve existing urban centres, which were usually surrounded by defensive ramparts. Rather than adapting these centres to accommodate new infrastructure for administration and economic development, they established *nouvelles villes* ("new towns") alongside them. In addition, they shifted the focus of political and economic life from the interior of Morocco—where it had long revolved around the royal cities of Fès, Meknès, and Marrakech—to the Atlantic coast. Casablanca was transformed from a sleepy coastal village into a bustling metropolis. Rabat became the capital and centre of administration. By the 1930s, bidonvilles ("tin can cities"), or shantytowns, were beginning to develop around major urban areas and have since become extensive. For many years the government tried to discourage these spontaneous settlements. More recently, however, it has been providing bidonvilles with electricity, piped water, and other facilities and encouraging residents to improve their structures. (W.D.Sw.)

The people. The population of Morocco is Arab and

Arabs and Berbers

Berber in origin, though the main difference between the two groups today is primarily linguistic. The Berber language, although greatly influenced by Arabic, has been preserved in the mountainous regions, which have long been areas of refuge. Berber-speaking inhabitants are divided into three ethnolinguistic groups: the Rif people (also called Riffi or Riffians) of the Rif Mountains, the Tamazight of the Middle Atlas, and the Shluh of the High Atlas and the Sous valley. With improved communications and the ongoing rural exodus to the towns, Arabic-Berber bilingualism has become common: today, in the late 20th century, the proportion of monolingual Berbers does not exceed 25 percent. The remainder of the Moroccan population primarily speaks Arabic (with French as an important secondary language) and is composed mainly of Arabized Berbers, descendants of Bedouin Arabs (who moved to Morocco with the armies of Islām in the 7th century or with the invading Hilāl tribe in the 11th and 12th centuries), and descendants of refugees from Spain. These latter were a mixture of Arab, Berber, and Iberian who fled from the Reconquista, the Christian reconquest of the Iberian Peninsula, which culminated in 1492.

Trade and cultural relations with black Africa since the European Middle Ages have resulted in the gradual growth of a significant black minority, living chiefly in the southern oases or in the royal towns, particularly Marrakech and Meknès. The Jewish minority—a considerable community until Jewish emigration to Israel began in 1948—consists of small Berber-speaking groups whose origins are obscure and of Arabic-speaking groups who arrived from Spain and other Mediterranean countries at various periods of history. However, the majority of the Moroccan population has a common culture and religion. Most Moroccans are Sunnite Muslims of the Malikite order.

Morocco's population growth rate remains high, though it appeared to be declining somewhat during the 1980s and was well below average for countries in the Middle East and North African region. Nonetheless, more than one-half of the population was under the age of 20 in the late 20th century, assuring high birth rates and continued high population growth for years to come. The opportunity to emigrate to western European countries traditionally offered a partial solution to Morocco's population explosion. By the early 1980s some 600,000 Moroccan workers and merchants had established themselves in western Europe, notably in France, Belgium, The Netherlands, and West Germany. Soon thereafter, however, the European labour market became closed to new workers, and Morocco's population problem was only slightly relieved by the open labour markets of some Arab nations, among them Iraq, Saudi Arabia, and Libya. (A.La./W.D.Sw.)

Patterns of emigration

The economy. As is true in most former colonies, the Moroccan economy remains heavily dependent on exports of raw materials. It is also characterized by a dichotomy between a large traditional sector and a smaller modern export-oriented sector. Altogether, the modern economy accounts for as much as 70 percent of the gross domestic product (GDP), even though it provides only about 30 percent of employment.

Viewed globally, the primary sector (agriculture, mining, fishing, and forestry) accounts for about 50 percent of the labour force and 25 percent of GDP; the secondary sector (industry and manufacturing, traditional handicrafts, and construction) for about 15 percent of the labour force and 25 percent of GDP; and the tertiary sector (commerce, administration, transportation, and service activities) for the remaining 35 percent of the labour force and 50 percent of GDP. Not included in these statistics is a large "informal" economy of street vendors, maids, nonlicensed tourist guides, porters, night watchmen, errand boys, and other underemployed and poorly paid individuals.

The large "informal" economy

The three leading exports in order of importance are phosphates and phosphate products, agricultural produce (primarily citrus fruits and market vegetables), and textiles. Tourism and remittances from Moroccan workers abroad are each roughly equal to phosphate exports as sources of foreign exchange. Major imports are semimanufactures and industrial equipment, crude oil, and food commodities.

Since the mid-1980s, under pressure from international lenders, the Moroccan government has been undertaking privatization and other economic reforms. Measures have included the selling of state-owned enterprises, currency devaluation, and changes in pricing policy to encourage local production.

Resources. Morocco is endowed with numerous exploitable resources. With approximately 21 million acres (8.5 million hectares) of arable land, 3 million of which are irrigable, and its generally temperate Mediterranean climate, Morocco's agricultural potential is matched by few other Arab or African countries. It also possesses some two-thirds of the world's reserves of phosphates, used for the manufacture of fertilizers and many other products. World prices for phosphates, however, have been low since the late 1970s. Other minerals include iron ore and coal, mined for Morocco's domestic use, and manganese, lead, and zinc, which are exported in small quantities. The fishing grounds in the Canary Current off Morocco's west coast are exceptionally rich in sardines, bonito, and tuna. However, the country still lacks the modern fleets and processing facilities to benefit fully from these marine resources.

Morocco's sandy beaches, sunshine, diverse environments, and well-preserved traditional culture give it outstanding potential for tourism, which it has already developed to a large degree. Its forests, covering about one-tenth of its total land area excluding Western Sahara, have substantial commercial value. Morocco is able to satisfy much of its timber needs by harvesting the high-elevation forests in the Middle and High Atlas. Its eucalyptus plantations enable it to be self-sufficient in charcoal which is used extensively for cooking fuel. Eucalyptus also provides the raw material for the country's paper and cellulose industry. Paper pulp is a valuable export. Cork from the country's plentiful cork oak forests is also exported on a significant scale.

A major weakness in the country's resource inventory is its shortage of energy resources. Oil exploration has proved to be disappointing. The country possesses some natural gas reserves, however, which have been tapped, and its hydroelectric potential, about half of which has been developed, is considerable. Nonetheless, Morocco must cover roughly four-fifths of its growing energy needs through imports. The principal energy import is crude oil, which Morocco refines domestically at several different facilities. (W.D.Sw.)

Agriculture. Morocco is one of the few Arab countries that has the potential to achieve self-sufficiency in food production. In a normal year Morocco produces two-thirds of the grains (chiefly wheat, barley, and corn [maize]) needed for self-sufficiency. The country exports citrus fruit and early vegetables to the European market; its wine industry is well developed, and production of industrial crops (cotton, sugarcane, sugar beets, and sunflowers) is being expanded. New crops such as tea, tobacco, and soybeans have passed the experimental stage, and the fertile Rharb Plain has proved to be favourable to their cultivation. The country is actively developing its irrigation potential. Plans call for permanent irrigation of well over 2.5 million acres. Livestock raising, particularly of sheep and cattle, is widespread. Morocco fills its own meat requirements and is attempting to become self-sufficient in dairy products. (A.La./W.D.Sw.)

Agricultural development and production

Industry. Industry accounts for about one-fourth of the GDP and is steadily growing in importance in the economy. Two particularly important components of the country's industrial makeup are the processing of raw materials for export and the manufacture of consumer goods for the domestic market. Many operations date back to the colonial period. Until the 1980s, government involvement was dominant, and the major focus was on import substitution. By the late 1980s, however, heavy emphasis was being placed on export-oriented industry, privatization of state operations, and new private investment, including foreign investment. The most important industrial activity is the transforming of phosphate ore into fertilizers and phosphoric acid for export. Food processing for export (canning of fish, fresh vegetables, and fruit) as well as for

Phosphate industries

domestic needs (flour milling, sugar refining, and so forth) is also important. A growing earner of foreign exchange is textile and clothes manufacturing using domestically produced cotton and wool. Refining of imported crude oil and production of cement for construction are other major industrial activities. Morocco's iron and steel industry is small but provides for a significant share of the country's domestic needs.

Finance and trade. Morocco's central bank, the Bank al-Maghrib, plays a preeminent role in the country's banking system. It issues currency, maintains Morocco's foreign currency reserves, controls the credit supply, oversees the government's specialized lending organizations, and regulates the commercial banking industry. Since the mid-1980s, with privatization and structural economic reforms under way, the central bank has had the difficult task of trying to encourage private investment and development while discouraging imports. Privatization has stimulated stock market activity: shares of large former state-owned operations are increasingly being traded on the Casablanca stock exchange. Government attempts to stimulate exports and control imports have not been particularly successful, however. Exports regularly cover only about half the value of imports, resulting in a chronic trade deficit that has proved resistant to change. The main imports are capital goods for industrial development, semimanufactures, crude oil, and food commodities (wheat, barley, flour, sugar, and raw materials to produce cooking oil). Countries of the European Community (EC), particularly France, are the main sources for imports, although Morocco has an impressively long list of trade partners. Major exports are phosphates and phosphate products, agricultural produce (particularly citrus fruits and market vegetables), and textiles and clothing. The EC again forms the main market. The EC market for Morocco's agricultural exports is likely to progressively diminish, however, because of increasing competition from EC members, such as Spain and Portugal, which produce many of the same crops.

Trade with the EC

Transportation and communications. Morocco's road network effectively integrates the country's diverse regions. Established during the colonial period, the network has been well maintained and gradually expanded ever since. The railway system connects the principal urban centres of the north, and new rail links, together with improved roads, are being established to El-Aaiún (Laâyoune) in Western Sahara. Morocco has some 20 ports along its lengthy coastline. Casablanca alone accounts for about one-half of all port tonnage. Other major ports include Safi, Mohammedia, Agadir, Nador, Tangier, Kenitra, and Jorf Lasfar. Nine airports capable of accommodating large aircraft service the country; the principal international airport is located near Casablanca. The state-owned Royal Air Maroc (RAM) airline provides regular service to Europe, North America, the Middle East, and western Africa. In the late 1980s and early 1990s the government undertook a major expansion and modernization of the telecommunications system. This nearly quadrupled the number of internal lines and greatly improved international communications.

Administration and social conditions. *Government.* Morocco has been a constitutional monarchy since 1962, with the king ostensibly ruling in conjunction with a parliament. King Hassan II, who was enthroned following his father's death in 1961, represents the latest monarch in a dynasty that extends back to 1666. In addition, he is the country's spiritual leader and traces his roots back to the Prophet Muḥammad. King Hassan has more inherent legitimacy than most heads of state, and this has been a major source of stability. However, despite the constitution, parliament, and presence of opposition parties, the king wields far more political power than do most rulers.

Although the parliament does have limited legislative power, its primary function is to discuss and ratify initiatives proposed by the king and his advisors. Two-thirds of the members of parliament are elected by universal suffrage (male and female citizens 21 years of age and older), and the remaining third is elected by a college formed of representatives from provincial and prefectural assemblies, professional bodies, and labour groups. In the event of "national emergencies," the king can disband parliament, and he did so from 1965 to 1977, during which time he ruled by direct decree.

The 15 or so political parties are closely monitored, and leaders are occasionally imprisoned for overstepping unwritten rules. The king has taken steps to win the favour of opposition parties through offering Cabinet appointments and government positions to their leaders. Since 1986, political parties have received state funding. They have failed to attract mass participation and remain primarily political organizations for the better-educated elite. The king's two major bases of support are the direct following of the masses and the well-cultivated loyalty of the security forces, which number well over 200,000 and include the Royal Armed Forces (army, air force, and navy), the National Police Force, the Royal Gendarmerie (mainly responsible for rural security), and the Auxiliary Forces (a reserve national guard).

Since 1977 the king has permitted a closely supervised amount of political expression. Elections have been held, parliament has been convened regularly, and circumspect criticism of social and economic conditions or government policies has been tolerated, though not criticism of the royal family, the institution of the monarchy, or certain key policies such as those dealing with Western Sahara or the Islāmic nature of the state. A significant new development during the 1980s and early 1990s was the emergence of Islāmic fundamentalist groups enjoying wide popular support. These groups are regarded as a political threat and have been closely monitored by the security forces.

The country is subdivided into three levels of government, all directly under the Ministry of the Interior. At the top are 49 (including four in Western Sahara) *wilāyāt* (provinces) and *'amālat* (urban prefectures), each ruled by a governor appointed by the king. Beneath this first-order subdivision are rural *qadawat* (districts) and municipalities, governed by *chefs de cercle* or *super qa'ids*. The third level comprises rural communes and autonomous urban centres, governed respectively by *qā'ids* and *pashas*. Lower-order officials are appointed either by the Ministry of the Interior or by the governors. At each level there are popularly elected bodies whose primary function is to help determine local matters and priorities, such as initiating development projects and deciding budget expenditures. However, they are supervised by the central government's representatives, who implement government policies and exercise considerable power within their administrative territories. (W.D.Sw.)

Structure of local government

Justice. In theory, the Qur'ān is the source of law. In effect the Qur'ānic jurisdiction, exercised by the qadis (Muslim judges who interpret and administer the religious law of Islām), is limited to matters relating to the personal status of Muslims. Rabbinical justice applies to Jews. All other matters, whether they concern Muslims, Jews, or others, are in the hands of the "modern" courts, which apply a code of laws inspired by the French. The various regional and local courts are beneath three courts of appeal and the supreme court, which convenes in Casablanca. All are supervised by the Ministry of Justice.

(A.La./W.D.Sw.)

Education. Morocco allocates approximately one-fourth of its budget to education. Much of this is spent on construction of schools to accommodate the rapidly growing population, more than two-fifths of whom are younger than age 15. Education is mandatory for children between the ages of 7 and 13 years. In urban areas most children in this age group attend school. On a national scale, however, the level of participation drops to about three-fourths. Males account for about 60 percent of the school population. Slightly more than half of the children go on to secondary education, including trade and technical schools. Of these, about 1 in 10 go on to higher education.

Morocco has 6 universities and 21 specialized institutes and polytechnics dispersed at urban centres throughout the country. Its leading institutions include Muḥammad V University in Rabat, the country's largest university, with faculties of arts and letters, science, medicine, law, engineering, education, and Islāmic studies and with branches in Casablanca and Fès; the University of al-Qarawiyin at

Fès, founded in the 9th century and a famous centre for Islāmic studies; and the Hassan II Agriculture and Veterinary Institute in Rabat, which conducts leading social science research in addition to its agricultural specialties.

Health and welfare. Morocco has a relatively favourable ratio of physicians and other trained medical personnel to population. The government has been emphasizing preventive medicine by increasing the number of dispensaries and health centres. An estimated one-half of the rural population, however, still lacks access to these facilities. In addition, only about three-fourths of the urban population and one-fifth of the rural population have access to safe drinking water. Infant mortality rates remain high, and at least one-fourth of the population experiences malnutrition. Certain endemic diseases of the past, such as trachoma, tuberculosis, and cholera, have been largely eliminated. Other diseases, such as hepatitis, remain prevalent, however, and new diseases, such as schistosomiasis (linked to the expansion of irrigation), are becoming more frequent. (W.D.Sw.)

Diseases

Cultural life. *The arts.* Arabic is the national and official language of Morocco; French and Spanish, however, are widely spoken, and English is increasingly used. For several years attempts have been made to revive the Berber culture, and authorities have created an institute of Arab and Berber cultures.

The production of literature has continued to grow and diversify. To the traditional genres—poetry, essays, and historiography—have been added forms inspired by Middle Eastern and Western literary models. French is used in publication of research in the social and natural sciences. Moroccan literature is published in both Arabic and French. Many Moroccan authors and educators also publish in France. Since independence a veritable blossoming has taken place in painting and sculpture, popular music, amateur theatre, and filmmaking. The Ministry of Tourism promotes music and dance. Each year it organizes a folklore festival at Marrakech, a jazz festival at Tangier, a festival of Andalusian music at Saïdia, and an African arts festival at Agadir. An August festival at Asilah, organized by private supporters, transforms the entire town into an immense studio where artists from four continents display their work.

Arts festivals

Broadcasting and the press. Morocco's government-owned radio and television network, Radiodiffusion Télévision Marocaine (RTM), broadcasts throughout the country. Radio broadcasts are in Arabic, French, Berber, Spanish, and English, and television broadcasts are in Arabic and French. In addition, there is a private television network headquartered in Casablanca and a private radio network in Tangier. Both are joint ventures of Moroccan and French investors, and both broadcast countrywide in Arabic and French. Moroccans in the north also receive Spanish radio and television stations. Given the estimated number of receivers in the country by the early 1990s, the potential radio audience was believed to include about 80 percent of the population and the potential television audience nearly 70 percent.

There are 11 daily newspapers in Morocco, 5 in Casablanca and 6 in Rabat. Five are published in Arabic only, four in French only, and two in both languages. Most are organs of political parties; the remainder are government-owned or government-leaning. In addition, there is a rich variety of periodicals representing various professions, trades, intellectual interests, and avocations. (A.La./W.D.Sw.)

For statistical data on the land and people of Morocco, see the *Britannica World Data* section in the BRITANNICA BOOK OF THE YEAR.

HISTORY

Literally visible from Europe at the Strait of Gibraltar and linked to Spain politically and culturally from the early Islāmic period until the 15th century, Morocco at the beginning of the 19th century was much less in contact with Europe than perhaps any other Muslim country bordering the Mediterranean. Geography provides a partial answer to this paradox. Morocco is not an easy country for people or ideas to penetrate, especially if those ruling within choose to ward them off—and such was the choice of Morocco's rulers.

Another paradox is that, while Morocco, cut up by mountains and desert and possessing no single predominant city such as Paris in France or Tunis in Tunisia, is a difficult country to hold together, it had begun to develop what can be called a protonationalism early in the Islāmic period. In a way that cannot be matched in any other country of the present-day Arab world, save possibly Egypt, Morocco's history since the rise of Islām can be traced in terms of successive ruling dynasties—from the Idrisids to the ʿAlawites, who still rule. Morocco at times has been the core of imperial structures extending beyond its borders, such as during the Almoravid and Almohad dynasties. It has had a major impact—at times militarily devastating, at times culturally enriching—beyond the Sahara in western Africa. At the same time, Morocco had seldom been absorbed for long in empires centred elsewhere. It resisted the push of the Spanish Reconquista in the 15th and 16th centuries, just as it never became part of the Ottoman Empire that for so long controlled virtually all the rest of the Arab world. At the beginning of the 19th century Morocco was, and wished to remain, self-contained. Yet, the premodern characteristics of a great divide between urban and rural life, of a near-subsistence economy, of cultural differences dividing Arabs from Berbers (perhaps just slightly less than half the population at that time), and of a tradition of resistance to any authority that could not be maintained by force was to make Morocco especially vulnerable to the economic and military advances of its European neighbours across the sea. (L.C.Br.)

Proto-nationalism

Decline of traditional government (1830–1912). During the French invasion of Algeria in 1830, the sultan of Morocco, Moulay (Mawlay) Abd ar-Rahman (1822–59), briefly sent troops to occupy Tlemcen but withdrew them after French protests. The Algerian leader Abdelkader in 1844 took refuge from the French in Morocco. A Moroccan army was sent to the Algerian frontier; the French bombarded Tangier on Aug. 4, 1844, and Essaouira (Mogador) on August 15. Meanwhile, on August 14, the Moroccan army had been totally defeated at Isly, near the frontier town of Oujda. The sultan then promised to intern or expel Abdelkader if he should again enter Moroccan territory. Two years later, when he was again driven into Morocco, the Algerian leader was attacked by Moroccan troops and was forced to surrender to the French.

Immediately after Abd ar-Rahman's death in 1859, a dispute with Spain over the boundaries of the Spanish enclave at Ceuta led to a declaration of war by Madrid and to the Spanish capture of Tétouan in the following year. Peace had to be bought with an indemnity of $20 million, the enlargement of Ceuta's frontiers, and the promise to cede to Spain another enclave—Ifni.

The new sultan, Sidi Muḥammad (1859–73), attempted without any marked success to modernize the Moroccan army. After his death, his son Moulay Hassan I (1873–94) struggled to preserve independence. After his death, his chamberlain, Ba Ahmed (Ahmad ibn Musa), ruled in the name of the young sultan Abd al-Aziz until 1901, when the latter began his direct rule.

Attempts at modernization

Abd al-Aziz surrounded himself with European companions and adopted their customs, scandalizing his subjects, particularly the religious leaders. His attempt to introduce a modern system of land taxation resulted in complete confusion because of a lack of qualified officials. Popular discontent and tribal rebellion became even more common, while a pretender, Bu Hamara (Bū Ḥmāra), established a rival court near Melilla. European powers seized the occasion to extend their own influence. In 1904 Britain gave France a free hand in Morocco in return for a French undertaking not to interfere with British plans in Egypt. Spanish agreement was secured by a French promise that northern Morocco should be treated as a sphere of Spanish influence. Italian interests were satisfied by a French undertaking not to hinder Italian designs on Libya. Possible German claims were ignored, thus enabling the sultan to arrange an international conference at Algeciras, Spain, in 1906 to discuss the whole Moroccan question.

The Algeciras Conference confirmed the integrity of

the sultan's domains but sanctioned French and Spanish policing of Moroccan ports and collection of the customs dues. In 1907–08 the sultan's brother, Moulay Abd al-Hafid, led a rebellion against him, denouncing him for his departure from Muslim ways. Abd al-Aziz took refuge in Tangier. Abd al-Hafid then made an abortive attack on French troops, which had occupied Casablanca in 1907, before proceeding to Fès, where he was duly proclaimed sultan and recognized by the European powers (1909).

The new sultan proved unable to control the country. Disorder increased until, besieged by tribesmen in Fès, he was forced to ask the French to rescue him. When they had done so, he had no choice but to sign the Treaty of Fès (March 30, 1912), by which Morocco became a French protectorate. In return the French guaranteed to maintain the status of the sultan and his successors. Provision was also made to meet the Spanish claim for a special position in the north of the country; Tangier, long the seat of the diplomatic missions, retained a distinctive administration.

The French protectorate (1912–56). In establishing their protectorate over Morocco, the French had behind them the experience of the conquest of Algeria and of their protectorate over Tunisia, and they took the latter as the model for their Moroccan policy. There were, however, important differences. First, the protectorate was established only two years before the outbreak of World War I, which was to bring with it a new attitude toward colonial rule. Second, Morocco had a tradition of a thousand years of independence; it had been strongly influenced by the civilization of Muslim Spain and had never been subject to Ottoman rule. These circumstances and the proximity of Morocco to Spain created a special relationship between the two countries. Morocco was also unique among North African countries in possessing a coast on the Atlantic, in the rights that various nations derived from the Act of Algeciras, and in the privileges that their diplomatic missions had acquired in Tangier. Thus, the northern tenth of the country, with an Atlantic and a Mediterranean coast, together with the desert province of Tarfaya in the southwest adjoining the Spanish Sahara, was excluded from the French-controlled area and treated as a Spanish protectorate. In the French sector, the French resident general became the real ruler of the country, subject to the approval of the Paris government. He worked through newly created departments manned by French officials. The outward forms of the traditional Moroccan government (*makhzan*) were preserved, though the negligible role that it actually played can be estimated from the fact that the grand vizier on the installation of the protectorate, Muḥammad al-Moqri, still held the same post on the recovery of independence 44 years later, when he was more than 100 years old. As in Tunisia, country districts were administered by *contrôleurs civils,* except in certain areas such as Fès, where it was felt necessary that officers of the rank of general should supervise the administration. In the south certain Berber chiefs (*qā'id*s or caids), of whom the best known was Thami al-Glaoui, were allowed to remain semi-independent.

The protectorate's government

The pre-World War II period. The first resident general, General (later Marshal) L.-H.-G. Lyautey, was a soldier of wide experience in Indochina, Madagascar, and Algeria. He was of aristocratic outlook and possessed a deep appreciation of Moroccan civilization. The character he gave to the administration exerted an influence throughout the period of the protectorate.

Abd al-Hafid could not reconcile himself to the new regime and, after a few months, joined his brother as a French pensioner in Tangier. In his place a more amenable brother, Moulay Yusuf, was recognized as sultan and succeeded in cooperating with the French without losing the respect of his own people. A new administrative capital was created on the Atlantic coast at Rabat. At the same time, a commercial port was developed at Casablanca. By the end of the protectorate, Casablanca was a flourishing city, with nearly a million inhabitants and a substantial industrial establishment. Lyautey's policy was to build new European cities beside or at some distance from the old Moroccan towns, thus preserving the country's ancient monuments. The remarkable rhythm of innovation was little interrupted by World War I. Though the French government had proposed to retire to the coastal area, Lyautey managed to retain control of all of the occupied area.

The development of Casablanca

After the war one major problem was the pacification of the outlying areas in the Atlas Mountains, over which the sultan's government often had had no real control. This was finally completed in 1934. Another problem was the extension of the uprising of Abd el-Krim from the Spanish to the French zone (see below *World War II and the attainment of independence: The Spanish Zone*).

Marshal Lyautey was succeeded by a civilian resident general in 1926. This marked a change to a more conventional colonial regime, accompanied by the extension of official colonization, the growth of European population, and the increasing impact of European thought on the minds of the younger generation, some of whom had by then received a French education.

As early as 1920 Lyautey had submitted a report saying that "a young generation is growing up which is full of life and needs activity. . . . Lacking the outlets which our administration offers only sparingly and in subordinate positions they will find an alternative way out." Only six years after Lyautey's report, young Moroccans both in Rabat, the new administrative capital, and in Fès, the centre of traditional Arab learning and culture, were meeting, quite independently of one another, to discuss demands for reforms within the terms of the protectorate treaty. They asked for more schools, a new judicial system, and the abolition of the regime of the Berber caids in the south; for study missions in France and in the Arab East; and for the cessation of official colonization—objectives that would be fully secured only when the protectorate ended in 1956.

On the death of Moulay Yusuf (1927) the French chose as his successor his younger son, Sidi Muḥammad (Muḥammad V). Chosen in part for his retiring disposition, this sultan was in time to reveal diplomatic skill and determination. Another significant event was the attempt to use the differences between Arabs and Berbers to counterbalance the Arab character of the sultan's government. This led to the issue of the 1930 Berber Decree, a crude French effort to divide Berbers and Arabs. The result was just the opposite of French intentions; it provoked a Moroccan nationalist reaction and forced the administration to modify its proposals. In 1933 the nationalists initiated a new national day called the Fête du Trône (Throne Day) to mark the anniversary of the sultan's accession. When he visited Fès in the following year, he received a tumultuous welcome, accompanied by anti-French demonstrations that caused the authorities to terminate the visit abruptly. This episode was soon followed by the organization of political parties of nationalist sentiment. These events coincided with the completion of the occupation of southern Morocco, which brought with it the Spanish occupation of Ifni. In 1937 rioting occurred in Meknès, where French settlers were suspected of diverting part of the town water supply to irrigate their own lands at the expense of the Muslim cultivators. In the ensuing repression, Muḥammad 'Allāl al-Fāsi, the main nationalist leader, was banished to Gabon in French Equatorial Africa, where he spent the following nine years.

The Berber Decree of 1930

World War II and the attainment of independence. At the outbreak of World War II in 1939, the sultan issued a call for cooperation with the French, and a large Moroccan contingent, mainly Berbers, served with distinction in France. The collapse of the protecting power in 1940 and the installation of the Vichy regime produced an entirely new situation. The sultan marked his independence by refusing to approve anti-Jewish legislation. When the Anglo-American landings took place in 1942, he refused to comply with the suggestion of the resident general, Auguste Noguès, that he retire to the interior. In 1943 the sultan was influenced by his meeting with United States President Franklin D. Roosevelt, who came to Morocco for the Casablanca Conference and was unsympathetic to continued French presence there. The majority of the people were equally affected by contact with the U.S. and British troops, who put them in touch with the outside

The Allied invasion

world to an unprecedented degree. Among the people at large, the effect of the newly introduced radio broadcasts in Arabic with which the combatants, Allied and Nazi alike, sought to attract Arab listeners to their side, was considerable. Amid these circumstances, the nationalist movement took the new title of Independence Party (Ḥizb al-Istiqlāl). In January 1944 they submitted to the sultan and the Allied (including the French) authorities a memorandum asking for independence under a constitutional regime. The nationalist leaders, including Ahmad Balafrej, secretary general of the Istiqlāl, were immediately arrested on an improbable charge of collaboration with the Nazis. This caused rioting in Fès and elsewhere in which some 30 or more demonstrators were killed. In the situation thus created, the initiative passed to the sultan, who in 1947 persuaded a new and reforming resident general, Eirik Labonne, to gain the French government's permission for him to make an official state visit to Tangier, passing through the Spanish Zone on the way. The journey became a triumphal procession; when the sultan finally made his speech in Tangier, it was under the emotion of his stirring reception in the Spanish Zone and Tangier. While emphasizing the links of Morocco with the Arab world of the East, he omitted the expected flattering reference to the French protectorate.

The regime of General Juin

The result was the replacement of Labonne by General (later Marshal) Alphonse Juin, of Algerian settler origin. With long experience in North African affairs, Juin expressed sympathy for the patriotic nationalist sentiments of young Moroccans and promised to comply with their wish for the creation of elected municipalities in the large cities. At the same time he roused opposition by proposing to introduce French citizens as members of these bodies. The sultan used his one remaining prerogative and refused to countersign the resident general's decrees, lacking which they had no legal validity. A state visit to France in October 1950 and a flattering reception did nothing to modify the sultan's views, and on his return to Morocco he received a wildly enthusiastic welcome.

On December 12 General Juin dismissed a nationalist member from a meeting of the Council of Government, which discussed budget proposals; the 10 remaining nationalist members walked out in protest. Juin began to think of the possibility of utilizing the Berber feudal notables, such as Thami al-Glaoui, to counter the nationalists. Thus, at a palace reception on Dec. 21, 1950, Al-Glaoui told the sultan to his face that he was not the sultan of the Moroccans but of the Istiqlāl and that he was leading the country to catastrophe.

In the face of Sidi Muḥammad's continued refusal to cooperate, Juin surrounded the palace with tribesmen, after having provided a guard of French troops supposedly to protect the sultan against his own outraged people. Faced with this threat, Sidi Muḥammad was constrained to disown "a certain political party," without specifically naming it, but he still withheld his signature from many decrees, including that admitting French citizens as municipal councillors. Juin's action was widely criticized in France, and on Aug. 28, 1951, he was replaced by General Augustin Guillaume. The sultan, on the anniversary of his accession (November 18), declared that he was hoping for an agreement "guaranteeing full sovereignty to Morocco" but (as he added in a subsequent letter addressed to the president of the French Republic) "with the continuation of Franco-Moroccan cooperation." This troubled situation continued until December 1952, when the trade unions in Casablanca decided to organize a protest meeting over the assassination of the Tunisian trade union leader, Ferhat Hashad (Hached), allegedly by French terrorists. A clash with the police followed; hundreds of nationalists were arrested and were held for two years without trial.

In April 1953 the head of a religious confraternity, Abd al-Ḥai al-Kittani, together with a number of Berber notables headed by Al-Glaoui, with the connivance of a number of French officials and settlers, began to work for the deposition of the sultan. The government in Paris, preoccupied with internal affairs, finally demanded that the sultan transfer his legislative powers to a council, composed jointly of Moroccan ministers and French directors, and append his signature to all the blocked legislation. The sultan yielded, but this was not sufficient for his enemies. On Aug. 18, 1953, Al-Glaoui delivered what may be called an ultimatum to the French government. The latter thereupon deported the sultan and his family, appointing in his place the more subservient Moulay Ben Arafa. This did nothing to improve the situation. Sidi Muḥammad at once became a national hero. The authorities in the Spanish Zone, who had not been consulted about the measure, did not conceal their disapproval. The Spanish Zone thus became a refuge for Moroccan nationalists.

The sultan's exile

In November 1954 the French position was further complicated by the outbreak of the Algerian rebellion. In June 1955 the Paris government decided on a complete change of policy and appointed Gilbert Grandval as resident general. His efforts at conciliation were obstructed by the tacit opposition of many officials and the outspoken hostility of the majority of the French settlers, and he was recalled. A conference of representative Moroccans was then summoned to meet in France, and at this conference it was agreed to replace the substitute sultan by a crown council. Sidi Muḥammad gave his approval to the proposal, but it took weeks to persuade the puppet sultan to withdraw to Tangier. Meanwhile, a guerrilla liberation army began to operate against French posts near the Spanish Zone.

On October 26 Al-Glaoui declared publicly that only the restoration of Muḥammad V could restore harmony. The French government agreed to allow the sultan to form a constitutional government for Morocco. In November Sidi Muḥammad returned to Rabat. On March 2, 1956, independence was proclaimed, and the sultan formed a government representative of the various elements of the indigenous population, while the governmental departments formerly headed by Frenchmen became ministries headed by Moroccans.

The Spanish Zone. The Spanish protectorate over Morocco covered about one-tenth of the kingdom, from Larache (El-Araish) on the Atlantic to 30 miles beyond Melilla (already a Spanish possession) on the Mediterranean. This was in the main a mountainous, Berber-speaking area that had often escaped the sultan's control. Spain also received a strip of desert land in the southwest, adjoining Spanish Sahara and known as Tarfaya. In 1934, when the French occupied southern Morocco, the Spanish took Ifni.

Spain appointed a *khalīfah,* or viceroy, chosen from the Moroccan royal family as nominal head of state and provided him with a puppet Moroccan government. This enabled Spain to conduct affairs independently of the French Zone while nominally preserving Moroccan unity. Tangier, though it had a Spanish-speaking population of 40,000, received a special international administration, under a *mandub,* or resident, theoretically appointed by the sultan, actually by the French. In 1940, after the defeat of France, Spanish troops occupied Tangier, but they withdrew again in 1945 after the Allied victory.

The Spanish Zone surrounded the ports of Ceuta and Melilla, which Spain had held for centuries, and included the iron mines of the Rif Mountains. As capital, the Spanish selected Tétouan. As in the French Zone, European-staffed departments were created; the country districts were administered by *interventores,* corresponding to the French *contrôleurs civils.* The first area to be occupied was that on the plain, facing the Atlantic, with the towns of Larache, Alcazarquivir (Ksar el-Kebir; Al-Qsar al-Kabir), and Asilah. That area was the stronghold of the former Moroccan governor Ahmad al-Raisuni (Raisuli), half patriot and half brigand. The Spanish government found it difficult to tolerate his independence, and in March 1913 he retired into a refuge in the mountains, where he held out until captured by another Moroccan leader, Abd el-Krim, 12 years later.

Abd el-Krim was a Berber and a good Arabic scholar who had a knowledge of both the Arabic and Spanish languages and ways of life. Imprisoned after World War I, he later went to Ajdir in the Rif Mountains to plan an uprising. In July 1921 he destroyed a Spanish force sent against him and then established the Republic of the Rif, which endured for five years. It was only when French

The Republic of the Rif

and Spanish forces, numbering more than 250,000 fully equipped men, combined that Abd el-Krim was then finally overwhelmed. In May 1926 he surrendered to the French and was exiled.

The remainder of the period of the Spanish protectorate was relatively calm. Thus, in 1936, General Francisco Franco was able to launch his attack on the Spanish Republic from Morocco and to enroll a large number of Moroccan volunteers, who served him loyally in the Spanish Civil War. Though the Spanish had fewer resources than the French, their subsequent regime was in some respects more liberal and less subject to racial discrimination. Instruction in the schools was in Arabic rather than in Spanish, and Moroccan students were encouraged to go to Egypt for a Muslim education. There was no attempt to set Berber against Arab as in the French Zone, though this may have been prevented by the introduction of Muslim law by Abd el-Krim himself. After the end of the Republic of the Rif, there was little cooperation between the two protecting powers. Their disagreement reached a new height when in 1953 the French, without consulting the Spanish, deposed and deported the sultan. The Spanish high commissioner did not recognize this action, and Muḥammad V was still regarded in the Spanish Zone as the sovereign. Nationalists, moreover, for the first time were given departmental office, and the zone served as a refuge for those who had to leave the French area.

In 1956, however, when the French decided to grant independence to Morocco, the Spanish authorities were taken by surprise and hesitated before following suit. A corresponding agreement was nevertheless reached on April 7, 1956, and was marked by a visit of the sultan to Spain. The Spanish protectorate was thus brought to an end without the troubles that marked the termination of foreign control in the French Zone. With the end of the Spanish protectorate and the withdrawal of the Spanish high commissioner, the Moroccan *khalīfah,* and other officials from Tétouan, the city again became a quiet, provincial capital. The introduction of the Moroccan franc to replace the peseta as currency, however, caused a great rise in the cost of living, and difficulties were also brought on by the introduction of French-speaking Moroccan officials. In 1958–59 these changes gave rise to disorders in the Rif. Tangier, too, lost much of the superficial brilliance that it had developed as a separate zone, as by degrees its special status was modified and its privileges were withdrawn. As in the former French Zone, there ensued a great drop in the number of European and Jewish inhabitants. The southern protectorate area of Tarfaya was handed back to Morocco in 1958. Ifni, in return for which the Spaniards had vainly hoped to gain a recognition of their right to Melilla and Ceuta, was finally handed over unconditionally in 1970.

Independence for Morocco

Ceuta, on the Strait of Gibraltar, and Melilla, farther east on the Mediterranean coast, continue to be Spanish *plazas* in Morocco, both with overwhelmingly Spanish populations. In October 1978 the United States turned over to Morocco its last military base in Africa, that at Kenitra.

Independent Morocco. The French protectorate had been successful in developing communications, in adding modern quarters to the cities, and in creating a flourishing agriculture and a modern industry of a colonial type. Most of these activities, however, were managed by Europeans who, by the end of the protectorate, numbered 360,000 in French Morocco. In the constitutional field there had been virtually no development. Though the government was in practice in the hands of the French, the sultan remained in theory an autocrat; and when independence was finally conceded he became so again in fact, subject only to his undertaking to the nationalists to introduce a constitution. By French insistence, the first Cabinet was composed of ministers representing the various groups of Moroccan society, and it included a Jew. Mubarak Bekkai, an army officer who was not a party man, was selected as premier. The sultan (who officially adopted the style of king in August 1957) selected the ministers personally and himself retained control of the army and the police; he did, however, nominate a Consultative Assembly of 60 members. His eldest son, Moulay Hassan, became chief of staff and by degrees successfully integrated the irregular liberation forces into the military after they had promoted a rising against the Spanish in Ifni (1957) and against the French in Mauritania.

In general, the change to Moroccan control, assisted by French advisers, took place smoothly. Relations with France, however, were badly strained because of the continuing Algerian problem, but independent Morocco remained dependent on French technology and finance.

A major political change occurred when the Istiqlāl split into two sections in 1959. The main portion, which was conservative, remained under the leadership of Muḥammad ʿAllāl al-Fāsī, while the smaller radical section, headed by Mehdi Ben Barka, Abdullah Ibrahim, Abd ar-Rahim Bouabid, and others, formed the National Union of Popular Forces (Union Nationale des Forces Populaires, or UNFP). Of these groupings the original Istiqlāl represented the more traditional elements, while the UNFP was formed from the intelligentsia and favoured socialism with republican leanings. Muḥammad V made use of these dissensions to assume the position of an arbiter above party strife. He nevertheless continued the preparations for the creation of a parliament until his unexpected death in 1961. Moulay Hassan succeeded him as Hassan II.

Division in the Istiqlāl

In 1963, when parliamentary elections were finally held, the two halves of the former Istiqlāl formed an opposition, while a party supporting the king's government was created out of miscellaneous elements and known as the Front for the Defense of Constitutional Institutions (FDIC). This included a new, predominantly Berber, rural group opposed to the Istiqlāl. The ensuing near deadlock caused the king to dissolve Parliament after only one year, resuming personal government with himself or his nominee as premier. In 1970 a new constitution was promulgated that provided for a one-house legislature. This did not survive an abortive coup by army elements against the monarchy in July 1971. The following year Hassan announced another constitution, but implementation was largely suspended following a second attempted military coup in August 1972. This latter coup was apparently led by General Muḥammad Oufkir; he had earlier been implicated in the kidnapping (1965) and disappearance in Paris of the exiled Moroccan UNFP leader Mehdi Ben Barka, who had been regarded as a likely candidate for the presidency of a Moroccan republic. Elections held in 1977 brought a landslide victory to the king's supporters. King Hassan's forceful policies to absorb Spanish (Western) Sahara gave him greatly increased popularity in the mid-1970s. This, in addition to his method of mixing efforts to co-opt the political opposition with periods of political repression, served to maintain royal control. By the early 1980s, however, several bad harvests, a sluggish economy, and the continued financial drain of the war in Western Sahara increased domestic strains, of which the violent riots in Casablanca in June 1981 were symptomatic.

Pro-monarchical FDIC

In foreign affairs Morocco sided with the western European powers rather than with the eastern bloc, while sharing the general outlook of Arab states on such questions as that of Palestine. Claiming Mauritania as a sphere of influence, the Moroccan government refused to recognize that country's independence before 1970. Nor would it recognize the eastern frontier where territory had been attached to French Algeria at Morocco's expense. This was of importance because of the vast iron-ore deposits in the region. In 1970 it was agreed that the iron ore would be exploited by both countries under the Algerian flag but exported through a Moroccan port. At the same time, a rapprochement with Mauritania signified an alignment of the three Maghrib states against a Spanish plan to develop the phosphate-rich Spanish Sahara into an independent state associated with Spain.

Subsequent developments in Spanish Sahara again caused tense relations between Morocco and Algeria. From 1974 King Hassan actively campaigned to assert Morocco's claim there (using this nationalist issue also to rally much-needed domestic support). In November 1975, after a United Nations mission had reported that the majority of Saharans wanted independence and that the principle of self-determination should be applied, Hassan responded

The "Green March"

with the "Green March": he called for 200,000 volunteers and sent them unarmed across the border to claim Spanish Sahara. Spain avoided a confrontation and signed an agreement relinquishing Spanish Sahara. The region was given over to joint Moroccan-Mauritanian administration as Western Sahara. By early 1976 the last Spanish troops had departed, leaving Morocco to struggle with the guerrillas of the Popular Front for the Liberation of Saguia el Hamra and Río de Oro (Polisario), actively supported by Algeria and later by Libya.

King Hassan offered a referendum in the area in 1981, but it was rejected by the Polisario leadership as being too much on Moroccan terms. Fighting continued and Morocco was able to secure some two-thirds of the territory within defensive walls by 1986. In the meantime the territory's government-in-exile, the Saharan Arab Democratic Republic, won recognition from an increasing number of foreign governments. The Western Sahara issue remained largely unresolved, despite improving relations with Algeria and repeated UN attempts at mediation.

Later in his career, Hassan actively promoted a program of democratization in Morocco and managed to recast his image as an old-style autocrat, reshaping himself and his country to reflect more progressive values and engaging in a vigorous campaign directed against corrupt public officials. New political freedoms and constitutional reforms enacted in the 1990s culminated in the election of the first opposition government in Morocco in more than 30 years (1997) and the release of thousands of political detainees.

Hassan also guarded his status as religious head of state and carefully nurtured those aspects of his public image that garnered widespread support in the countryside and among the urban poor, thereby checking his main political opponents, Islamic revivalists. Muhammad VI succeeded to the throne upon the death of his father in July 1999.

(N.B./L.C.Br.)

For later developments in the history of Morocco, see the BRITANNICA BOOK OF THE YEAR.

Tunisia

The Republic of Tunisia (in Arabic Al-Jumhūrīyah at-Tūnisīyah) has an area of 63,378 square miles (164,150 square kilometres). It occupies a position of strategic importance in the Mediterranean, where its situation and case of access have kept it open to virtually every historical influence in the region. It is bounded by Algeria to the west and southwest, Libya to the southeast, and the Mediterranean Sea to the east and north. The capital is Tunis (Tūnis).

PHYSICAL AND HUMAN GEOGRAPHY

With its 750 miles (1,200 kilometres) of coastline, Tunisia has often been compared to the hull of a ship, solidly moored on the continent but also freely washed by the waves; in consequence, its destiny, as its leaders never tire of repeating, is at once Mediterranean and Maghribian. Because the Maghrib constitutes a single geographic entity, the largely undemarcated boundaries separating Tunisia from Libya and from Algeria do not assume the form of any natural barrier but, rather, have been shaped by the vicissitudes of history. Unlike its immediate neighbours, who are petroleum-rich, Tunisia has somewhat meagre resources at its disposal. In addition, its usable territory is limited and its domestic market is restricted, and consequently the problem of promoting economic development is particularly difficult.

Tunisia's strategic situation

The land. *Relief and drainage.* Tunisia is characterized by moderate relief. The Tunisian Dorsale, or High Tell, a southwest-to-northeast mountain range that is an extension of the Saharan Atlas (Atlas Saharien) of Algeria, tapers off in the direction of the Cape Bon peninsula in the northeast, south of the Gulf of Tunis. The highest mountain, Mount ash-Sha'nabī (Djebel Chambi), located near the centre of the Algerian border, rises to 5,066 feet (1,544 metres), while Mount Zaghwān (Djebel Zaghouan), about 30 miles southwest of Tunis, reaches 4,249 feet (1,295 metres). Between the limestone peaks of the central Tunisian Dorsale and the mountains of the Northern Tell, which include the sandstone ridges of the Kroumirie Mountains in the northwest (reaching altitudes of 3,000 feet) and the Mogod Mountains, running along the deeply indented coastline to the north, lies the Majardah (Medjerda) Valley, formed by a series of ancient lake basins covered with alluvium. Containing the country's only perennially flowing river, which empties into the Gulf of Tunis, this valley was once the granary of ancient Rome and remains to this day the richest grain-producing region of Tunisia.

To the south of the Tunisian Dorsale lies a region of steppes known as the High Steppes in the west and the Low Steppes in the east. These have altitudes ranging from about 600 to 1,500 feet and are crossed by north-south secondary ranges. Farther south there is a series of chott (salty lake) depressions. Large plains border the eastern coasts; south of Sūsah (Sousse) lies the As-Sāḥil (Sahel) plain, and south of Qābis (Gabès) the Al-Jifārah (Gefara) Plain. The extreme south is desert, much of it part of the Great Eastern Erg.

Soils. Tunisia's most fertile soils are found in the well-watered intermontane valleys in the north, where rich sandy clay soils formed from alluvium or soils high in lime content cover the valley bottoms and plains. Aside from these and from the plains of the High Steppe region, where some clay soils of medium fertility may be found, soils in the rest of the country tend to be rocky or sandy in texture. In the dry south, moreover, they are often also saline because of excessive evaporation. The humid coastal plain in the east, running between the Gulfs of Ḥammāmāt and Gabes (Qābis), where Tunisia's thriving olive plantations are found, is the most agriculturally productive of these coarse-textured soil areas.

Climate. Tunisia is situated in the warm temperate zone between the 37th and the 30th parallels of latitude. In the north it has a Mediterranean climate characterized by mild, rainy winters and hot, dry summers with no marked intervening seasons. This changes southward to semiarid conditions on the steppes and to desert in the far south. Saharan influences give rise to the sirocco, a seasonal hot, blasting wind from the south that can have a seriously drying effect on vegetation.

Temperature and rainfall

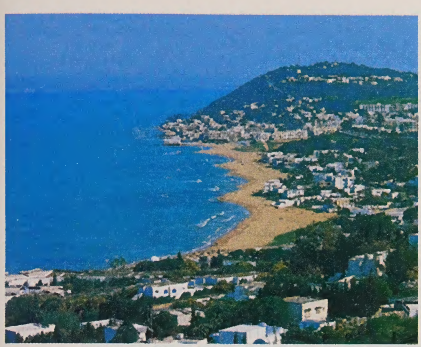
Temperatures are moderated by the sea, being less extreme at Sūsah on the coast, for example, than at Al-Qayrawān (Kairouan) inland. Temperatures at Sūsah average 44° F (7° C) for the month of January to a high of 89° F (32° C) for the month of August. Comparable temperatures at Al-Qayrawān are 40° F (4° C) in January and 99° F (37° C) in August.

The amount of rainfall varies considerably from north to south. A mean annual rainfall of about 60 inches (1,520 millimetres) occurs in the Kroumirie Mountains in northwestern Tunisia, making it the wettest region in North Africa, as compared with less than 4 inches at Tawzar (Tozeur) in the southwest. Generally, from the middle of autumn to the middle of spring, northern Tunisia receives more than 16 inches of rainfall, and the steppe region receives from 4 to 16 inches. Amounts are also highly irregular from one year to another, and irregularity increases southward toward the desert. Harvests vary as a result, being poor in dry years.

Plant and animal life. The vegetation and animal life of the country are affected by these climatic conditions. From north to south, the cork oak forest of the Kroumirie Mountains, with its fern undergrowth sheltering wild boars, gives way to scrub and steppes covered with esparto grass and populated with small game, and finally to the desert, where hunting is forbidden so as to preserve the remaining gazelles. Scorpions are found in all regions; among dangerous snakes are the horned viper and the cobra. Desert locusts sometimes damage crops in the southern part of the country.

Four demographic regions

Settlement patterns. Tunisia is divided into four natural and demographic regions: the north, which is relatively fertile and well watered; the semiarid central region; As-Sāḥil (the Sahel) in the east central coastal region, which is preeminently olive-growing country; and the south, where, except in the oases, all vegetation disappears. In the central and southern regions, there are still tribes that have preserved a certain cohesion through following a quasi-



La Marsa beach on the Gulf of Tunis, northeastern Tunisia.
Steve Vidler/Leo de Wys, Inc.

nomadic way of life. In the north and east, on the other hand, particularly along the coasts, the population is quite mixed and more dense, the life of the cultivator is more complex, the villages are more crowded, and the cities are larger. City populations have expanded at the expense of the countryside and by the late 20th century had encompassed more than three-fifths of the country's people; about one-ninth of Tunisia's population lives in Tunis alone. Growth has also been significant in the cities of Bizerte, Qābis, Qafṣah, Ṣafāqus, Sūsah, and Jundūbah.

The people. *Ethnic composition.* Tunisia's population is essentially Arab Berber. However, throughout the centuries Tunisia has received various waves of immigration that have included Phoenicians, sub-Saharan Africans, Jews, Romans, Vandals, and Arabs; Muslim refugees from Sicily settled in the As-Sāḥil after their homeland was captured by the Normans in 1091. The most notable immigration, however, was that of the Spanish Moors (Muslims), which began after the fall of Seville, Spain, in 1248 and turned into a veritable exodus in the early 17th century. As a result, 200,000 Spanish Muslims settled in the area of Tunis, in the Majardah valley, and on the Cape Bon peninsula in the north, bringing with them their urban culture and more advanced agricultural and irrigation techniques. From the 16th to the 19th century, the Turks brought their own blend of Asian and European traditions.

Linguistic composition. The cultural Arabization of the country had been completed by the end of the 12th century. Less than 1 percent of the population, in the south, still speaks the Berber language. French, introduced during the protectorate (1881–1956), paradoxically came into wider use after independence because of the spread of education. Although Arabic is the official language of the country, French continues to play an important role in the press, education, and government.

Religion. Muslims constitute virtually all of the population, and Islām in its Malikite Sunnite form is the state religion. Christian and Jewish minorities have declined substantially since independence; non-Muslims numbered more than 300,000 in 1956 and now only about 50,000.

Demographic trends. The population of Tunisia doubled during the last three decades of the 20th century. The country's natural growth rate is less rapid, however, than those of the other North African countries. Emigration has depressed the growth rate, with hundreds of thousands of Tunisians being employed abroad, notably in France and the Middle Eastern countries. Tunisia's relatively favourable demographic situation is reflected in its high life expectancy (among the highest in Africa), higher living standards, declining infant mortality rate, marriages at older ages, and progressive aging of the population.

The economy. Tunisia has a well-diversified economy, although it remains dominated by only a few large sectors. The economy is heavily dependent on mineral exports, especially petroleum and phosphates, and agricultural products. Tourism is also a significant source of revenue and foreign exchange, as are remittances from migrant workers living abroad. While foreign debt has been brought under control, the country suffers from a regional imbalance between the north and As-Sāḥil, which are more fertile and more economically developed, and the arid central and southern regions, which have fewer natural advantages.

Dependence on mineral exports

After a brief experiment with socialism in the 1960s, Tunisia shifted its economic doctrine toward a mixed planned and market economy. However, the economy fell into crisis in the early 1980s, the result of an over-reliance on oil revenues, foreign aid, and labour remittances. In the mid-1980s a comprehensive program was introduced to liberalize the economy, which helped restore Tunisia's international credit standing, stabilize public finances, reduce budget deficits and inflation, improve trade balances, and increase foreign and domestic investments. Public-sector reforms, deregulation, and privatization have also been implemented. By the end of the 1990s, the country's per capita gross national product equaled those of the lesser developed nations of Europe.

There are three large professional organizations: the General Union of Tunisian Workers, the principal trade union; the Tunisian Union of Industry, Commerce and Handicrafts, the main employers' organization; and the National Union of Tunisian Farmers, the principal agricultural union.

Resources. Tunisia's natural resources are limited. The lumber industry is essentially confined to the exploitation of oak and cork from the Kroumirie Mountains of the north, while the esparto grass of the plains is used for the manufacture of quality paper. Until the discovery of petroleum, the principal mineral resource was phosphate; of this, one-third is exported, with the remainder used by domestic chemical industries. Fertilizer is also a chief export.

Petroleum was discovered in the extreme south in 1964 at the Al-Burmah (El-Borma) field. Hydrocarbons are the third most valuable export after textiles and chemicals. As production fell in the 1980s, the government began developing several of the country's smaller oil fields. Nearly a dozen deposits were being exploited by the early 1990s, the largest fields being Al-Burmah and Ad-Dūlāb in southern Tunisia, Sīdī al-Yatā'im (Sidi el-Itayem) north of Ṣafāqis, the Ashtart field in the Gulf of Gabes, and the Tāzirkah field in the Gulf of Ḥammāmāt.

Petroleum reserves

In the early 1990s, Tunisia's petroleum reserves were estimated to be more than two billion barrels, a volume sufficient to maintain the country's low rate of extraction for several decades but insufficient to prevent Tunisia from becoming a net importer of petroleum products. Since then natural gas production has significantly increased, and foreign investment has been encouraged. Major British investments in the Al-Miskar field in the mid-1990s contributed to Tunisia's achieving self-sufficiency in natural gas production. Tunisia receives about 5 percent in royalties on gas that is pumped through a pipeline running through Tunisia, connecting the Algerian gas fields to Sicily.

Agriculture. Some two-thirds of Tunisia is suitable for farming, and more than one-fifth of the working population is employed in agriculture, yet agricultural production is still inadequate to meet the needs of Tunisia's growing population. Cereals, in particular, must be imported, as must meat and dairy products; sheep, goats, and cattle are raised but not in numbers sufficient to supply domestic demand. Low crop yields are partly a result of the division of the property into small, inefficient plots and from outdated farming methods. Climatic variations—periodic droughts and sporadic rainfall—often jeopardize harvests. Much of the country's agricultural investment has focused on irrigation schemes, the construction of wells and dams, and programs to prevent soil erosion and desertification. Nonetheless, Tunisia exports a fair amount of agricultural produce. The principal commodities are citrus fruits, olive oil, grapes, tomatoes, melons, figs, and dates. The fishing industry also contributes to the country's exports.

Industry. The industrialization of Tunisia has encountered two major difficulties. Raw material and power

supplies are inadequate, and the domestic market is limited. Notable and sometimes costly projects, such as the Manzil Bū Ruqaybah (Menzel-Bourguiba) iron-smelting complex, located near Bizerte, however, have been successfully established since independence was achieved in 1956. Existing industries produce foodstuffs, textiles, clothing, construction materials, household articles, and fertilizers. More than half of Tunisia's industry is located in Tunis. In the early 1970s, efforts were made to decentralize and to develop the south economically; for example, the state-owned Industries Chimiques Maghrébines (Maghrib Chemical Industries) complex, which produces phosphoric acid, was opened at Qābis in 1971. Tourism, however, remains Tunisia's leading industry. A vibrant handicraft industry has developed also in its wake. The number of tourists, mainly from western Europe, Libya, and Algeria, has increased steadily since the 1960s.

(M.Ta./J.I.C.)

Trade, finance, and management of the economy.

Importance of primary production

Tunisian overseas trade still reflects the importance of primary production. Exports are dominated by petroleum, fertilizers, and foodstuffs, but clothing has grown in importance. Countries of the European Community account for two-thirds of Tunisia's imports and exports. About a quarter of all trade is with France, with which Tunisia reached an agreement on trade and tariffs following the abolition of a customs union in 1959. The balance of payments is frequently adverse, and in some years this has obliged the government to limit imports.

The strength of the dinar and of the economy has been helped by international confidence in the political stability of Tunisia. The Central Bank of Tunisia performs the functions of an issuing bank. (W.C.B./J.I.C.)

Transportation. The network of roads and of railways is sufficiently dense so that all cities of any importance are linked with the interior regions. Tunisia is connected by both road and rail with Algeria and Morocco but only by road with Tripoli (Ṭarābulus), Libya, and Cairo, since the railway ends at Qābis. Work is being undertaken to modernize and extend the railway network.

The principal ports are Tunis-Ḥalq al-Wādī (La Goulette), which is the outport of Tunis; Ṣafāqis; Bizerte; and Sūsah, as well as the new port of Qābis in the south. An oil pipeline runs from Edjeleh, Alg., to the port of Aṣ-Ṣukhayrah (La Skhira, or Cekhira), on the Gulf of Gabes.

Despite the construction of airports at Al-Munastīr, Jarbah (Djerba), Ṣafāqis, and Tawzar, all of which handle domestic or tourist (charter) flights, international air traffic is directed mainly through Al-ʿUwaynah airport near Tunis.

Administration and social conditions. *Government.* The Tunisian constitution was promulgated in 1959 and amended in 1988; it defines Tunisia as a republic whose religion is Islām and whose official language is Arabic. Legislative power is exercised by the unicameral Chamber of Deputies, which consists of 141 delegates elected for five-year terms by universal suffrage. Executive power is in the hands of the president of the republic, who is head of state and head of the government. He must be a Muslim and is elected for a five-year term by universal suffrage at the same time as the deputies; since 1988 he has been limited to three consecutive terms.

The country is administered by the Cabinet, headed since 1969 by a prime minister. The Cabinet ministers are responsible to the president rather than to the Chamber of Deputies, which, however, holds the power to censure the Cabinet. If such censuring occurs, the president may dismiss the Chamber of Deputies and hold fresh elections. If censured again by the new Chamber, the government must resign.

The Council of State comprises two judicial bodies: an administrative body dealing with legal disputes between individuals and state or public institutions, and a public audit office. The court system consists of magistrate courts at the local level, courts of the first instance, courts of appeal, and a high court in Tunis. Judicial power is exercised by judges whose independence is constitutionally guaranteed.

The constitution guarantees "freedom of opinion, expression, press, publication, assembly, and association" ("under the conditions defined by law"), as well as the right to form trade unions. Despite the introduction of new political parties in November 1981 and permission for a multiparty system in 1988, Tunisia has continued to be governed under a one-party system, that of the Democratic Constitutional Assembly party (originally called the Neo-Destour, to distinguish it from an older Destour Party founded in 1920). The Democratic Constitutional Assembly party, allied with the UGTT, controls the Chamber of Deputies. All Tunisians, including women, who are at least 20 years of age can vote. There is typically a massive turnout for elections, with 90 percent of the registered voters participating.

Local administration

The country is divided into 23 administrative areas called *wilāyāt* (provinces; singular *wilāyah;* French: *gouvernorats*), which are headed by walis (governors). Each province is designated by the name of its chief town and is in turn subdivided into units called *muʿtamadiyāt* (delegations; French: *délégations*), whose number varies according to the province's size. Delegations are administered by a *muʿtamad* and are in turn divided into varying numbers of districts called *manṭaqa turābiyyas.*

Education. Education is free to all students, and scholarships in schools and universities are offered largely on the basis of merit and need. The number of students, schools, and teachers, and the level of literacy have all increased steadily since independence.

This growth has posed problems of financing—education absorbs about one-seventh of the national budget—and of finding enough job opportunities for qualified people. More emphasis has been placed on technical, vocational, teacher, and agricultural training. The large University of Tunis (founded 1960) is the country's major institution of higher education. Two new universities were opened at Al-Munastīr (near Sūsah) and Ṣafāqis in the mid-1980s.

Health and welfare. The living standards of the population in general are modest but rising, with a strong program of social welfare in place and with continuing efforts to advance the role of women through legal equality. The advantages available consist, in addition to the distribution of milk to newborn babies and of school lunches, of free medical care for the destitute and of the extension of the social security system, which provides medical benefits, hospitalization, and maternal and family benefits, to virtually all wage earners. There is also a good network of hospitals and clinics, which has contributed to a relatively low death rate overall and, in particular, to the lowest infant mortality rate on the African continent.

The state of the arts

Cultural life. Tunisia is a country that prides itself on its strong and unique cultural life. It is an Arabic-speaking Muslim country that was deeply imbued with French culture during the 75 years of the protectorate, which ended in 1956. Indications of this are that four of the country's six major daily newspapers are in French and radio programs in French are broadcast regularly. Although Tunisians generally use French in all scientific disciplines, they remain genuinely attached to Arabic in the literary sphere—in poetry, the novel, and the short story. Several literary reviews, the most important of which is *Al-Fikr* ("Thought"), open their pages to youthful talents and stimulate literary output. Modern Tunisian literature, the subject of great debate on radio and television and in the various government-sponsored Houses of Culture (Maisons de la Culture), has made remarkable progress.

Although the Tunisian cinema is still in its infancy, having to its credit no more than a few successful films, contemporary Tunisian painting can already lay claim to a certain tradition. Some of the artists enjoy a genuine local celebrity and also have exhibited abroad. Many have benefited from sales to tourists, but Tunisians have generally been concerned about the influence of tourism upon their social and cultural lives. The music conservatory devotes attention mainly to national traditions but also emphasizes the classical European heritage.

A major effort is in progress to diffuse and decentralize cultural benefits through local libraries, theatres, and museums, and traveling libraries make films and books available to the most remote corners. Television, which naturally plays an important role, likewise covers the en-

tire country; its programs are in Arabic and French and provide information, education, and entertainment.

(M.Ta./J.I.C.)

For statistical data on the land and people of Tunisia, see the *Britannica World Data* section in the BRITANNICA BOOK OF THE YEAR.

HISTORY

Tunisia was called Ifriqiyah in the early centuries of the Islāmic period. That name, in turn, comes from the Roman name for Africa. The smallest of the Maghrib states, Tunisia is also the most cohesive. By the beginning of the 19th century virtually all its inhabitants were Arabic speakers. Berber, the earlier language of all the Maghrib, survived in Tunisia in only a few pockets, especially in the extreme south. The vast majority of the population was Muslim, with perhaps 5 percent being Jewish. A single major city, Tunis, dominated the countryside politically and culturally. Tunis itself was located near the site of the earlier Carthage. More easily controlled from within than any other Maghrib country, Tunisia was also more open to the influence of people and ideas coming from abroad. Roman Africa, for example, was the most intensively Christianized portion of North Africa, and Ifriqiyah was later more quickly and more thoroughly Islāmicized.

A small state with limited resources, Tunisia, however, often managed a considerable autonomy within the framework of larger empires ruled from afar. This status was achieved, for example, under the 'Abbāsids in the 9th century and later under the Ottomans. This geographic and historical legacy helped prepare Tunisia for the shocks that it would receive in the 19th century as a land caught between an expanding Europe and a declining Ottoman Empire. Yet, Tunisia proved itself to be as vulnerable economically as it was militarily. (L.C.Br.)

The growth of European influence. In 1830, at the time of the French invasion of Algiers, Tunisia was a province of the Ottoman Empire but autonomous in fact. Because the principal military threat had long come from neighbouring Algeria, the reigning bey of Tunisia, Ḥusayn, cautiously went along with French assurances. Ḥusayn Bey even accepted the idea that Tunisian princes be appointed rulers of Constantine and Oran. It soon became clear that the scheme had no chance of success, however, and it was abandoned.

Then, in 1835, the Ottoman Empire seized the opportunity of a disputed succession in Libya to depose the ruling dynasty there and to reestablish direct Ottoman rule. Thereafter, the vulnerable beylik of Tunis found itself surrounded by two larger powers—France and the Ottomans—both of whom sought hegemony in Tunisia. From that time until the establishment of the French protectorate in 1881, Tunisian rulers sought to keep the larger outside powers in balance while working to strengthen the state from within.

Attempts at reform

Aḥmad Bey, who ruled from 1837 to 1855, was an avowed Westernizer. He brought in Western advisers (mainly French) to help create a modern army and navy and related industries. Conscription was introduced to the great dismay of the peasantry. More acceptable were Aḥmad's steps to better integrate Arabic-speaking native Tunisians into the government, which had long been dominated by Mamlūks and Turks. Aḥmad abolished slavery and took other steps intended to bring Tunisia more in line with Europe, but he also exposed his country to Europe's infinitely greater economic and political power. These governmental innovations imposed upon a stagnant economy increased financial obligations that were met by higher taxes. These, in turn, provoked unrest in the countryside.

The next bey, Muḥammad (1855–59), sought to turn his back on Europe, but this was no longer possible. The execution of a Tunisian Jew for blasphemy brought swift British and French action that forced the bey to issue the Fundamental Pact ('Ahd al-Amān; Sept. 9, 1857), a civil rights charter modeled on the Ottoman rescript of 1839.

The final collapse of the Tunisian beylik came during the reign of Muḥammad aṣ-Ṣadiq (1859–82). By nature disposed to Westernizing reforms, he was, however, too weak either to control his own government or to keep the several European powers at bay. In 1861 the first constitution (*dustūr*) in the Arab world was proclaimed, but this promising step toward representation and responsible government was brought to naught by runaway indebtedness exacerbated by the practice of securing loans from European bankers at exorbitant rates.

When the principal minister, Muṣṭafā Khaznadār (who had served from the earliest days of Aḥmad Bey's reign), attempted to squeeze more taxes out of the hard-pressed Tunisians, the countryside rose in a revolt (1864) that almost overthrew the regime, but a combination of governmental guile and brutality managed to restore order.

Tunisia was bankrupt in 1869, and an international financial commission—with British, French, and Italian representation—was imposed on the country. One last important attempt to strengthen Tunisia from within and thus avoid European domination was made during the reformist ministry of Khayr ad-Dīn (1873–77), one of the most impressive statesmen of the 19th-century Muslim world. Enemies from within the Tunisian government and European consular intrigues, however, forced him from office. All that was needed for France to establish control in Tunisia was the acquiescence of France's principal rival, Britain, and this was obtained at the Congress of Berlin in 1878.

French occupation

The end came in 1881 when the French, on the pretext that some Tunisian tribespeople had moved into Algerian territory, invaded the country and imposed on the bey the Treaty of Kasser Said (Al-Qaṣr as-Sa'id) that sanctioned French military occupation, transferred to France the bey's authority in foreign relations and finance, and provided for the appointment of a French resident minister as intermediary in all matters of common interest. This provoked an uprising in southern Tunisia during which Sousse (Sūsah) was bombarded and captured in July 1881; Kairouan (Al-Qayrawān) was then captured in October, and Gafsa (Qafṣah) and Gabès (Qābis) in November. After the death of the bey Muḥammad aṣ-Ṣadiq, his successor, 'Alī, was constrained to sign an undertaking to introduce such administrative, judicial, and financial reforms as the French government might consider useful. This agreement, known as the Convention of Al-Marsa and signed in 1883, made French control complete.

The protectorate (1881–1956). The arrangement thus arrived at was very different from that in Algeria. The basis was a treaty, not outright conquest. The bey remained in theory an absolute monarch; Tunisian ministers were still appointed, and the framework of the old government machinery was preserved. Tunisians continued to be subjects of the bey. There was no confiscation of land; mosques were not converted into churches; and Arabic remained an official language. Nevertheless, the supreme authority passed in fact into the hands of the French resident general. Under French guidance the finances were soon brought into order, and a modern communications system was established. Though there was none of the wholesale confiscation of land and displacement of population that had occurred in Algeria, the most fertile portions of northern Tunisia, comprising the Majardah Valley and the Cape Bon peninsula, passed largely into the hands of Europeans. Valuable phosphate mines were brought into operation near Gafsa in the south, while the extensive establishment of French and Italian colonists in the Majardah Valley resulted in a considerable export of vegetables.

Young Tunisians

By the 1890s a small Western-trained group—the members of which came to be called "Young Tunisians"—began to push for both Westernizing reforms and greater Tunisian participation in government. Their conduct during the protectorate was necessarily cautious; their major weapon, the newspaper *Le Tunisien*, was founded in 1907 as a French-language publication, an Arabic edition not appearing until 1909. Increased modern-style education was a principal goal. The Young Tunisians sought simultaneously to educate their compatriots and to persuade the more liberal French to help move Tunisia toward modernity. There was no explicit talk of independence.

Even this moderate protonationalism came to grief before French repression in 1911–12. Little nationalist activity

took place during World War I (1914–18), but the postwar period brought the first attempt at mass political organization with the creation of the Destour Party (Constitution Party, so named for the short-lived Tunisian constitution of 1861). In 1920 the Destour Party presented to the bey and to the French government a document that in effect demanded the establishment of a constitutional form of government in which Tunisians would possess equal rights with Europeans. The immediate result was the arrest of 'Abd al-Azīz ath-Tha'alibi, the Destour leader. Two years later, the aged bey, Muḥammad an-Nasir, requested the adoption of the program of the Destour, failing which he threatened to abdicate. The resident general, Lucien Saint, responded by surrounding the bey's palace with troops, with the result that the demand was withdrawn. Saint thereupon introduced repressive measures, together with minor reforms, that pacified Tunisian sentiment and weakened the nationalist movement for several years.

Emergence of Bourguiba

In 1934 a young Tunisian lawyer, Habib Bourguiba, and like-minded colleagues broke with the Destour Party to form a new organization, the Neo-Destour, which aimed at gaining mass support. Under Bourguiba's vigorous leadership the new party supplanted the existing Destour and its old-fashioned leaders. Attempts by the French to suppress the new movement spread its popular appeal. The arrival of the Popular Front government to power in France in 1936 enabled the Neo-Destour to extend its propaganda there also. When the Popular Front government collapsed, renewed repression in Tunisia was followed by civil disobedience; and in 1938 serious disturbances resulted in the arrest of Bourguiba and other leaders of the party, which was officially dissolved.

World War II. On the outbreak of war in 1939, Neo-Destour leaders were deported, still untried, to France. They were released by the Nazis when they occupied Vichy France in 1942 and, since Hitler regarded Tunisia as a sphere of Italian influence, handed over to the Fascist government in Rome. There they were treated with deference, in the hope of eliciting a declaration favourable to the Axis. Bourguiba, however, steadily refused, in spite of the suggestions of some of his companions. In March 1943, after a noncommittal broadcast by him, the Neo-Destour leaders were finally allowed to proceed to Tunis, where the reigning bey, Muḥammad al-Munsif (Moncef), formed a ministry of Destour sympathies.

The assumption of power by the Free French after the Nazi retreat resulted in complete disillusionment. The bey himself was deposed, while Bourguiba escaped imprisonment only by fleeing in disguise to Egypt (1945). He began a vigorous campaign of propaganda for Tunisian independence. In view of the emancipation of the eastern Arab states, and later of the neighbouring, relatively backward Libya, the French felt compelled to make concessions. In 1951 a government with nationalist sympathies was allowed to take office, of which the secretary-general of the Neo-Destour, Salah Ben Youssef, became a member. Bourguiba was allowed to return to Tunisia. When, however, this government wished to establish a Tunisian parliament, the result was further repression. Bourguiba was confined, and most of the ministers were put under arrest. This resulted, for the first time, in outbreaks of terrorism; and nationalist bands began to operate in the mountains, virtually paralyzing the country.

Outbreak of terrorism

In July 1954 the French premier, Pierre Mendès-France, promised to grant complete autonomy to Tunisia, subject to a freely negotiated convention. Bourguiba was released and was able to supervise the negotiations without directly participating. In June 1955 the convention was finally signed by the Tunisian delegates, though it imposed strict limits in the fields of foreign policy, education, defense, and finance, and a mainly Neo-Destour ministry was formed. Salah Ben Youssef denounced the agreement as too restrictive, refused to attend a specially summoned congress unanimously supporting Bourguiba, and organized a brief armed resistance in the south; this was quickly put down, and Ben Youssef fled the country. He was assassinated in 1961.

Independence. Having conceded full independence to Morocco, the French were no longer inclined to resist the same for Tunisia, and an accord was reached on March 20, 1956, for Tunisian independence, with Bourguiba as prime minister. On July 25, 1957, the rule of the beys was abolished and a republic was declared, with Bourguiba assuming the presidency.

Domestic development. The best organized mass political party in the Arab world, the Neo-Destour Party (from 1964 to 1988, the Destourian Socialist Party; from 1988, the Democratic Constitutional Assembly) ensured that independent Tunisia could move quickly with reforms. Advances in education, the liberation of women, and legal reforms were especially impressive. Economic development was less dramatic, but the government creditably gave attention to the more impoverished parts of the country. In 1961 Ahmad Ben Salah took charge of planning and finance (adding the portfolio of education in 1968). His ambitious efforts at forced-pace modernization, especially in agriculture, were foiled, however, by rural and conservative opposition. Expelled from the party in 1969 and imprisoned, he escaped in 1973, to live in exile. His fall brought a move to a more conservative orientation.

In 1975 the Chamber of Deputies unanimously bestowed the presidency for life on the sick and aged Habib Bourguiba. Hedi Nouira, noted for his financial and administrative skills, became prime minister in November 1970. A decade later, in 1980, Muḥammad Mzali replaced the ailing Nouira. This inaugurated an effort to restore dissidents to the party and then, in 1981, to grant amnesty to many who had been jailed for earlier disturbances. Bourguiba was persuaded to accept a multiparty system, but results of the elections of November 1981 were disappointing to those who sought political liberalization. The National Front, an alliance of the Destourian Socialist Party and the trade union movement, swept all 136 parliamentary seats, a result received with cynicism and dismay by the opposition. National elections in 1986 were boycotted by the major opposition parties, and the National Front once again carried the vote. In November 1987, amid widespread unrest and rising Islāmic fundamentalism, Bourguiba was declared mentally unfit to rule and was removed from office. He was succeeded by General Zine el-Abidine Ben Ali, whom he had appointed as prime minister in October 1987. Bourguiba's long rule, widely popular in early years except among traditionalist groups, had later provoked increasing if largely passive opposition among Tunisians. In declining health since at least the early 1970s, Bourguiba was less able to mask his autocratic tendencies by the ample political skills that he had once possessed. The Ben Ali era has not thus far produced the political liberalization expected. In the national elections in 1989 the president gained 99 percent of the vote, and the Democratic Constitutional Assembly won all 141 seats in the legislature. Local elections in 1990, boycotted by opposition parties, were swept by the ruling party as well.

Foreign relations. Three crises in Franco-Tunisian relations were the French bombing raid on the Tunisian village of Sāqiyat Sidī Yūsuf in 1958, during which France claimed the right of pursuit of Algerian rebels; the Bizerte incident of 1961, concerning the continued military use of that port and airfield facility by France; and the suspension of all French aid in 1964–66 after Tunisia abruptly nationalized land held by foreigners. Such difficulties aside, postindependence Tunisian relations with France have been good. Tunisia has also been successful in establishing good relations with the United States and most European states, skillfully building up a multinational pattern of economic and technical aid.

Tunisia's relations with the Arab world have been subject to oscillations. There was a dispute with Egypt and the majority of Arab states when, in 1965, Bourguiba urged a more diplomatic approach toward Israel. Since independence there have also been several periods of tension with Algeria and Libya. Generally, however, Tunisia has been able to increase its standing in the Arab world. When Egypt was expelled from the Arab League for having signed a peace treaty with Israel in 1979, the Arab League moved its headquarters from Cairo to Tunis, where it remained until it was moved back to Cairo in 1990. The Palestine Liberation Organization under Yāsir 'Arafāt opened its

headquarters in Tunis in August 1982 after being forced to leave Beirut. (N.B./L.C.Br.)

Tunisia's decidedly Western orientation after independence bore the strong mark of Bourguiba. His departure from power in 1987, coupled with the rise of Islāmic fundamentalism and increasing Tunisian ties with the Arab world, have produced changes. The Tunisian government, for example, opposed the United States-led coalition of forces against Iraqi President Saddam Hussein's invasion of Kuwait in August 1990, a stand warmly supported by the Tunisian people. This stance created long-standing difficulties in relations with the Gulf states, however. Gen. Zine al-Abidine Ben Ali, Bourgiba's successor, ruled at the head of the Constitutional Democratic Assembly in a virtual one-party government, winning reelection in 1995 and 2000. Some token opposition movements were allowed to exist, but on the whole dissent was suppressed and dissenters imprisoned. (N.B./L.C.Br./Ed.)

For later developments in the history of Tunisia, see the BRITANNICA BOOK OF THE YEAR.

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(J.I.C./B.H.W./J.M.A.-N./L.C.Br./W.D.Sw./M.Br./G.L.F./K.Su.)

North America

The third largest of the world's continents, North America occupies the northern portion of the landmass generally referred to as the New World, the Western Hemisphere, or simply the Americas. Mainland North America is shaped roughly like a triangle, with its base in the north and apex in the south; associated with the continent is Greenland, the largest island in the world, and such offshore groups as the Arctic Archipelago, the Bahamas, the Greater and Lesser Antilles, the Queen Charlotte Islands, and the Aleutian Islands.

North America is bounded on the north by the Arctic Ocean, on the east by the North Atlantic Ocean, on the south by the Caribbean Sea, and on the west by the North Pacific Ocean. To the northeast, Greenland is separated from Iceland by the Denmark Strait, and to the northwest, Alaska is separated from the Asian mainland by the much narrower Bering Strait; North America's only land connection is to South America at the narrow Isthmus of Panama.

North America has a total area of some 9,418,000 square miles (24,392,000 square kilometres). Its greatest north-south extent exceeds 5,000 miles (8,000 kilometres), and its broadest east-west distance is approximately 4,000 miles. Mount McKinley in Alaska, at 20,320 feet (6,194 metres) above sea level, is the continent's highest point; and Death Valley in California, at 282 feet (86 metres) below sea level, is its lowest. North America's coastline of some 37,000 miles is notable for the great number of indentations, particularly in the northern half.

The name America is derived from that of the Italian merchant and navigator Amerigo Vespucci, one of the earliest European explorers to the New World. Although at first the term America was applied only to the southern half, the designation soon was applied to the entire landmass; those portions that widened out north of the Isthmus of Panama became known as North America, and those that broadened to the south became known as South America. According to some authorities, North America begins not at the Isthmus of Panama but at the narrows of Tehuantepec, with the intervening region called Central America. Under such a definition, part of Mexico must be included in Central America, although that country lies mainly in North America proper. To overcome this anomaly, the whole of Mexico, together with Central and South American countries, also may be grouped under the name Latin America, with the United States and Canada referred to as Anglo-America. This cultural division is a very real one; yet Mexico and Central America (including the Caribbean) are bound to the rest of North America by strong ties of physical geography. Greenland also is culturally divided from, but physically close to, North America.

North America was the first continent to achieve its current approximate size and shape, and it contains some of the oldest rocks on the Earth. Its geologic structure is built around a stable platform of Precambrian rock called the Canadian (Laurentian) Shield. To the southeast of this rose the ancient Appalachian Mountains; and to the west rose the younger and considerably taller Cordilleras, which occupy nearly a third of the continent's land area. In between these two mountain belts are the generally flat regions of the Great Plains in the west and the Central Lowlands in the east.

The continent is richly endowed with natural resources, including great mineral wealth, vast forests, immense quantities of fresh water, and some of the world's most fertile soils. These have allowed North America to become one of the most economically developed regions in the world, and its inhabitants enjoy a high standard of living. North America has the highest average income per person of any continent and a food intake per person considerably greater than the average for Asia. Although it is home to less than 10 percent of the world's population, its per capita consumption of energy is almost six times as great as the average for all the other continents.

North America's first inhabitants are believed to have been ancient Asiatic peoples who migrated from Siberia to North America sometime during the last (Wisconsin) glacial advance. The descendants of these peoples, the various Indian and Eskimo peoples, largely have been supplanted by peoples from the Old World. People of European ancestry constitute the largest group, followed by those of African and of Asian ancestry; in addition there is a large group of Latin Americans, who are of mixed European and Indian ancestry. (J.W.W./Ed.)

This article treats the physical and human geography of North America, followed by discussion of geographic features of special interest. For discussion of individual countries of the continent, see the articles CANADA, MEXICO, and UNITED STATES OF AMERICA. Other North American countries are treated in articles on regions under the titles CENTRAL AMERICA and WEST INDIES. For discussion of major cities of the continent, see specific articles by name—*e.g.*, MEXICO CITY, NEW YORK CITY, and TORONTO. For discussion of the indigenous peoples of the continent, see the articles AMERICAN PEOPLES, NATIVE and PRE-COLUMBIAN CIVILIZATIONS. The principal treatment of North American historical and cultural development is contained in the articles mentioned above and in the article LATIN AMERICA, HISTORY OF. For further discussion of arts and literature, see the articles AMERICAN LITERATURE; AMERICAN PEOPLES, ARTS OF NATIVE; CANADIAN LITERATURE; and LATIN-AMERICAN LITERATURE. For further references, see also the *Index*.

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PHYSICAL AND HUMAN GEOGRAPHY

Geologic history

GENERAL CONSIDERATIONS

Continents have collided and broken apart repeatedly over geologic time. When they separate, new ocean basins develop between the diverging pieces through the process of seafloor spreading. Spreading, which originates at oceanic ridges, is compensated (to conserve surface area) by subduction—the process whereby the seafloor flexes and sinks along inclined trajectories into the Earth's interior—at deep-sea trenches. Closure of ocean basins by subduction of the seafloor results in continental collisions.

The material moved laterally from spreading ridges to subduction zones includes plates of rock up to 60 miles (100 kilometres) thick. This rigid outer shell of the Earth is called the lithosphere, as distinct from the underlying hotter and more fluid asthenosphere. The portions of lithospheric plates descending into the asthenosphere at subduction zones are called slabs. The 14 independent lithospheric plates that make up the present surface of the Earth are bounded by an interlinking system of oceanic ridges, subduction zones, and laterally moving fractures known as transform faults. Over geologic time, the system of plate boundaries has continually evolved as new plates have formed, expanded, contracted, and disappeared.

The outermost layer of the lithosphere is called the crust. It is composed of low-density material crystallized from molten rock (magma), produced by partial melting of the lithosphere or asthenosphere. The average thickness of the oceanic crust is about four miles. Oceanic plateaus and seamounts are localized areas of abnormally thick oceanic crust that have resulted from submarine volcanism promoted by hot jets, or plumes, rising from deep within the Earth's interior (*i.e.*, from the mantle). Oceanic crust is transient, being formed at the oceanic ridges and destroyed at the trenches. It has a mean age of about 60 million years.

Continental crust

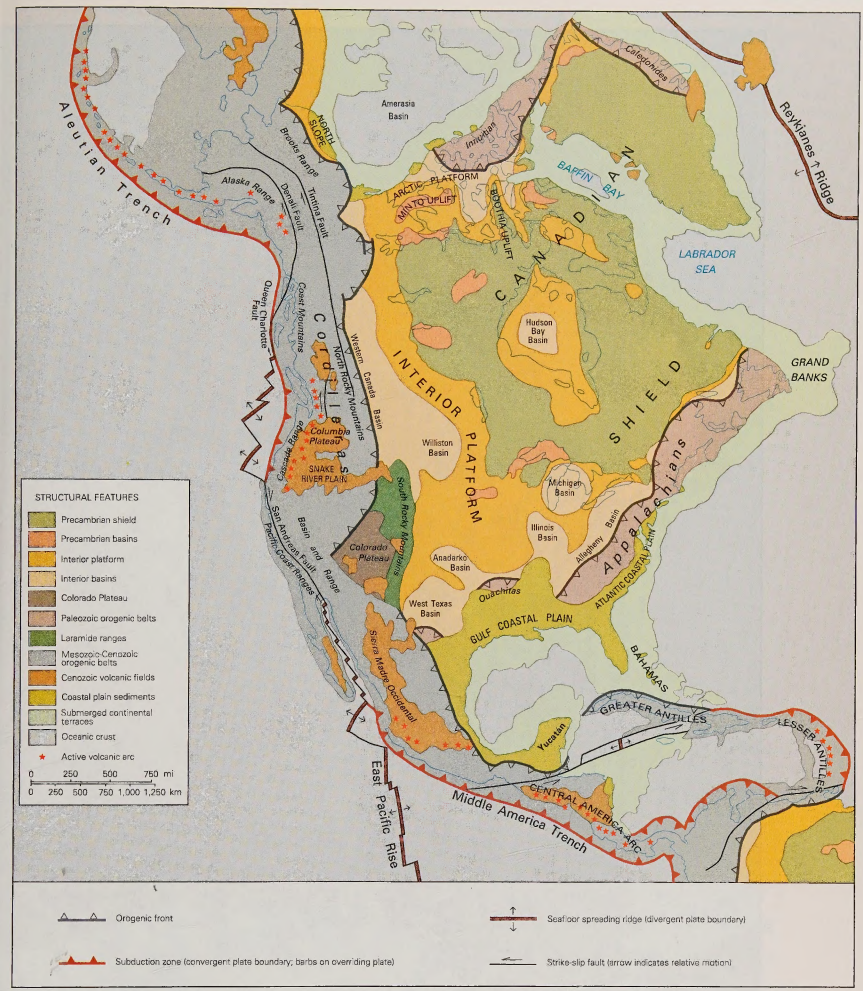
Continental crust averages 22 miles in thickness, accounting (according to Archimedes' principle of fluid displacement) for its mean surface elevation of about 3 miles above that of the ocean floor. Continental crust is more complex than oceanic crust in its structure and origin and is formed primarily at subduction zones. Lateral growth occurs by the addition of rock scraped off the top of oceanic plates as they are subducted beneath continental margins. Such margins are marked by lines of volcanoes, called volcanic arcs, that manifest additions to the crust resulting from partial melting of the wedge of the asthenosphere situated above the descending slab and below the continental plate (melting is promoted by the release of water from the slab, which lowers the melting point in the wedge). Subduction zones located within ocean basins (where one oceanic plate descends beneath another) also generate volcanic arcs, which are called island arcs. Island arcs consist of materials that tend to be transitional between oceanic and continental crust in both thickness and composition. The first continents appear to have formed by the accretion of island arcs.

Continental crust resists subduction. Consequently, the mean age of the continents is almost two billion years, more than 30 times the average age of the oceanic crust. Thus, continents are the prime repositories of information concerning the Earth's geologic evolution, but understanding their formation requires a knowledge of processes in the ocean basins from which they evolved.

TECTONIC FRAMEWORK

Structural plan. North America is unique among the continents in having stable interior lowlands of great antiquity that are almost completely enclosed by younger orogenic belts (belts of former or actual mountain ranges resulting from crustal deformation related to subduction or continental collision). These lowlands include the Canadian (Laurentian) Shield and an interior platform of crystalline rock that is covered by a veneer of virtually flat-lying sedimentary rock.

The continent's peripheral orogenic belts originated at plate boundaries, and they are of Paleozoic age (540 to 245 million years ago) in the east and Mesozoic to Cenozoic age (245 million years ago to the present day) in the west. These belts are partly covered, and locally breached, by coastal plain sediments of the Arctic Ocean in the north, the Gulf of Mexico in the south, and relatively young volcanic fields in the west. A gap in the Paleozoic orogenic belts between the Appalachian Mountains of Newfoundland and the East Greenland Caledonides is a consequence of seafloor spreading at the mid-Atlantic Reykjanes Ridge, which caused a small portion of the system (the Rockall Bank in the North Atlantic and northwestern Britain) to drift eastward.



Structural features of North America.
Adapted from Paul F. Hoffman, Geological Survey of Canada

The Canadian Shield. The Canadian Shield is the principal area of North America where rocks of Precambrian age (*i.e.,* those that are more than about 540 million years old) arch to the surface. The shield was rifted apart between Canada and Greenland by abortive seafloor spreading in the Labrador Sea and in Baffin Bay between 90 and 40 million years ago. The Greenland Shield is now largely ice-covered. During the past 2.5 million years, the Canadian Shield also has provided centres of ice accumulation from which continental ice sheets advanced southward repeatedly.

The shield is an aggregate of at least four discrete continents that were fused together between about 2.0 and 1.8 billion years ago. Three of the constituent continents behaved as relatively rigid dies, called cratons, that indented and pervasively deformed the remaining continent

The three cratons


GREENLAND (Den.)
LABRADOR SEA
ATLANTIC OCEAN
Baffin Bay
Hudson Bay
CANADA
ARCTIC OCEAN
BEAUFORT SEA
CHUKCHI SEA
BERING SEA
PACIFIC OCEAN
ROCKY MOUNTAINS
MACKENZIE MTS.
UNITED STATES
ALASKA
Gulf of Alaska
ALEUTIAN ISLANDS
ST. LAWRENCE ISLAND
QUEEN ELIZABETH ISLANDS
BAFFIN ISLAND
VANCOUVER ISLAND
CHARLOTTE ISLANDS
PRINCE OF WALES ISLAND
Arctic Circle
180° 170° 160° 150° 140° 130° 120° 110° 100°
80°
70°
60°
50°
40°


National capitals
International boundaries
Canals
Aqueducts
Reefs
Dams
Waterfalls
Salt lakes
Glaciers
Swamps and marshes
Sand areas
Spot elevations in metres (1 m = 3.28 ft.)
ELEVATION (in metres)
4000
3000
2000
1000
500
200
0
Below sea level
UNITED STATES
MEXICO
Gulf of Mexico
Bay of Campeche
YUCATAN PENINSULA
ISTHMUS OF TEHUANTEPEC
GREATER ANTILLES
LESSER ANTILLES
CARIBBEAN SEA
BERMUDA (U.K.)
THE BAHAMAS
CUBA
JAMAICA
HAITI
DOMINICAN REPUBLIC
CAYMAN ISLANDS (U.K.)
TURKS AND CAICOS (U.K.)
PUERTO RICO (U.S.)
VIRGIN ISLANDS (U.S.)
BRITISH VIRGIN ISLANDS (U.K.)
ANGUILLA (U.K.)
ANTIGUA AND BARBUDA
MONTSERRAT (U.K.)
SAINT KITTS AND NEVIS
GUADELOUPE (Fr.)
DOMINICA
MARTINIQUE (Fr.)
SAINT VINCENT AND THE GRENADINES
SAINT LUCIA
BARBADOS
GRENADA
ARUBA (Neth.)
NETHERLANDS ANTILLES (Neth.)
TRINIDAD AND TOBAGO
BELIZE
HONDURAS
GUATEMALA
EL SALVADOR
NICARAGUA
COSTA RICA
PANAMA
Tropic of Cancer
Equator
Scale 1:31,366,000
1 inch equals approx. 495 miles
0 100 200 300 400 500 mi
0 100 250 500 750 km
Chamberlin Trimetric Projection
BERING SEA
ALEUTIAN ISLANDS
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during their mutual aggregation; the Slave craton lies to the northwest, the Nain craton to the northeast, and the Superior craton to the south of the intervening nonrigid Churchill province, which may be composite in origin. The structural grain of the cratons is truncated at their margins, suggesting that they originated by the fragmentation of larger continents that formed more than 2.6 billion years ago. Small remnant basins of essentially flat-lying Precambrian sedimentary rocks are arbitrarily included in the shield because of their age, although they have more in common structurally with the interior platform and basins.

Interior platform and basins. Nearly horizontal strata of sedimentary rocks overlie Precambrian crust that extends beyond the limits of the Canadian Shield. The sedimentary cover is less than a mile thick on the platform, but it increases to about 2.5 miles in the Hudson Bay, Michigan, Williston, and Illinois basins and up to 4 miles and more in troughs adjacent to the peripheral orogenic belts. The sedimentary rocks provide sensitive records of differential basement subsidence, the geomorphic evolution of the peripheral orogenic belts, fluctuations of sea level, and climatic changes related in part to latitudinal continental drift.

Paleozoic orogenic belts. Erosional remnants of ancient mountain ranges occur along the eastern, northern, and southern margins of the continent. The mountains were created mainly between 400 and 300 million years ago, when North America collided with other continents to form the ancient supercontinent of Pangaea. The Ouachita Orogen (mountain chain) formed when the south-facing margin of North America collided with South America, the Appalachian Orogen when the southeast-facing margin collided with northwestern Africa, the Caledonian Orogen when the northeast-facing margin collided with northwestern Europe, and the Franklinian Orogen when the Arctic margin collided with crust that now underlies the Barents shelf off northern Europe and Alaska north of the Brooks Range. The portions of the orogenic belts next to the continental interior are composed mainly of folded sedimentary rocks indigenous to North America. The parts closer to the modern oceans are more diverse and include rock masses that originated outside the continent. A striking observation from paleogeographic reconstructions is that the present-day ocean basins opened along lines close to the lines of closure of the preceding Paleozoic oceans.

Passive continental terraces. Sediments younger than 200 million years are draped across the rifted eastern, northern, and southern margins of the continent. The rifted margins formed when the Atlantic and Arctic oceans and the Gulf of Mexico began to open. Rivers transported great quantities of sediment to the Gulf of Mexico and the Arctic Ocean. In both areas the resulting sediments are now pierced from below by fingerlike masses of salt, called salt domes, that often are many miles in diameter. In the Arctic, sediments older than about 40 million years were crumpled during the counterclockwise rotation of Greenland as it drifted away from northeastern Canada. Sediments deposited along the Atlantic margins of North America lie mostly underwater.

Mesozoic and Cenozoic orogenic belts. The youngest mountain ranges formed along the western margin of the continent (the Cordilleras) and around the Caribbean Sea.

Formation of the Cordilleras

The development of the Cordilleras occurred mainly after the Atlantic Ocean began to open and North America started drifting westward over the floor of the Pacific Ocean, about 180 million years ago. As a result, sedimentary and volcanic rocks were sheared off the Pacific Plate that was being subducted and were accreted to the leading (western) edge of the continent. Simultaneously, volcanic arcs formed inland of the continental margin. For about 30 million years North America has been overriding the East Pacific Rise, a centre of seafloor spreading, resulting in a fundamental segmentation of the Cordilleras. As the seafloor west of the spreading axis moves sideways (northward) relative to North America, those segments of the continental margin that have crossed the spreading ridge (*i.e.*, California and northwestern Canada) are characterized by faults (the San Andreas and Queen Charlotte) with right-lateral displacements and by the absence of trenches or volcanic arcs.

The present Caribbean Sea floor originated as a submarine plateau in the eastern Pacific basin. For about 80 million years, it has progressively penetrated the gap formed earlier by the separation of the North and South American plates. As the two plates (including the western Atlantic) drifted westward, subduction and arc volcanism occurred along the eastern margin of the Caribbean, and the northern and southern margins of the Caribbean were sheared and dismembered. Arc volcanism in Central America is related to subduction of the Pacific Ocean floor at the Middle America Trench off the region's Pacific coast; it is mirrored by subduction of the Atlantic floor beneath the Lesser Antilles volcanic arc.

Cenozoic volcanic fields. Volcanism in the Cenozoic Era (*i.e.*, in the past 66.4 million years) is related to subduction-zone processes, mantle plumes, and crustal stretching. Volcanic arcs occur in the Lesser Antilles, Central America, Mexico, the Cascade Range, the Gulf of Alaska, and the Aleutian Islands. Vast areas of Mexico, New Mexico, and Colorado east of the main volcanic arc were blanketed by volcanic ash flows between 38 and 28 million years ago. Lines (or tracks) of volcanic activity that become older from east to west may emanate from melting sites, or hot spots, beneath the drifting continental plate. The Anahim volcanic belt of central British Columbia and the Snake River lava plain of Idaho are examples of such tracks. The Yellowstone caldera marks the active eastern end of the Snake River track. The Columbia Plateau basalts of Oregon and Washington, which are 14 to 17 million years old, resemble lava floods associated with the establishment of mantle plumes. Flood basalts in coastal and offshore eastern Greenland are related to the separation of Greenland and northwestern Europe under the influence of the Iceland mantle plume about 68 million years ago. Lavas in coastal areas of western Greenland are related to the separation of Greenland from Baffin Island. The Basin and Range Province, a vast area of crustal stretching in the western United States, contains numerous relatively small volcanic fields, mostly less than about 15 million years in age.

TECTONIC EVOLUTION

Chronological summary

North America is an ancient continent in several respects. It contains the oldest rocks found on the Earth, its interior has been stable for the longest period of time, and it was the first continent to achieve approximately its present size and shape. Although its known geologic history spans almost four billion years, two ages stand out as turning points. The first was about 1.8 billion years ago, when several continental fragments coalesced to form the stable crust underlying the Canadian Shield and northern interior platform. The second occurred about 600 million years ago, when fragmentation of ancestral North America created the continental margins along which the peripheral orogenic belts developed. It was then that the present size and shape of the continent was determined.

Precambrian time. *4.0 to 3.0 billion years ago.* The oldest rocks in North America (and in the world) occur in the Canadian Shield. Their ages have been calculated from precisely measured ratios of the steady radioactive decay of trace amounts of uranium and lead isotopes in the mineral zircon. Rocks at least 3.8 (and possibly up to 3.96) billion years old (Acasta gneiss) occur southeast of Great Bear Lake in the northwestern corner of the shield. In the northeastern part of the shield, rocks as old as 3.8 billion years are found on the formerly contiguous coasts of western Greenland and Labrador. Rocks in the Minnesota River valley, near the southern limit of the shield southwest of Lake Superior, range in age up to 3.66 billion years. There are many occurrences of rocks between 3.5 and 3.0 billion years old, but, like the older rocks, none are known to be more than a few tens of square miles in extent. The compositional range of the old rocks is essentially the same as that of much younger rocks, implying similar processes of formation.

3.0 to 2.6 billion years ago. The interval between 3.0 and 2.6 billion years ago was one of rapid crustal growth

in North America, during which most of the Canadian Shield and the crust beneath the northern Great Plains was formed. In any given region, relatively thin primeval oceanic crust evolved into thick continental crust over a period of about 50 million years. The repeated melting and resolidification of this crust led to progressive vertical differentiation as lighter components separated from heavier ones and were distributed at the top. As the thickened crust emerged above sea level, it was stripped by erosion and redeposited in adjacent depressions as detrital sediment. As exposed in the Canadian Shield, the thickened crust consists of multifarious granitic intrusions and subordinate enclaves of folded and faulted volcanic and sedimentary rocks. The enclaves, known as "greenstone belts," contain minable concentrations of gold, silver, copper, zinc, and lead. Regional geologic mapping and isotope dating indicate that the processes of crustal thickening tended to occur incrementally in zones a few tens of miles wide and many hundreds of miles long. The overall process of crustal transformation has much in common with activity associated with plate convergence, where oceanic volcanic arcs and derived sedimentary rocks are accreted onto the leading edge of the overriding plate and later are intruded by magmas generated in the mantle above the subducted plate.

Continental breakup

2.6 to 2.0 billion years ago. The crust that had already formed 2.6 billion years ago soon began to break up into continental fragments. The largest of these fragments forms the Superior province, which is located in the south-central part of the Canadian Shield and is some 1,500 miles wide. The Slave province (300 miles wide) and the Nain province (500 miles wide) are located in the northwestern and northeastern parts of the shield, respectively. Between these three provinces is the sprawling Churchill province—which may be a composite of four or more individual fragments named the Wyoming, Hearne, Rae, and Burwell subprovinces. The process of continental breakup began about 2.45 billion years ago along the southern margin of the Superior province, producing extensive sets of parallel dikes (vertical sheets of crystallized intrusive magma) and rift valleys containing lavas having chemical compositions characteristic of plates undergoing horizontal stretching. Following continental separation, sediments accumulated on subsiding continental shelves. (The shelf sediments deposited about 2.4 billion years ago are particularly significant in that they contain discrete layers strewn with boulders dropped from shelf ice, implying that seawater then had a temperature range similar to that of the present.) Continental fragmentation continued episodically until about two billion years ago. Because it is difficult to track the drift of continental fragments of such antiquity, it is not known how many parent continents are represented by the fragments now located in North America. Striking similarities between contemporaneous shelf sediments on the southern margins of the Wyoming and Superior provinces and between the crust of the Superior and Hearne provinces, however, suggest that they originally may have been juxtaposed.

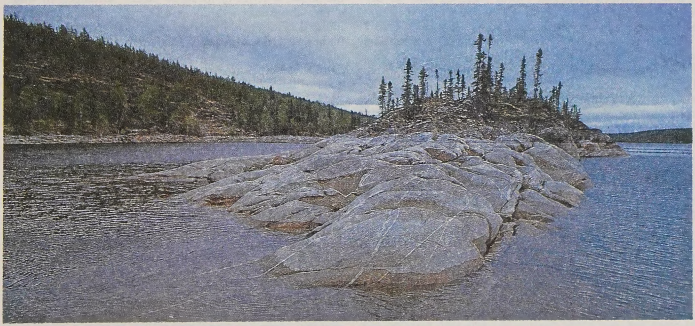
2.0 to 1.8 billion years ago. The continental fragments constituting interior North America coalesced between 2.0 and 1.8 billion years ago. The amalgamation began about 1.97 billion years ago, when the Slave province collided obliquely with the western Churchill province. The collision produced the Thelon orogenic belt, which stretches from central Alberta to the northwestern corner of Greenland. About 1.85 billion years ago the Superior province collided with the southern Churchill province to form the bowlike Trans-Hudson orogenic belt, the crest of which underlies Hudson Bay. The zonation of the Trans-Hudson belt is typical of collision zones: granitic rocks representing the eroded roots of a continental volcanic arc occur along the Churchill province margin, the medial zone comprises relics of oceanic island arcs, and the Superior province margin is characterized by shelf sediments overthrust by slivers of oceanic crust. The Nain province had already collided obliquely with the eastern Churchill province 1.82 billion years ago, forming the Torngat Mountains, which parallel the coast of northern Labrador. All three collisions were preceded by subduction of oceanic plates beneath the Churchill province. Consequently, the Churchill province experienced much more magmatism, metamorphism, and deformation in this interval than did the Slave, Superior, or Nain provinces.

Accretion of volcanic island arcs

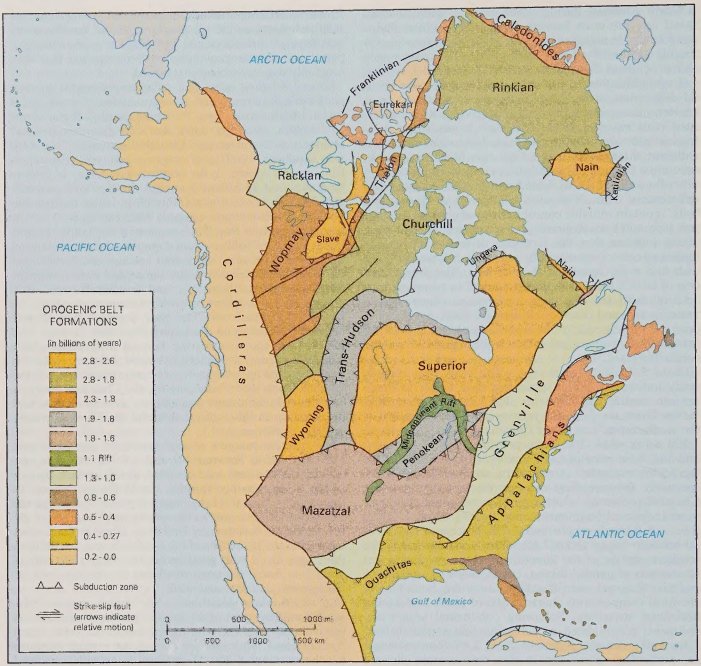
The external margins of the composite protocontinent also were active between 1.9 and 1.8 billion years ago. Volcanic island arcs were accreted to the western margin of the Slave province forming the Wopmay Orogen, to the southern margin of the Superior province forming the Penokean Orogen, and to the southeastern margin of the Nain province forming the Ketilidian Orogen. Thus, what is now the stable interior of the continent was, 1.85 billion years ago, laced with great mountain ranges; 50 million years later found the crust of all but the southern part of the interior platform coalesced.

1.8 to 1.6 billion years ago. The buried crust underlying the southern part of the interior platform was accreted immediately after the continental fragments to the north had coalesced. This younger crust in the interior platform has been sampled by oil drilling. It extends westward beneath the Colorado Plateau of western Colorado and eastern Utah and the surrounding Cordilleras and eastward into parts of the younger Grenville and Appalachian orogenic belts. This crust is much like that formed earlier in the shield: diverse granitic bodies intrude altered and deformed volcanic and derived sedimentary rocks. The rocks are believed to have originated in oceanic volcanic

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Precambrian bedrock of the Canadian Shield rising out of Reindeer Lake, on the border between northeastern Saskatchewan and northwestern Manitoba.



Orogenic belts of North America, with the postorogenic cover removed.
Adapted from Paul F. Hoffman, Geological Survey of Canada

island arcs between 1.8 and 1.7 billion years ago. They were accreted piecemeal to the protocontinent to the north and then subjected to regional northwest-southeast compression between 1.69 and 1.64 billion years ago. This event, called the Mazatzal orogeny, may be related to a collision between ancestral North America and an unknown continent to the south, and it concluded the main accretionary stage of North America.

1.6 to 1.3 billion years ago. Hundreds of granitic and subordinate basaltic magma bodies were emplaced in a broad zone from southeastern California to the coast of Labrador from about 1.6 to 1.3 billion years ago. The magmas were generated by repeated partial melting in the crust and mantle over a period of 250 million years. In Labrador, where the magmas are best exposed, they form subcircular intrusive bodies, called batholiths, that are up to 95 miles in diameter and 6 miles thick. The magmatism was most profuse in the new crust of the southern interior platform, which was blanketed by up to 4 miles of volcanic ash flows derived from the partial melting of the lower crust.

Magmatism seems not to have been induced by deformation of the continental plate but may have been a consequence of hot mantle upwelling beneath the plate. (A similar style of magmatism occurred from 300 to 150 million years ago in new crust near the active southern margin of the supercontinent Pangaea. Heat buildup beneath the stationary supercontinent induced a large-scale upwelling from the mantle that ultimately contributed to supercontinental breakup. By analogy, North America may have been part of an earlier supercontinent between 1.6 and 1.3 billion years ago.)

A thick sedimentary prism exposed in the northwestern corner of the Canadian Shield and the adjacent Cordilleras may mark a contemporaneous continental margin. To the south, a series of localized basins developed in what is now the Rocky Mountains. The Belt basin, centred in Idaho and western Montana, contains large base-metal ore bodies embedded in sediments up to 12 miles thick. It originated as an enclosed basin floored by highly stretched continental crust or trapped oceanic crust, which is analogous to the structure found in the present-day Black Sea. The Belt basin

1.3 billion to 950 million years ago. The interval between 1.3 billion and 950 million years ago began with continental rifting and culminated in the Grenville orogeny along the southeastern margin of the continent. Northwest-trending dikes were abruptly intruded across the entire northwestern half of the Canadian Shield 1.27 billion years ago. The dikes radiate from the northwestern corner of the shield, which was flooded by mantle-derived lava. Lava fields and fault-bounded sedimentary basins also formed in northern Baffin Island and in northeastern and northwestern Greenland. These deposits signify rifting that may have accompanied the opening of an ocean basin to the northwest. The closure of that basin may be recorded by southeast-directed thrust faulting in some of the same deposits. In the southeastern shield, from the Great Lakes to southern Greenland, rift-related magmatism began about 1.33 billion years ago and continued episodically for about 230 million years, when mantle-

derived lava up to 16 miles thick flooded the 800-mile-long Midcontinent Rift that arcs through Lake Superior. The short time span and large volume of magma effused suggest that hot mantle plume heads impinged on the base of the North American Plate in northwestern Canada and Lake Superior about 1.27 and 1.10 billion years ago, respectively.

The Midcontinent Rift developed contemporaneously with northwest-directed crustal-scale thrusting in the Grenville orogenic belt. The belt is exposed principally along the southeastern margin of the Canadian Shield, but inliers occur in the Appalachians, East Greenland Caledonides, Texas, and Mexico. It has been traced at depth across the eastern and southern fringes of the interior platform. Thrusting occurred mainly between 1.16 and 1.05 billion years ago and caused a doubling in the thickness of the crust, the rise of great mountains, and the exhumation of rocks altered under midcrustal conditions of elevated temperature and pressure. Sediment eroded from the Grenville orogenic belt was carried away by rivers and deposited in what is now the western Arctic platform and the northern Canadian Cordillera. The northwestern part of the Grenville belt consists of crust that belonged to the continent before thrusting began; the southeastern part comprises slices of crust formed offshore between 1.5 and 1.3 billion years ago and accreted to the continent at the time of Grenvillian thrusting. The orogenic belt presumably records collisions between eastern North America and other continents and belongs to a contemporaneous system of orogenic belts that is represented on other continents. The collisions may be related to the amalgamation of a new supercontinent.

950 to 600 million years ago. Between 950 and 600 million years ago, renewed rifting led to continental breakup along the north-facing (Franklinian), northeast-facing (Caledonian), southeast-facing (Appalachian), south-facing (Ouachita), and west-facing (Cordilleran) margins of North America. Rifting began about 780 million years ago in the Cordilleras and somewhat later on the other margins. It was accompanied by deposition of thick, laterally continuous wedges of sediment and sporadic volcanism and intrusive magmatism. The sediments typically include glacial deposits and contain the first soft-bodied animal fossils. The identities and former positions of the continents that drifted away from North America are subjects of much speculation: the Cordilleran margin may have been juxtaposed with Australia and eastern Antarctica, the Ouachita margin with southern Africa, the Appalachian margin with western South America, and the Caledonian and Franklinian margins with northwestern Europe and Siberia.

The first fossils

Paleozoic and early Mesozoic time. *600 to 250 million years ago.* Following continental breakup, lithospheric cooling caused the rifted margins to subside, which—combined with a concomitant global rise in sea level—resulted in extensive flooding of continental shelves. A sheet of sandstone was deposited as the shoreline was pushed far into the continental interior. As sources of sand retreated, the then-equatorial continent became framed by broad, shallow shelves on which limestones thousands of feet thick accumulated. Shallow-shelf conditions were interrupted by the accretion of volcanic island arcs or continental fragments, culminating about 300 million years ago when Laurentia collided with the southern hemispheric continent of Gondwana (Gondwanaland) to form the supercontinent Pangaea.

The first collision occurred between 470 and 460 million years ago, when a volcanic arc collided with and deformed the Appalachian margin (the Taconic orogeny). Younger volcanic arcs, some built on strips of crust that originated on the northwestern margin of Gondwana, then drifted northward and were accreted to the Appalachian margin between 450 and 410 million years ago (the Acadian orogeny). Simultaneously, the continent Baltica (consisting of the Baltic Shield and the Russian platform) collided with Laurentia to form the Caledonian orogenic belt of eastern Greenland and Norway. In the northern continental interior, a zone of crustal shortening of Caledonian age (420 to 400 million years ago) extends from the Boothia Peninsula of north-central Canada northward to the Arctic Ocean and southward to Hudson Bay. The Franklinian margin of Canada and Greenland was deformed between about 380 and 360 million years ago (the Ellesmerian orogeny), when northern extensions of the Caledonian orogenic belt were sheared westward to northern Ellesmere Island; these extensions occur as so-called exotic crustal fragments, all of which have histories more than 380 million years old that are incompatible with the adjacent indigenous Franklinian margin.

Exotic crustal fragments

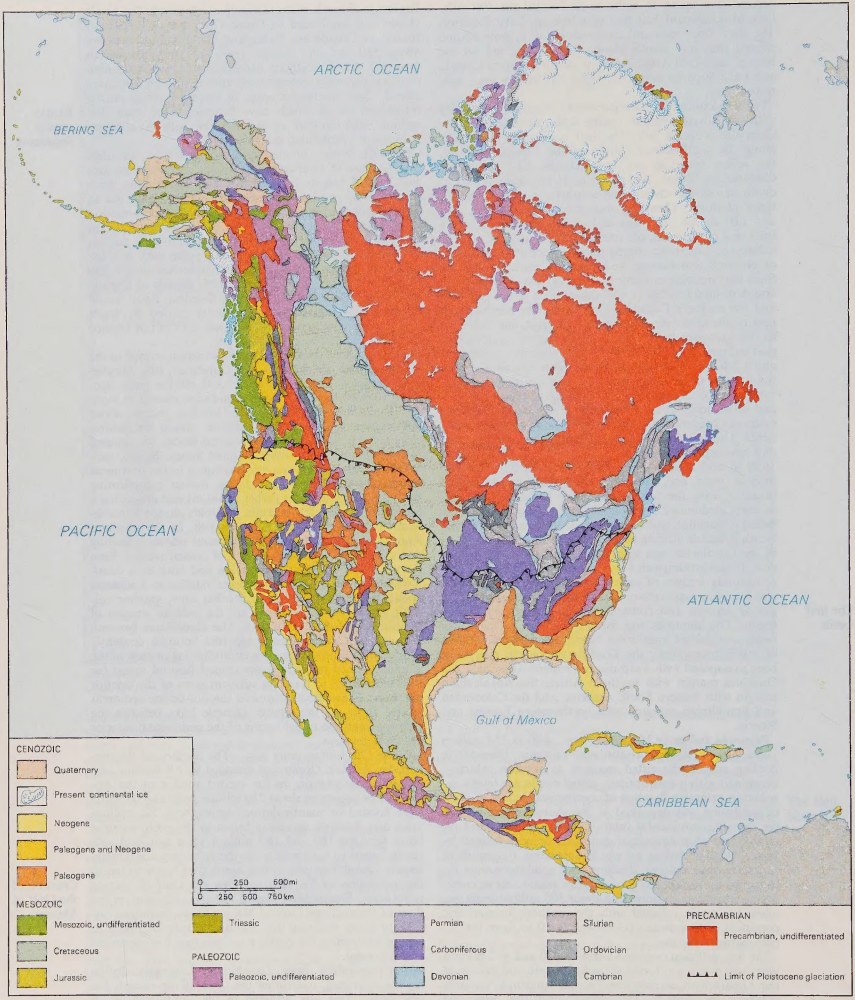
The early history of the Cordilleras is difficult to interpret because of later dismemberment, but volcanic arcs that formed mainly between 380 and 360 million years ago were accreted to the continent from California to Alaska immediately thereafter. The resulting deformation (the Antler orogeny) was close in age to the Ellesmerian orogeny in the Arctic. The arcs formed on or near ancient continental crust (2.0 to 2.4 billion years old), but the origin of the material in these arcs is uncertain. By 330 million years ago, the northern Arctic islands of Canada had begun to subside; the resulting Sverdrup Basin would be the major repository of sediment carried by rivers draining the continental interior until the Gulf of Mexico formed some 150 million years later.

In the southern Appalachians, deformation related to the amalgamation of Laurentia and Gondwana (the Alleghenian orogeny) also began about 330 million years ago. Relative northward motion of Gondwana caused its western promontory to override the Ouachita margin about 305 million years ago. The collision caused discontinuous crustal deformation (the ancestral Rocky Mountains) throughout the southwestern United States. By 290 million years ago, Gondwana was impinging to the northwest against the southern Appalachians, further complicating structures formed by the earlier collisions and producing a broad belt of new thrust faults and folds along the northwestern periphery of the orogenic belt. In the northern Appalachians broadly contemporaneous sideways faulting was caused by the lateral escape of crustal wedges from the area of continental indentation and later by a counterclockwise rotation of Gondwana relative to Laurentia about 270 million years ago. By that time, another volcanic island arc had formed off the western margin of Laurentia and was accreted to the Cordilleras between 260 and 240 million years ago (the Sonoma orogeny). Mountains resulting from crustal thickening in each of the aforementioned collision zones caused flexural moats (or foreland basins) to form on adjacent parts of the interior platform. These moats captured interior-bound sediment eroded from the mountains. Genetic links between the collisions and the ovoid basins of the continental interior are more tenuous.

250 to 120 million years ago. The opening of the present-day Atlantic Ocean was presaged by rift faulting and related sedimentation on the eroded surface of the Appalachians beginning about 230 million years ago. The rifts were flooded by mantle-derived lavas about 201 million years ago. Seafloor spreading began in the proto-Atlantic basin between 180 and 160 million years ago, and sediment began to accumulate on the subsiding continental terrace. Simultaneously, rifting along the Ouachitas led to the separation of Yucatán, creating the Gulf of Mexico in its wake. Evaporation caused salt to precipitate on the floor of the enclosed Gulf of Mexico basin. Sediment carried by rivers draining the continental interior began to fill the basin from the north, a process that has continued to the present.

Creation of the Gulf of Mexico

After separating from Gondwana, Laurentia drifted rapidly westward, overriding the floor of the eastern Pacific basin. This was reflected in the Cordilleras by an upsurge in arc magmatism on the continental margin between 180 and 140 million years ago. Thrust faulting and folding crumpled the sedimentary rocks to the east (the Sevier orogeny). In addition, former offshore island arcs and other oceanic crustal fragments were accreted to the advancing continental margin. The central part of the Cordilleras in Canada and Alaska was accreted piecemeal, also between 180 and 140 million years ago, but there is disagreement as to whether the western part was accreted



Geologic structure of North America.

in the same interval or between 110 and 70 million years ago (the two parts are separated by the deeply eroded granitic batholiths exposed in the Coast Mountains of British Columbia).

Late Mesozoic and Cenozoic time. *120 to 30 million years ago.* After the abortive opening of the Gulf of Mexico, South America drifted away from Yucatán, creating a proto-Caribbean gulf that opened eastward into the Atlantic and was separated from the Pacific basin by an east-dipping subduction zone and related volcanic arc near the present location of Central America. Sometime between 80 and 60 million years ago, a large submarine plateau composed of unusually thick oceanic crust (possibly formed in the Pacific basin during initiation about 90 million years ago of a hot spot now located beneath the Galápagos Islands) arrived at the subduction zone oppo-

site the proto-Caribbean gulf. Because the oceanic plateau was too buoyant to be subducted, it began to override the proto-Caribbean gulf, carrying the Antilles volcanic arc on its prow. The plateau—which now floors the Caribbean Sea—continued its penetration into the westward-drifting North and South American plates until the volcanic arc on its northeastern margin (the Greater Antilles) collided with the Bahamas limestone platform sometime between 60 and 35 million years ago. This collision initiated a reorganization of Caribbean tectonics. The collision zone, notably the island of Cuba, was sheared off the Caribbean Plate and became fixed to the North American Plate. An east-dipping subduction zone was reestablished beneath Central America, detaching the Caribbean Plate from the Pacific. Continued subduction of the central Atlantic lithosphere beneath the eastern part of the Caribbean Plate gave rise to the Lesser Antilles volcanic arc.

Continental separation

Meanwhile, seafloor spreading in the Atlantic basin moved northward: continental separation occurred at about 120 and 100 million years ago on the eastern and northern margins, respectively, of the Grand Banks of Newfoundland; about 90 million years ago in the Labrador Sea; and about 70 million years ago in Baffin Bay and eastern Greenland. Continental breakup in the northern North Atlantic about 70 million years ago was accompanied by voluminous volcanism related to inception of a mantle plume from a hot spot now centred beneath Iceland. Spreading in the Labrador Sea and in Baffin Bay resulted in the counterclockwise rotation of Greenland around an axis near Devon Island in the Canadian Arctic islands. To the northwest, the rotation of Greenland caused widespread folding and faulting of sediments in the Sverdrup Basin between 70 and 35 million years ago (the Eurekan orogeny). In the western Arctic, far northern Alaska was relocated from its former position adjacent to the Arctic margin of Canada. There is disagreement as to whether the relocation was accomplished through a counterclockwise rotation or a left-lateral shearing of Arctic Alaska relative to Arctic Canada. Separation of the two began about 92 million years ago and created the oceanic Amerasia basin in its wake.

North America continued to override the Pacific basin, but tectonic activity in the Cordilleras varied in space and time according to the age, angle, obliquity, and relative velocity of the oceanic plates being subducted beneath the continental margin. From 120 to about 80 million years ago, the relative eastward motion of the Pacific floor resulted in crustal accretion and arc magmatism along the western continental margin. Thereafter, the inception of a new oceanic spreading ridge resulted in subduction with a strong northward component of motion in Canada and Alaska. Consequently, the main locus of accretion and arc magmatism shifted to southern Alaska, and strips of previously accreted crust were displaced northward along the western margin of Canada.

In the western United States, a broad region of crustal shortening developed as far east as the Rocky Mountains between 80 and 50 million years ago (the Laramide orogeny). Simultaneously, arc magmatism ceased near the coast but migrated up to 600 miles to the east. These effects are attributed to changes in the angle of the subducting slab, which became shallower, coincident with increased subduction velocity and the hypothesized subduction of a buoyant oceanic plateau. A sharp decrease in subduction velocity in the northwestern United States and adjacent Canada between 60 and 50 million years ago coincided with an end to thrusting in the Rocky Mountains and an episode of crustal extension and melting to the west. In the southwestern United States and Mexico, crustal stretching and melting triggered extensive volcanism between 40 and 30 million years ago and may have been caused by the collapse or thermal dissipation of the low-angle slab. In general, crustal extension was most evident in areas of earlier crustal thickening, a relationship which suggests that overthickened crust was susceptible to gravitational collapse when plate convergence slowed.

30 to 2.5 million years ago. About 30 million years ago North America began to override the East Pacific Rise, an oceanic spreading ridge. This activity placed a progressively longer segment of the coast in contact with the plate west of the ridge. The western plate—which contains the Pacific Coast Ranges of California—has been moving to the northwest relative to North America along the San Andreas Fault system. Active subduction and arc volcanism have been limited to the regions south (the Sierra Madre Occidental) and north (the Cascade Range) of the San Andreas system, which now extends from the Gulf of California in Mexico to Cape Mendocino in northern California. (An analogous gap in subduction and arc volcanism between northern Vancouver Island and the Gulf of Alaska is related to the Queen Charlotte Fault system.) To the east, crustal stretching and related volcanism has continued to shape the distinctive topography of the Basin and Range Province. The Colorado Plateau, however, has resisted the stretching that has occurred on three sides of it. East of the Cascade Range, a great flood of mantle-derived (basaltic) lava formed the Columbia Plateau between 17 and 14 million years ago. Subsequently, the locus of magmatism migrated eastward, forming the Snake River basin and the active Yellowstone volcanic centre. This and other lesser volcanic tracks across the Cordilleras may be products of stationary mantle plumes overridden by the drifting continent. Uplift rates have increased in the past few million years in many parts of western North America, notably in the Sierra Nevada, the Colorado Plateau, the Coast Mountains, the Rocky Mountains, and the Great Plains, but the underlying causes are not well understood.

Plate movement along the San Andreas Fault

The past 2.5 million years. Continental ice sheets developed abruptly 2.5 million years ago in North America, a date based on the appearance of ice-rafted debris in ocean-sediment cores. As glaciation began much earlier in Antarctica (37 million years ago), it is suspected that a specific causal factor—presumably involving a change in ocean-atmosphere circulation—was involved in addition to the overall global cooling trend related to the emergence of greater continental landmass over the past 70 million years. Proposed causes include establishment of the Isthmus of Panama and the increase of plateau uplifts in the western United States and Central Asia. From 2.5 until about 1.0 million years ago, the ice sheets did not reach as far south as the Great Lakes. According to oxygen-isotope records from ocean-sediment cores (the isotopic ratios are correlated with glacial ice volume), glaciation waxed and waned with a 41,000-year rhythm that corresponded to the variation in the proximity of the Earth's orbit to the Sun (the obliquity cycle), the effect of which is greater at higher latitudes. Almost 700,000 years ago, the maximum extent of the ice sheets reached the Great Lakes. It is then thought that glacial periodicity came to be governed primarily by the 100,000-year orbital-eccentricity cycle, although the 23,000- and 19,000-year precessional cycles also came into play—the climatic effect of the latter being stronger at lower latitudes. (For an explanation of these and related matters, see GEOCHRONOLOGY: *Pleistocene Epoch: Cause of the climatic changes and glaciations.*)

Glacial periodicity

At the time of the last glacial maximum (about 18,000 years ago), ice sheets had spread from centres located (in descending order of size) southeast and northwest of Hudson Bay, Greenland, the Canadian Cordillera, Baffin Island, and Newfoundland. The last glacial recession took place from 13,000 to 6,000 years ago but was interrupted by a sharp advance between 11,000 and 10,000 years ago (called the Younger Dryas event) that was most evident around the North Atlantic. The advance coincided with an apparent temporary diversion of glacial meltwater from the Mississippi River to the St. Lawrence drainage system. It has been postulated that this discharge of cold, fresh water disrupted the Atlantic Ocean circulation system that warms the North Atlantic. A more recent cooling episode, the so-called Little Ice Age between about AD 1450 and 1850, has had no satisfactory explanation. The repeated glaciations scoured the Canadian Shield and deposited topsoil in the continental interior, which in modern times has aided farming in the southern portion of North America and geologic research in the northern part; what the north lacks in soil, however, it makes up for in fresh water. (P.F.H.)

The land

Although the geologic processes that shaped the North American continent have been so important that the 19th-century American historian Frederick Jackson Turner once contended that the life of America flowed down the arteries of its geology, the continent nevertheless has been altered considerably by climate and drainage and, to some extent, by soils and vegetation. The resultant physiographic regions dominate the contemporary geography of the continent.

RELIEF

The central shield. The central shield consists of a low plateau (averaging 1,400 feet in elevation) that is tilted at its edges and sinks down to Hudson Bay at its centre. It has a rough surface of old worn mountains and domes that rise above flat, geologically ancient basins. The shield represents an area that has undergone extensive erosion and sculpting by ice and weathering processes. The southern edge has the mountainous Algomans and Laurentians (more than 2,000 feet) and rises to above 5,000 feet in the great dome of the Adirondacks. The eastern edge is somewhat higher, rising to nearly 6,000 feet in the Torngats and more than 7,000 feet in Baffin Island; in Greenland, too, it tilts up to more than 6,000 feet. The western rim is much lower, reaching only about 600 feet in parts. The Snare and Nonacho ranges west of Hudson Bay lift the edge of the plateau to nearly 2,000 feet. Faulting broke the northern rim into a series of prongs, extending into southeastern Ellesmere Island and across Victoria Island, with sea-drowned channels and low sedimentary basins in between forming the Canadian Arctic Archipelago.

The entire shield was under successive ice sheets during the Pleistocene Epoch (1,600,000 to 10,000 years ago), and its high eastern rim still contains relics of these glacial advances and retreats. Ice-cut valleys in the higher areas, ice-plucked basins everywhere, and ice-deposited ridges known as eskers and drumlins point to a major centre of ice accumulation and dispersion over central Labrador, still noted for its heavy snow cover. Greenland also was a main centre of glacial advance and retreat, while Keewatin in western Canada was an important secondary focus. After most of the ice had melted and its tremendous weight had been lifted from the crust, portions of the shield began to rise, leaving traces of former beaches along the coasts of Greenland, Baffin Island, Labrador, and the Gulf of St. Lawrence; these provided narrow but vital benches for human settlement. Ice-cut rock basins have left countless lakes, and parts of the surface of the central shield are almost more water than land.

Relics of glaciation

The marginal mountains. *The Appalachians.* Erosion also profoundly altered the marginal mountains. The Appalachians have been planed down to such an extent that their crest lines are smooth-topped for hundreds of miles. Several levels at which summits accord with each other in height indicate a series of uplifts followed by planations. In Canada the highest level lies at about 4,000 feet, in the flattops of the Shickshocks (French: Chic-Chocs); another exists at 2,000 feet on Mount Carleton; and lower ones lie at roughly 1,100 and 600 feet in the Acadian ranges. In New England, mountains like Mounts Washington and Monadnock, which are composed of highly resistant rock, rise above a broad mass of ridges at just above the 2,000-foot level; these ridges, in turn, rise above the 1,100-foot-high New England Upland. Pleistocene glaciation deepened and straightened the valleys, strewing their sides and parts of the coast with debris. Portions of sea-



Physiographic regions of North America.

buried end moraines, which mark the limit of the tonguing glaciers, form offshore banks east of Newfoundland, Nova Scotia, and New England. The unglaciated Appalachian Mountains—*i.e.*, those located south of the Susquehanna River—have striking accordances of long flat-topped summits at altitudes of about 2,500 feet and broad terraces at 500 to 600 feet. The Ridge and Valley section's pattern of drainage consists of short, deep gaps across the ridges and long parallel stretches in between. East of the Blue Ridge extends the Piedmont Upland, terminating abruptly in the fall line, where its rivers plunge down to the Atlantic Coastal Plain over rapids or falls. The Hudson-Mohawk gap represents a major break between the northern and the southern Appalachians and affords a natural point of entry to the interior of the continent.

The Cordilleras. Taking up about a third of North America, the Cordilleras completely dominate Alaska and Central America and swell out widely in the U.S. Rocky Mountains.

The six zones of the Canadian Cordilleras

In Canada the Cordilleras consist of six well-marked zones: the 10,000- to 12,000-foot-high Rocky Mountains, continuing north into the Brooks Range of Alaska; the Rocky Mountain Trench, a profound fault feature forming the headwaters of the Columbia, Fraser, Peace, and Yukon rivers; the interior uplands and old fold mountains from the Selkirk and Okanogan ranges in the south to the Cassiar Mountains and the Yukon Plateau in the north, mostly lying at altitudes of about 2,400 feet but with ridges above 8,000 feet; the Coast Mountains, extending north into the Alaska Range and including lofty volcanoes in the north; the Inside Passage from Puget Sound to Alaska, which is possibly a downfaulted zone flooded by the sea; and a structurally complex outer island arc, running from Vancouver Island to the Aleutians. The magnificent scenery of the northern Rocky Mountains, including U-shaped valleys often extending westward into sea-drowned fjords, has resulted from frequent glaciation, and some areas still nurse sizable glaciers.

In the United States the Rockies, typified by flat or gently folded rocks, sweep south from Canada into northern Montana as the Lewis Range. They then change to a group of domes or long anticlines with "parks" or broad basins between them. This park-and-dome area is characterized by the "peeling back" of younger rocks from the cores of much older, primary rocks at the heart of the anticlines. The southern Rockies have striking volcanic peaks. West of the Rockies and east of the Pacific coast ranges is a vast region of intermontane plateaus, extending from eastern Washington state to northern Mexico. The immense lava tablelands of the central Columbia–Snake River basin are known as the Columbia Plateau. To the south lie the Basin and Range Province and the Colorado Plateau. The former, extending from southern Oregon and Idaho to northern Mexico, apparently is the result of the splitting of a broad central plateau by a great number of fault ridges, the slopes of which plunge under basins partly filled with debris worn from the ridges. The region includes all of the continent's major deserts. The Colorado Plateau is a massive feature with a series of relatively flat-bedded ridges, made steplike by faulting action and intruded by domes of igneous rocks. Its slow rate of uplift was matched by the steady downcutting of the Colorado River, producing, in the Grand Canyon, one of the most spectacular gorges in the world. Westward rise the mountains of the Sierra Nevada, which reach to nearly 15,000 feet, are intensively folded and faulted, and continue north in the Cascade Range, which is marked by some of North America's most beautiful volcanic cones. Seaward of this mountain zone is a line of depressions marked by Puget Sound, the Central Valley of California, and the Gulf of California. These are separated by knots of volcanoes, as in the Klamath Mountains, and enclosed by the ranges along the Pacific coast, including the Olympic Mountains of Washington. This whole area has been profoundly faulted. Along some of the faults, notably the San Andreas, earthquake shocks occur, and occasionally these have produced devastating results.

In Mexico the folded ranges of the Sierra Madre to the west and east of the central Mexican Plateau terminate in the grandeur of a mass of high volcanoes of 15,000 to 17,000 feet located to the south of the fertile lake-filled basins of Guadalajara and Mexico City. The Balsas River basin then makes a distinct break. To the south the Sierra Madre del Sur and the mountains of Guatemala and Honduras exhibit a west-east trend. This structural region includes a sweep of fold mountains of from 4,000 to 6,000 feet, with Caribbean extensions in Jamaica, southern Cuba, the island of Hispaniola, and Puerto Rico. These mountains swing southward through the West Indies, a chain of volcanic islands fringed with coral reefs or limestone plateaus. Another arc, of two lines of fold mountains on either side of a trench through western Nicaragua, dominates Central America and links it with the folds of western Colombia, in South America.

The structural break at the Sierra Madre del Sur

The lowlands. Long irregular ridges of coarse morainic deposits mark the outer limits of the advance of the Cordilleran ice sheets, which swept down preexisting river valleys in the Rockies, and the larger, thicker continental sheets, which advanced south out of Canada. The long, tonguing loops of end moraines of the continental ice sheet are prominent features north of the Missouri and Ohio rivers—some running for hundreds of miles and standing 300 or 400 feet above the plains. Several glacial advances—perhaps as many as 10 or more—successively covered the lowlands with glacial drift. Four of these have been named for the extent of their southern advances: the Nebraskan crossed the Missouri River; the Kansan extended as far as the lower Missouri and the Ohio rivers; the Illinoian overlay these older areas as far as southern Illinois; and the Wisconsin heaped its moraines over the prairies of southern Canada and the plains of the Great Lakes and the Ohio, Mohawk, and Hudson rivers (see also below *Drainage*). Evidence of deposits from other major advances may be buried beneath the drift from later glaciers.

In the ice-free areas, lowlands are river-molded. Streams debouching from the Rockies have spread sands, occasionally whipped up into sand hills, well beyond their banks; those funneling into the Mississippi River have created a vast alluvial plain running out into the Mississippi delta.

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Esker, narrow ridge of gravel and sand left by a retreating glacier, winding through the Keewatin district near the Thelon River in the Northwest Territories.

In addition, the Coastal Plain is marked by lines of sand hills, which are the relics of stranded beaches that eroded as the plains were lifted slowly out of the seas in post-glacial times.

Detailed discussion of the Alaskan mountains, Appalachian Mountains, Great Plains, North American Desert, Pacific coast ranges, Rocky Mountains, Sierra Madre, and Sierra Nevada can be found in *North American geographic features of special interest* at the end of this article.

DRAINAGE

Drainage conditions and water supply are affected markedly by climate, though they also reflect topography. North America has one of the longest rivers in the world (the Mississippi) and also a drainage system with one of the greatest water capacities (the St. Lawrence–Great Lakes system). It is a continent of immense rivers—largely because of their vast drainage area in the long and broad plains between the central shield and the marginal mountains. Rivers that rise in the Canadian Shield, the Appalachians, or the Cordilleras and flow into the Interior Lowlands must travel a great distance to reach the sea. The Great Lakes–St. Lawrence system on the east and the Mackenzie River on the west drain much of the outer edges of the shield. The Nelson River takes advantage of the low saddle in the shield to carry out the gathered waters of the Saskatchewan and the Red rivers by way of Lake Winnipeg to Hudson Bay, which also has fairly long rivers draining into it from the uptilted edges of the shield. The vast Missouri-Mississippi-Ohio system receives waters from the Cordilleras, the Canadian Shield, and the Appalachians to unite the Central and Gulf lowlands in the heartland of the continent. From the Rocky Mountains, long rivers like the Colorado, Columbia, Fraser, and Yukon flow west to the Pacific. Fed by perpetual snowpacks and ice, they are particularly valuable as sources of water in the arid Southwest.

There is a marked east-west asymmetry to North America's drainage: the chief continental divide, along the Rockies, is well to the west, thus shedding the longest rivers to the east. The longest tributaries—the Peace into the Mackenzie, the Saskatchewan into the Nelson, and the Missouri into the Mississippi—are all west of the main streams. The chief gulfs—Hudson Bay, the Gulf of St. Lawrence, and the Gulf of Mexico—taking the discharge of many of the rivers, are on the east. All these factors helped the European settlers move from their Atlantic bases into the heart of North America by facilitating travel. Considerable north-south disparity also exists in North America's drainage pattern: there are no rivers or lakes south of the Rio Grande that approach the size of those found to the more humid north.

Lakes. Lakes abound in North America. Most of them are products of glaciation, which has had a vast effect on the continental drainage pattern—notably by widening the passes through the northern Appalachians and the Cordilleras and by forming big lakes in ice-deepened basins. The Great Lakes proper have a fascinating history, as Lakes Superior and Huron were vast synclinal depressions even in Precambrian times. In the place of the present eastern lower Great Lakes (Erie and Ontario), a scarp-and-vale topography existed, with the high front of the Niagara limestone scarp separating vales of shale to the west and east. The glaciers picked out the vales and synclines and greatly deepened them into ice-cut basins, where water gathered; as the ice melted away, the Great Lakes formed. While the ice front of the glaciers was blocking the St. Lawrence outlet, the early lakes drained southward into the Mississippi-Ohio, the Susquehanna, and the Mohawk-Hudson systems. When the ice retreated from the Gulf of St. Lawrence, the lakes sought the lower outlet through the St. Lawrence River, decreasing the level of the Great Lakes and leaving beaches around them that stand out as raised beaches, or strandlines. The land, depressed under the enormous weight of the ice, has been rising since, lifting the old beaches above the present diminished bodies of water. Similar strandlines follow the Gulf of St. Lawrence, once under glacial Lake Champlain; Lake Winnipeg, once part of the immense glacial Lake Agassiz; and Lake Athabasca and Great Slave and Great Bear lakes, which also are the relics of once deeper and larger glacial lakes. The western lakes were formed by ice blocking the free drainage of water to Hudson Bay or the Beaufort Sea. Farther south, in the Great Basin, a pluvial (rainy) period of climate during the Pleistocene, matching the ice age in the north, gave rise to the enormous Lakes Lahontan and Bonneville. The Great Salt Lake is a relic of Lake Bonneville, the ancient strandlines of which are up to 1,000 feet above the present shoreline. Similarly, present-day Lake Chapala in Mexico represents only a small portion of the large body of water that accumulated on the Mexican Plateau and whose level fluctuated during several pluvial periods. The contribution of all these—and many more—lakes to the drainage of North America has been outstanding. Much of the Canadian Shield is so riddled with lakes and swamps as to form an amphibious landscape.

The Great Lakes

Rivers. The river regimes of North America exhibit great variety. Northward-flowing rivers, like the Yukon, Mackenzie, Red, and Nelson and the rivers of eastern Canada, freeze in winter. Because their upper courses then thaw before the lower sections are free of ice, their lower (northern) reaches frequently flood, especially if the thaw is late enough to coincide with early summer rains. The St. Lawrence runs high in spring and early summer; the winter precipitation falls on a frozen surface and serves mainly to heighten runoff during the spring thaw.

The Mississippi system also is frequently swollen in spring as melting snows in the upper parts of the drainage basin are added to runoff from spring rains in the southern Great Plains and southeastern states; flooding can then become a major hazard. River water is kept high by the rains that tropical gulf air and local convection storms bring until midsummer. A marked falloff then occurs, giving way to full flow in late autumn and winter as polar continental air reactivates mid-continental storm tracks. Most other eastern rivers have two periods of high water, occurring in early summer and late winter.

The Mississippi system

In the American Southwest, winter is the main period of flooding, as rivers dwindle appreciably in summer. The northern Pacific region, by contrast, has rain in all seasons, though with a winter maximum. In the southern tropical regions, rivers have a much more regular regime, running full throughout the year, except in the dry rain-shadow areas leeward of the mountains.

Detailed discussion of the Colorado River, Columbia River, Great Lakes, Mackenzie River, Mississippi River, Panama Canal, Rio Grande, St. Lawrence River and Seaway, and Yukon River can be found in *North American geographic features of special interest* at the end of this article.

SOILS

Before 1960, climate was the main basis used for categorizing soils, with a division first into humid and arid groups and then into subgroups according to the way in which temperature and moisture acted together to produce different horizons (layers) in the soil. Since then, soil classification has come to depend on the unique characteristics of soils and their horizons. The current system of soil classification, called soil taxonomy, involves hierarchical groupings of soils based on types of horizons, temperature, colour, drainage or wetness, chemistry, and mineralogy. Eleven major categories of soils have been identified, all of which can be found in various parts of North America. Most of these still can be placed into two broad groupings that reflect their general vegetation cover: forest soils and grassland and desert soils; some soil categories, however, cannot be placed into either grouping.

Eleven major categories

Forest soils. The forest soils are the most widespread in North America and typically occur in humid regions.

Spodosols. The cool temperate climatic zone is characterized by spodosols, which typically form on sandy materials under coniferous or mixed coniferous and deciduous forest. They are easily recognized by a leached, acid, grayish white horizon near the surface. Relatively infertile because of deep leaching of otherwise nutrient-poor sands,



Soils of North America.

spodosols are best left to forest or to crops that prefer acid conditions, such as potatoes. They extend under the boreal forest (taiga) from Alaska to Newfoundland.

Andisols. Only since about 1989 have andisols been recognized as a distinct soil category; before then they were considered to be a subcategory of inceptisols. Andisols are formed in volcanic ash and are found throughout the tectonically active belt of the Cascades and north into Canada. There, layers of ash have accumulated and formed these highly fertile, though easily eroded, black soils.

Alfisols. Alfisols are found in the warm-summer subregion of the cool temperate zone, primarily in the Laurentian mixed-forest vegetation region. They are characterized by an upper horizon leached of iron and aluminum compounds, humus, and clay. These materials accumulate in the subsoil, where they form a reddish, clayey subsoil. Alfisols are the moderately fertile, grayish brown soils so typical of the glaciated parts of the northeastern United States; large parts of the dairy regions of Wisconsin and New York are centred on these soils.

Ultisols. Bright red and yellowish red ultisols occur south of the glaciated areas, extending southward from the lower Ohio valley and Chesapeake Bay to the Gulf Coastal Plain. They correspond to the area of the southeastern mesothermal climate, which has a long growing season and rainfall of up to 60 inches per year. Deep leaching and great age have resulted in the loss of many of the essential nutrients from these soils; heavy fertilization is required for such typical crops as tobacco, cotton, and corn (maize). Because many ultisol areas of the southern United States have been in row-crop tillage for several centuries, severe erosion has resulted, further limiting their productivity.

Oxisols. The tropical climates of southern coastal Mexico and Central America, with constantly high temperatures of 65° to 82° F (18° to 28° C) and perennial rainfall of from 80 to 120 inches, have caused intense weathering of rock. The resulting soils, called oxisols, are deep red in colour, are extremely infertile, and may even harden irreversibly into bricklike laterite after being drained and cultivated. In these soils, red iron and aluminum hydroxide and sesquioxide compounds, the residual products of rock decay, have accumulated. Deep and strongly acidic, these lateritic soils support primarily grazing and pastoral activities or swidden agriculture.

Grassland and desert soils. Soils in this group cover an extensive area of North America and generally are found in the drier regions of the continent.

Mollisols. Marking the transition between humid and arid soils, mollisols are found in the open parkland or the tall-grass prairie of the Great Plains or in the humid prairies of the western Central Lowlands. Unlike the forest soils mentioned above, these soils have formed under grassland vegetation and have been heavily influenced by the closely matted roots in the dense sod of the thick-

Formation of mollisols

growing grasses. The roots eventually decay underground, turning into humus and giving mollisols a dark brown or black colour. With a short rainy period from April to mid-July followed by considerable evaporation during the dry, sunny summer, whatever leaching occurs is not pronounced. The leached horizon is shallow and passes down to a horizon in which the upward movement of water caused by evaporation from the surface has brought up salts, especially lime, which neutralizes the acidity of the surface soil. Extremely fertile soils of neutral pH, mollisols make up most of the Wheat Belt of the central Great Plains. Farther east, where rainfall is higher, the Corn Belt of Illinois and Iowa also is centred on mollisols.

Vertisols. Vertisols form in materials with a high clay content where there are distinct wet and dry seasons; they are distinguished by the large cracks that form in the surface during dry periods. These soils are limited in North America to small areas of Mexico and Texas. When irrigated, vertisols are highly productive for growing cotton and for use as rangeland.

Aridisols. Characterizing the dry climates of the intermontane basins of the United States, most of the Mexican Plateau, and the southwest Pacific Coast, aridisols are found where vegetation is sparse and where, accordingly, little humus has formed at the surface. Leaching is rare and virtually ineffective; strong evaporation leads to the upward movement of alkaline salts through capillary action, which often leaves a skin of white crystals on the surface. Aridisols are too rich in lime and, often, sodium to be fertile unless they are extensively irrigated and the salts are removed.

Other soils. Three soil types are distinguished by their relative youth—*i.e.,* their greater affinity to parent minerals than to the vegetation associated with them—and can be found in most vegetational environments.

Entisols. The very youngest soils are entisols. These soils strongly resemble their geologic parent materials, as there has been insufficient time to alter these materials into soils with strongly developed horizons. Disturbed landscapes also have soils classified as entisols, such as the many square miles of land occupied by freeway medians and urban centres in North America. Such natural landscapes as the Sand Hills of Nebraska also are areas of entisols. Because disturbed or eroded sites or recently deposited materials like river alluvium are common in all landscapes, entisols are found widely scattered throughout North America.

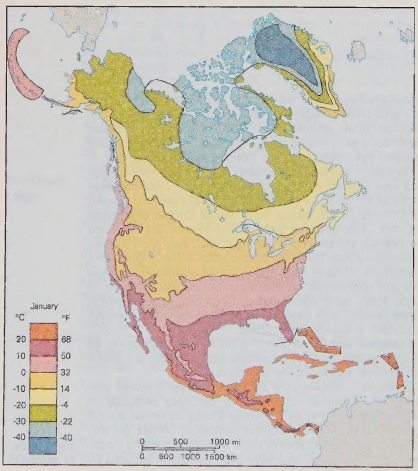
Inceptisols. Inceptisols are slightly more weathered and developed than are entisols; like entisols, inceptisols are not uniquely associated with any particular climatic regime but are widespread across the continent. They are common in the tundra landscapes of northern Canada and Alaska and in the high elevations of the Cordilleras, and they constitute the fertile soils of the Pacific Northwest and of the coasts of British Columbia and Alaska. Many of the soils formed from acid glacial tills in the mountains of New England also are inceptisols.

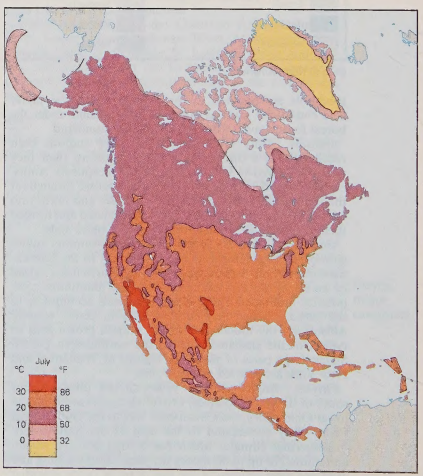
Histosols. Saturated with water for many months of the year, histosols constitute nothing more than deep accumulations of organic materials. They are especially common beneath the coniferous forests of the Great Lakes area and in Canada, where geologically recent glaciation has left many areas of standing water or shallow lakes. The cool climate of these areas also limits decomposition of wood fragments, grasses, sedges, and mosses that may have accumulated in the wet sites. Histosols also are known as peat and muck.

CLIMATE

Climate has had considerable influence on relief—particularly in the extremes of cold or hot and dry or humid landscapes; and, in turn, climate has been affected by relief. The enormous width of the continent in the higher latitudes has led to a great extension of Arctic and cool temperate climates, while the tapering south has greatly reduced the land area under tropical conditions. The Cordilleras of Canada and the United States have wet, windward slopes facing the Pacific and dry, leeward slopes facing the interior. Most storms are driven from west to east by a strong mid-continental air flow called the jet stream, and these storms most often converge on the New England region.

Temperature. While the greater part of North America falls within the temperate zone—a fact that made it attractive to European settlers—large cool-to-cold areas lie in the north and extend as far south as the Ozark Mountains in winter. The continent's northerly position means that Greenland, the Canadian Shield, the Mackenzie Lowlands, and the northern part of the Cordilleras have unusually long and cold winters. Much of this land has permanently





Average temperatures for January (left) and July (right) for North America.

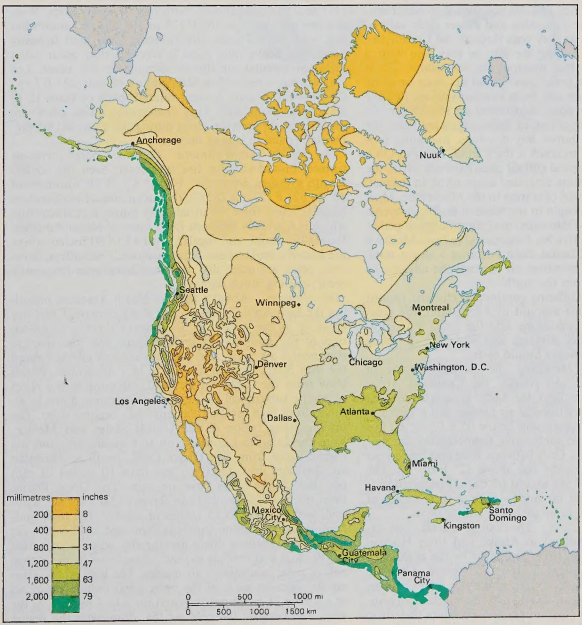
Chilling effect of frozen subsoils and seas

frozen subsoil (permafrost) and is under snow and ice most of the year. The frequently frozen seas interlacing the Canadian Arctic Archipelago, together with innumerable northern lakes, produce an enormous chilling effect on the air above, and the temperatures for these huge regions are 6° to 8° F (3° to 4° C) cooler than the average for their latitude. The North Pacific, warmed by an extension of the Kuroshio (Japan Current), has a positive anomaly of 8° to 10° F (4° to 6° C) warmer than the average for its latitude. Related trends over the northern part of the North Atlantic affect Iceland and Europe rather than North America but still raise the temperatures off the northeast coasts by perhaps 2° F (1° C). The climate thus shows marked contrasts between the maritime and continental areas. Notably warm temperatures extend northward along the west coast from Vancouver Island to Alaska, while a great cold loop extends down the Mackenzie plains and the Canadian Shield over the heart of the continent. The chilling effects of the immense Greenland ice cap drag cold continental conditions southward over the northeast coast at least as far as Newfoundland. The average January temperatures of Annette Island in the Alaskan panhandle, about 34° F (−1° C), of Fort Smith, N.W. Terr., −14° F (−26° C), and of Nain, Labrador, 1° F (−17° C), show the difference between coastal and continental conditions and also between the west and the east coasts; these differences are negligible in the tropical parts of North America.

Precipitation. Most of the continent is humid and provides a good water supply for settlement and development. From mid-California north, the windward sides of mountains along the Pacific coast are bathed with rain- or snow-laden westerlies, giving from 40 to 200 inches (1,000 to 5,000 millimetres) of precipitation per year. Westerlies again reassert themselves east of the Rockies—especially east of the Missouri River and Red River of the North—bringing moderately wet (20 inches) to wet (45 inches) conditions in the central and eastern regions. Two main areas exist where precipitation amounts generally are low. The first is in the far north and northeast, under the influence of extremely cold and relatively dry winds, with a thin dusting of winter snow and a meagre fall of summer rain in the Canadian Arctic Archipelago and Greenland. The other is in the south and southwest, where the mid-latitude high-pressure system produces subsiding and descending air that greatly inhibits rainfall. The high pressure also leads to dry offshore winds from mid-California to southern Mexico. Since these winds blow from the interior out to sea, they carry little moisture, with annual precipitation in that area usually less than 10 inches.

Air masses. The continent's air masses reflect different conditions of temperature and humidity; they include northern and southern components, subdivided into continental (dry) and maritime (moist) types. In the north are found the Arctic air mass, over Greenland and the Canadian Arctic Archipelago; the polar continental, over northern central Canada; the polar Pacific, over Alaska and the northern Pacific shores; and the polar Atlantic, off the Atlantic provinces of Canada and New England. The southern half of the continent is characterized by the subtropical Pacific air mass, off the western United States; the tropical continental mass, over the intermontane basins of the Cordilleras from Utah southward; the tropical gulf, centred in the Gulf of Mexico and the Caribbean; and the tropical Atlantic, off the southeastern United States.

The polar continental, the tropical gulf, and the polar Pacific are the most influential air masses. The polar continental reflects the spread of a negative temperature anomaly over much of the continent. It is a cool-to-cold



Average annual precipitation for North America.

mass of stable air forming an immense dome of high pressure above the Canadian Shield, with winds blowing outward to sweep over Labrador and New England or southward across the Great Lakes and the Great Plains. At its maximum, it extends from the Canadian Arctic Archipelago to the Ozark Mountains. In winter it joins with the Arctic air mass over Greenland to make a formidable body of cold, heavy air that carries subzero weather as far south as the Ohio River valley and may overflow the Appalachians and penetrate into the Rockies. Exceptionally, it can produce killing frosts into the Central Valley of California, the Texas Gulf Coast, and central Florida. In the spring it shrinks northward before the swift advance of the tropical gulf air, which is drawn northward by low pressures developed in the Mississippi River basin as the heart of the continent heats up. This air mass is warm, moist, and unstable; at its height in late July, it extends two enormous loops of warm air, one northwestward up the Mississippi and down the Mackenzie and the other northeastward up the Ohio and down the St. Lawrence. The July average of 60° F (16° C) is then carried north of Edmonton, Alta., in the west and to Quebec in the east. The storm-generating polar Pacific air mass is active from northern California to Alaska, especially in the winter, when its mild, wet air reflects the North Pacific temperature anomalies. When the tropical continental air mass moves to the north and east, it is responsible for extremely hot, droughtlike conditions in the Great Plains in the summer and for mild spells in the Great Lakes region in the fall, the latter period called "Indian summer."

Pacific Coast storm tracks

Storm tracks. Where cyclones (low-pressure cells) develop persistently along the advancing air-mass edges, strong storm tracks occur. Pacific storm tracks thread the Strait of Georgia, Puget Sound, and the Inside Passage to Alaska. In summer they shift north of Prince Rupert; in the depth of winter they migrate southward to San Francisco. Moving up the Columbia and Fraser river valleys, these storms weaken as they pass through the Cordilleras, only to form again on the lee side as they join with a stream of Pacific air that overtops the mountains. These draw in air from the polar continental air mass on their advancing cold sectors and from tropical gulf air in their warm sectors. As the polar continental air mass begins to expand in September, a line of storms tracking from the Mackenzie River to James Bay develops, migrating progressively southward to reach a track from Texas to Ohio in January. As the tropical gulf air mass expands north, the successive tracks become activated again until, in August, the gulf air brings a swirl of storms to the Mackenzie. Most of these storm tracks begin in the western plains, converge on the Great Lakes–Ohio area, and then bunch together in the climatically active St. Lawrence–Hudson–Mohawk zone. The Atlantic Coastal Plain becomes a storm track in winter as tropical maritime air contests the advance of the continental air from the north.

Climatic regions. Differing continental climatic regions reflect the considerable amount of Arctic land, the great spread of temperate conditions, and the small but significant tropical area; dry climates also stand out in strong contrast to the prevailingly humid ones.

The Arctic zone. Including the northern parts of the Canadian Shield and Alaska, the Canadian Arctic Archipelago, and Greenland, the Arctic zone is dominated by Arctic and polar continental air masses and is perennially cold or cool. Temperatures below 0° F (−18° C) last for 5 to 7 months, and subfreezing temperatures can persist for 8 to 10 months. Only between June and September do temperatures frequently rise above 32° F (0° C). The frost-free season does not exceed 60 days. Precipitation is low—especially in the far north—with 2 to 4 inches of summer rain, plus 30 to 60 inches of winter snow.

Zone of long, severe winters

The cool temperate zone. The cool temperate zone extends from Newfoundland to Alaska and from Hudson Bay to the Ohio River. It is dominated by the polar continental air mass. Winters are long and severe. After the period of "Indian summer" that continues into October, temperatures fall quickly and do not rise substantially until April or early May. In January and February they drop to below 32° F (0° C) in the Ohio River valley and below 0° F (−18° C) north of the Great Lakes, with minimum temperatures as low as −20° to −80° F (−29° to −62° C). Winter killing of crops and spring and autumn frosts are a hazard in the Canadian parts of the region, where the frost-free season is from 90 to 120 days. A swift transition occurs with spring; tropical gulf air raises monthly mean temperatures to more than 50° F (10° C) in June and to more than 60° F (16° C) in July. Precipitation is moderate, from 15 to 35 inches; as evaporation is low, however, most precipitation is effective for plant growth. The maximum precipitation occurs in summer to fall, when the James Bay, Alberta, and Wyoming storm tracks are activated and when moist gulf air is in place.

The warm temperate zone. On the southeast coasts of the United States, the warm temperate zone extends to the Mississippi River and over the Gulf Coast; the zone is strongly influenced by the tropical gulf air mass. The long frost-free season exceeds 200 days. The tropical air spreads north in February and dominates the region until November, when polar continental air descends. Winters are mild, with January means of from 40° to 54° F (4° to 12° C). July averages are tropical, being as high as 83° F (28° C).

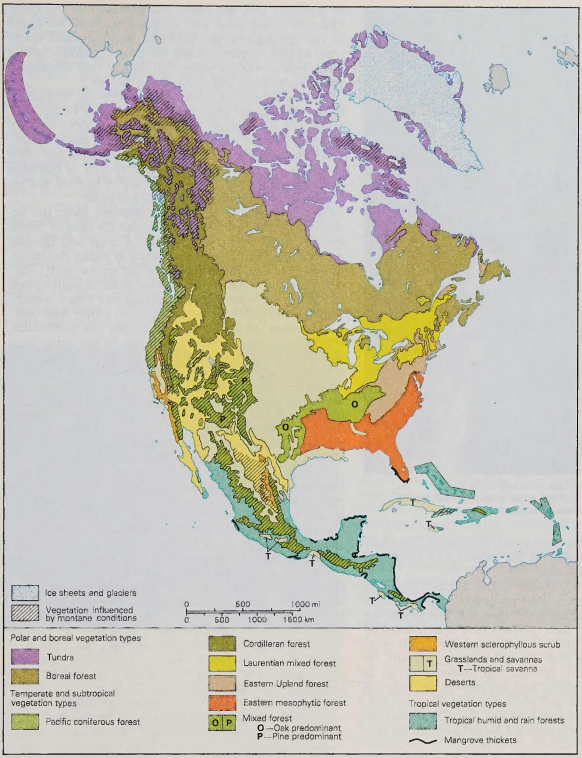
This warmth and the long growing season allow subtropical crops to be grown. Rainfall is ample (40 to 60 inches) and benefits from the presence of the Colorado and Texas low-pressure systems and from the strong summer movement of tropical maritime air. By then the landmass is intensely heated; and this, combined with the air movement, produces frequent thunderstorms, especially in early summer. Hurricanes are an annual hazard along the Gulf of Mexico and up the lower Mississippi valley.

In the American Southwest a Mediterranean type of climate is found. Summers are dry there, since the tropical continental air is dominant. July means of 70° to 80° F (21° to 27° C) are typical, with bright, sunny skies. Winters are mild (45° to 50° F [7° to 10° C]) and somewhat wet, with polar Pacific airs swinging south and bringing occasional heavy rain. Frost is rare but may occur when polar continental air thrusts through to the coast. Los Angeles has a record low temperature of only 23° F (−5° C). Snowfall is rare. Annual rainfall totals of from 15 to 30 inches, along with high evaporation rates, often are insufficient for growing crops during the summer; supplemental irrigation is then necessary.

The tropical humid climate. Central America, with its tropical humid climate, has no winter; even the coldest month averages above 64° F (18° C). With summers of 80° to 82° F (27° to 28° C), the mean annual temperature range is lower than the usual daily range, a characteristic which is markedly different from most of North America. Rainfall is ample and regular, with 45 to 80 inches where the easterly trade winds blow onshore. Lee valleys, however, often are quite dry. Summer hurricanes frequently recur, causing much damage.

Factors in the Southwest's aridity

Dry climates. About a third of North America, including the high Arctic latitudes, has a dry climate. Chief dry areas lie in the American Southwest, where a combination of the mid-latitude high-pressure belt, the tropical continental air mass, and the rain-shadow effects behind the high Sierra Nevada has led to lack of rainfall. Winds blow from the continent outward, discounting the effect of Pacific subtropical air. As the winds move down in altitude from high interior plateaus, they become drier. The intermontane region of the United States and Mexico, from the Columbia River basin to Guadalajara, and the Pacific Coast from San Diego, Calif., south to Mazatlán are therefore arid, receiving less than 10 inches of rain per year. Some years have no rain. The Great Plains, from the South Saskatchewan River to Mexico, are semiarid, with from 8 to 15 inches of rainfall; the high midcontinental jet stream usually is depressed southward over them, strengthening down-moving dry wind from across the Rockies and tending to fend off cyclones from tropical gulf or polar continental air masses. The high Arctic areas are dry because most of the open water (which could act as a source of moisture) is frozen for 6 to 9 months of the year, and because the cold air that dominates the region can hold little moisture.



Vegetation zones of North America.

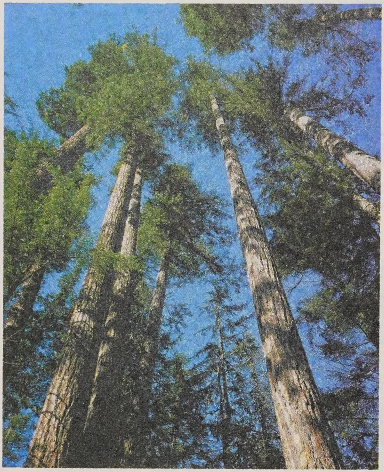
PLANT AND ANIMAL LIFE

North American vegetation communities and their associated fauna are closely allied to soil, as their habitats, too, reflect the powerful influences of climate. Forests dominate the humid regions and once covered about two-thirds of North America; grassland, scrub, desert vegetation, or tundra typify the dry third of the continent.

Forest communities. *The Pacific coniferous forest.* Offering one of the great spectacles of the continent, the Pacific coniferous forest consists of immense redwoods and firs forming vast cathedral-like groves, where the tall trunks rise hundreds of feet like great pillars to support a canopy of evergreen branches overhead. A long growing season and a heavy, constant supply of moisture have combined to foster the tallest and largest trees found in North American forests; redwoods and western cedar along the north coast of California give way to Douglas fir and western hemlock from Oregon to British Columbia and Sitka spruce in Alaska. In the south red-stemmed arbutuses lend a Mediterranean touch; giant-leaved maple, oak, and ash are common in the middle sector; and birch and aspen are the subdominants in the north. This coastal forest is one of the continent's chief sources of construction timber. It also is a major source of pulp and paper and a home for large numbers of red deer and mountain elk and also of black bear, lynx, and beaver. Fish-eating hawks and eagles abound. North America's greatest runs of salmon are seen there, as the fish swarm upstream to spawn in mountain lakes; while off the Queen Charlotte Islands lies one of the continent's chief halibut fisheries. The meeting of the Kuroshio, a warm current from across the Pacific, with the cool water along the western offshore deeps provides ideal conditions for abundant fish life. The faulted and glaciated coasts with great fjords and perennial rivers attract fish inland and thus facilitate fishing.

Fish-breeding conditions in the offshore deeps

The boreal forest. One of the greatest sweeps of forest in the world, the boreal forest (or taiga) extends in a vast and virtually unbroken sheet of green eastward from the Aleutian Islands through Alaska and northern Canada to the island of Newfoundland. Its conifers are much shorter than those of the Pacific Coast but grow in denser, sometimes almost impenetrable, stands. The boreal forest essentially is the domain of spruce and balsam fir, with various species of pine becoming significant in the west and jack pine and tamarack in the east; interspersed among the conifers are such handy deciduous species as white birch. From Alaska through the Mackenzie plains to Keewatin, white spruce dominates; through eastern Canada and up-



Douglas fir trees (*Pseudotsuga menziesii*) in the Pacific coniferous forest on the western slope of the Cascade Range, near Mount Baker in northwestern Washington.
© Pat O'Hara

land New England, the black spruce is common, especially on wet soils. The region is the Western Hemisphere's greatest source of pulpwood.

Great herds of caribou shelter in the northern fringes of this forest in the winter. They are preyed upon by packs of timber wolves. Farther south deer, elk, and moose are still common, though their numbers have been reduced by humans. Both black and brown bears are frequently seen, especially in berry patches. Many fur-bearing animals, including martens, mink, beavers, and muskrats, occur, as do squirrels. In the spring pickerel run up the rivers to spawn, and lake trout and whiting live in the cool, deep waters of the innumerable northern lakes. Whitefish are caught in great numbers in Great Slave Lake, but because of pollution they are much less prevalent in the Great Lakes than they once were. Cod and haddock are found in vast numbers on the banks off Newfoundland southward to New England, where the cold Labrador Current mixes with part of the warm Gulf Stream, thus stimulating aquatic conditions and encouraging fish life.

The boreal forest is home to an enormous bird population. Year-round residents include species of jay, owl, raven, and woodpecker, while summer migratory birds include such waterfowl as the common loon, mallard duck, and Canada goose and large flocks of warblers and other songbirds. Summer also brings huge swarms of blackflies and mosquitoes, which are a nuisance to humans but are important as a food source for fish and birds.

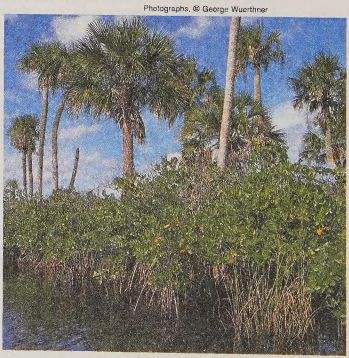
The Cordilleran forest. The Cordilleran forest lies between the Pacific coniferous forest and the interior boreal forest. On the west it is made up of cedar and Douglas fir, with Sitka and Engelmann spruce at higher elevations; while, in the east, it has more pine and spruce, with lodgepole pine and white spruce making close, straight-limbed stands. On the intermontane plateaus and ridges, western hemlock and yellow or sugar pine form groves with parkland between. Altitude and aspect dictate tree distribution, with tall and dense fir woods occurring on the wetter faces at lower levels, spruce blanketing the higher slopes, and pine abundant mainly on the drier exposures. At elevations above the tree line, scattered clumps of subalpine firs are found in sheltered areas, these giving way to Alpine tundra at higher altitudes and ultimately to ice and snow on the highest peaks. Animal life is rich there, as this region is the continent's chief game preserve. Species include elk and deer in the fir-spruce forests, antelope in the open parkland, and goats high up in the Alpine pastures. Preying on these are the mountain lion and the occasional pack of wolves. The grizzly bear keeps to higher and less accessible haunts, but the black bear is common in the lower forests. Mountain trout are abundant in streams.

Game animals

The Laurentian mixed forest. Lying in the warm-summer region of the cool temperate zone, the Laurentian mixed forest occurs in the Great Lakes–St. Lawrence, the upper Mississippi–Ohio, and the New England lowland regions. It consists mainly of deciduous hardwoods—beech, maple, oak, and birch—but also has a good deal of coniferous softwood, including pine and the eastern hemlock. White pine and white and red oak once were abundant but have largely been cut for timber. American elm, which formerly was dominant in the moister soils, largely has been killed everywhere by Dutch elm disease. The long, hot, humid days of summer, when tropical gulf air predominates, lead to huge-crowned, large-leaved trees, which shed their cover with the return of winter under

Photographs, © George Wuerthner





Two contrasting North American forest types.
(Left) Boreal forest (taiga), with white spruce, birch, and low shrubs, near the Fortymile River, a tributary of the Yukon River, east-central Alaska. (Right) Mangroves with palms on the Loxahatchee River, southeastern Florida.

polar continental airs. Rain or snow fall most of the year and thus provide ample moisture for dense growth. Deer are common, especially in areas of partially cleared land where a patchwork of forest and agricultural fields exists; but the moose population has been reduced by overhunting. Wolves, too, largely have been hunted out, a fate that the bear also is suffering, and beavers have been reduced to a small population. Squirrels are still common, but wild mink and marten have become rare. The passenger pigeon that once made this forest its home was hunted to extinction, but numerous other bird species reside there permanently or as summer migrants.

The Eastern Upland forest. Also known as the Acadian forest in Canada, the Eastern Upland forest covers much of the central and southern Appalachians; there, polar continental airs are pronounced, while altitude modifies the tropical maritime winds. The growing season ranges from 90 to 120 days, and winter cold brings subzero temperatures. The forest, therefore, consists of fast-growing evergreen softwood species such as black spruce and balsam fir, along with aspen, alder, birch, and numerous flowering species. Deer are plentiful, as are such small fur-bearing animals as muskrat and squirrel.

© Willard Clay—Tony Stone Worldwide



Azaleas (*Rhododendron*) blooming in the Eastern Upland forest, Blue Ridge Mountains, northern Virginia, U.S.

The Eastern mesophytic forest. Extending from the mid-Atlantic states to northern Florida, the Eastern mesophytic forest is a mixture of hardwoods and softwoods. On the clays of river bottoms and the coast plain, great-crowned oaks form a tall, dense forest, mixed with hickory, walnut, and yellow poplar on the lower slopes of rivers and with ash and elm on higher slopes. Chestnut and elm at one time were widespread but were virtually eliminated by diseases. With warm summer temperatures and abundant rainfall, many subtropical trees and bushes, such as pawpaws, crape myrtles, magnolias, laburnums, rhododendrons, and mimosas, flourish. Live oaks and gum trees are also distinctive of the area. On the sandy soils left by old stranded shorelines, magnificent stands of loblolly, longleaf, and slash pines form the Southern Pineries, now one of America's major sources of timber and pulpwood. Occasional hurricanes bring torrential rains and high winds to the forest, resulting in the widespread blowdown of trees. The white-tailed (Virginia) deer, black bear, raccoon, and opossum are typical animals. Wild turkey, once plentiful but then made rare through overhunting, have made a comeback.

Mangrove thickets. Ringing southern Florida and the Mexican lowlands facing the Caribbean, mangrove thickets are backed by quick-oak and palms. Ibis fleck the woods with their gleaming white feathers. Water moccasin and other venomous snakes are common in swamps, as are alligators.

The Western sclerophyllous scrub forest. In the hills of southern California and throughout much of the American Southwest the Western sclerophyllous forest occurs. There trees and small shrubs must be adapted both to dry, hot summers when the tropical continental air is dominant and to moist, mild winters when polar Pacific air sweeps down from the north. A thin, short, open scrub of chaparral, or stunted evergreen oak, mixed with yellow pine and sagebrush, is typical. Frequent fires are a natural part of this community, keeping plants widely spaced and giving an impression of openness. Pronghorns, jackrabbits, mountain pumas, coyotes, land turtles, and snakes are common. Hawks are typical, preying on small desert rodents.

Role of fires

The tropical rain forest. Tropical rain forests provide dense covering of all windward slopes in southern Mexico and Central America. The forests consist of such tall, broad-leaved evergreen trees as mahogany, ironwood, and palm, which form a spreading canopy over a lower tier of tree ferns, grape bays, gum trees, rattans, and mangroves laced with lianas and covered with epiphytes. Numerous species of plants are widely scattered in the forest. Wildlife also is varied, with a great number of parrots, cockatoos and nutcrackers, troops of monkeys, and many snakes and iguanas. Leopards are still quite common. Ants, beetles, and flies feed on the decaying vegetation, and bacterial activity is high. This is an environment in which such tropical diseases as yellow fever, malaria, and blackwater fever historically have taken a heavy toll. A dry, tropical scrub of thorn trees, cactus, and sagebrush often replaces forest across a remarkably short distance on leeward slopes and in rain-shadow basins.

Grassland and desert communities. Covering about a third of North America, grassland, desert, and tundra—all virtually treeless environments—are found in the drier and colder regions.

Tropical savannas. Located in patches in subhumid parts of Central America, tropical savannas usually occur at the intermediate levels of the lee slopes of mountains and on plateaus. They are significant in Guatemala and the Yucatán Peninsula of Mexico. Heavy, though short-lived, summer rains bring on a thick rapid growth of tall grasses; cyclones associated with the northeastern trade winds bring enough rain during the rest of the year to maintain a thin cover. Fires and hurricanes are frequent agents that disturb vegetation on the savannas.

Temperate grasslands. The temperate grasslands, or prairies, form a belt between forest and desert, mainly on the Great Plains but also on the mid-slopes of the intermontane basins, above the salty desert flats. At the "break of the plains" on the eastern subhumid margin, invaded by rain-bearing tropical gulf airs in spring and early summer, the grasslands consist of a dense growth of tall grasses, such as big and little bluestem and Indian grass, along with small berry bushes, wild roses, and stunted aspen trees. These are the tall-grass prairies that once were home to most of America's bison, before hunters virtually exterminated the species. "Wet" prairie exists in the middle Mississippi basin, where the annual rainfall exceeds 30 inches; its origin has been attributed to repeated burnings by Plains Indians, either to stampede bison in mass hunts, to burn off trees and thicken the grass to provide pasture, or to expedite travel. Farther west, where rainfall drops below 17 inches (in Texas) or 15 inches (in Alberta), vegetation is less luxuriant, and shortgrass prairie is typical. In the westernmost parts of the plains, grasses are found only in bunches, with areas of generally bare ground and gravel between. The vegetation is made up of bluestem bunchgrass, thin needlegrass, and tough grama and wire grasses, along with patches of cactus, sagebrush, or, farther south, mesquite grass. These regions still pasture many small antelopes, although they mainly have been turned into rangeland for cattle or sheep.

The "break of the plains" and the tall-grass prairies



Dense tropical rain forest near the Caribbean coast, northern Costa Rica.
© Gary Braasch

Deserts. Desert vegetation is found in intermontane basins and along arid coasts of the western United States and in northern Mexico. Extensive salt flats and mountains with rocky soils make this a harsh environment for all but the most drought-tolerant plants. Frost and snow are not uncommon in the Great Basin Desert of Nevada, Utah, and Wyoming, which is dominated by sagebrush and by scattered shortgrasses. Creosote bush, saltbush, mesquite, and many species of cactus, including the treelike saguaro, are common in the Sonoran and Chihuahuan deserts of Arizona, New Mexico, and northern Mexico. Animal life is primarily reptilian and tends to be nocturnal.

Tundra. Across northern Canada and on the many islands in the Arctic Ocean lies a vast marshy plain called the tundra. There the growing season is only 45 to 60 days, and frost is possible year-round. Too cold for trees, this community contains only a few plant species, such as sedge, moss, lichen, cotton grass, and heath. In sheltered areas willow and alder shrubs and some dwarf birches are found. Shallow permafrost inhibits infiltration of the already meagre amounts of meltwater and rainfall into the ground. This, coupled with the flatness of the tundra landscape, make for wet, boggy conditions throughout much of the growing season. Biting flies, mosquitoes, and gnats are innumerable. Many species of birds summer in the region; caribou and polar bear are typical mammals.

The human imprint on the landscape. Before the arrival of Europeans in North America, the impact of human activity on the environment seems to have been minimal. The attitude of the European immigrants and their descendants favoured clearing the forests and killing off the wildlife, with the aim of making room for agriculture and urban centres. In a continent that was so vast and at the same time so empty, they also developed the idea

(Left) © George Wuerthner, (right) © Patrick Morrow/First Light





Vegetation in two contrasting dry-climate regions of North America.
(Left) Elephant tree (*Bursera microphylla*) and cardon (*Pachycereus*) in the Sonoran Desert, Baja California, northwestern Mexico. (Right) Cotton grass (*Eriophorum*) and mosses in the Arctic tundra, northern Yukon Territory, Can.

that environmental resources were unlimited and only awaited people to exploit them. It should be remembered that many of these immigrants came from a Europe in which, during the Agricultural and Industrial revolutions, there had been an increasing attack on natural resources, particularly associated with the rise of heavily industrialized cities. When the United States and Canada became industrialized, they used coal, oil, iron, other metals, and wood with extravagance and often with great waste. The waste products of the factories of these nations started to pollute air, land, and water; and, as cities with enormous populations began to appear, most people came to live in an environment sharply modified by human activity.

By the mid-20th century, the people of the United States had killed off about four-fifths of the nation's wildlife, cut more than half of its timber, plowed up nearly all its grassland, and used up two-fifths of its high-grade iron ore; the nation was consuming its oil so fast that, even with its great resources, it began to import enormous quantities from other countries. Soil erosion also became rampant, as agriculture was practiced carelessly or on land with marginal producing capacity. Conscious of the great drain on the resources of the nation and suffering from the increasing ill effects of pollution, the United States began attempts to conserve its reserves of forest, soil, water, fuels, and minerals; and the country has come to lead the world in its conservation programs, particularly in renewing forests and grasslands, conserving soils, and effectively controlling the waters. Canada, too, has an active conservation program and was the first North American country to pass clean-water legislation to help fight the pollution of its lakes and streams. Mexico likewise has initiated an active, though limited, conservation effort. Other environmentally positive actions—such as recycling materials otherwise discarded as solid waste, and energy conversion—have helped in the northern part of the continent to offset the effects of increased population pressure on the land. (J.W.W./R.J.Sc.)

Conservation programs

The people

In global terms, North America long remained a relatively empty and economically undeveloped land until about AD 1500. After that the continent began to receive great numbers of people from the Old World—primarily Europe and Africa—and it underwent a profound transformation. The discussion that follows primarily covers the nonindigenous peoples of mainland North America. The ethnohistory of the North American Indians is treated in more detail in the article AMERICAN INDIANS, and that of the Mesoamerican peoples is discussed in PRE-COLUMBIAN CIVILIZATIONS; for treatment of the peoples in the Caribbean region, see WEST INDIES, THE.

THE NORTH AMERICAN INDIAN HERITAGE

The date of the arrival in North America of the initial wave of peoples from whom the American Indians (or Native Americans) emerged is still a matter of considerable uncertainty. It is relatively certain that they were Asiatic peoples who originated in northeastern Siberia and crossed the Bering Strait (perhaps when it was a land bridge) into Alaska and then gradually dispersed throughout the Americas. The glaciations of the Pleistocene Epoch (1,600,000 to 10,000 years ago) coincided with the evolution of modern humans, and ice sheets blocked ingress into North America for extended periods of time. It was only during the interglacial periods that people ventured into this unpopulated land. Some scholars claim an arrival before the last (Wisconsin) glacial advance, about 60,000 years ago. The latest possible date now seems to be 20,000 years ago, with some pioneers filtering in during a recession in the Wisconsin glaciation.

These prehistoric invaders were Stone Age hunters who led a nomadic life, a pattern that many retained until the coming of Europeans. As they worked their way southward from a narrow, ice-free corridor in what is now the state of Alaska into the broad expanse of the continent—between what are now Florida and California—the various communities tended to fan out and to hunt and forage in comparative isolation. Until they converged in the narrows of southern Mexico and the confined spaces of Central America, there was little of the fierce competition or the close interaction among groups that might have stimulated cultural inventiveness. Although great architectural and scientific advances did occur in Mesoamerica, there was markedly less in the way of metallurgy, transportation networks, and complex commerce than among the contemporary civilizations of Asia, Europe, and sections of Africa. Cities appeared first among the Olmec in the strategic narrows between Mexico and Central America and among the Maya in portions of Guatemala, the Yucatán Peninsula, and Honduras. Subsequently, the Toltec and Aztec created some remarkable cities in the high Mexican Plateau and developed a society whose crafts and general sophistication rivaled those of Europe. These dense populations were based on a productive agriculture that relied heavily on corn (maize), beans, and squash, along with a great variety of other vegetables and fruits, fibres, dyes, and stimulants but almost no livestock.

Cultural achievements

The size of the pre-Columbian aboriginal population of North America remains uncertain, since the widely divergent estimates have been based on inadequate data. Luis de Velasco, a 16th-century viceroy of New Spain (Mexico), put the total for the West Indies, Mexico, and Central America at about 5,000,000; some modern scholars, however, have suggested a figure two to five times larger for the year 1492. The pre-Columbian population of what is now the United States and Canada, with its more widely scattered societies, has been variously estimated at somewhere between 600,000 and 2,000,000. By that time, the Indians there had not yet adopted intensive agriculture or an urban way of life, although the cultivation of corn, beans, and squash supplemented hunting and fishing throughout the Mississippi and Ohio river valleys and in the Great Lakes–St. Lawrence river region, as well as along the Gulf of Mexico and Atlantic Coastal Plain. In those areas, semisedentary peoples had established villages, and, among the Iroquois and the Cherokee, powerful federations of tribes had been formed. Elsewhere, however, on the Great Plains, the Canadian Shield, the northern Appalachians, the Cordilleras, the Great Basin, and the Pacific Coast, hunting, fishing, and gathering constituted the basic economic activity; and, in most instances, extensive territories were needed to feed and support small groups.

The history of the entire aboriginal population of North America after the Spanish conquest has been one of unmitigated tragedy. The combination of susceptibility to Old World diseases, loss of land, and the disruption of cultural and economic patterns caused a drastic reduction in numbers—indeed, the extinction of many communities. It is only since about 1900 that the numbers of some Indian peoples have begun to rebound.

THE EUROPEAN HERITAGE

The European attitudes toward the environment. When European colonizers entered North America, they regarded the continent as a virtual wilderness, one waiting to be settled and developed economically. The indigenous agriculture in what is now the United States and Canada seemed strange and rudimentary to them, and it had made only a slight dent in the vast forests and grasslands. There were no herds or flocks of domesticated grazing animals exploiting the natural pastures, and mineral deposits, water power, and other resources were being ignored by the aborigines. The Europeans saw no reason why they should not claim land they thought could be used to better advantage; and they proceeded to buy out, exterminate, or push out the Indians—when they did not enslave them—and established their supremacy over the land.

The dispossession of the Indians. The process of removing the Indians from their ancestral lands led to bitter disputes. The British tried to end one such problem by setting up the Proclamation Line of 1763 along the Appalachian divide, allowing whites to take over what lay to the east but attempting to reserve what lay to the west as Indian territory. After their independence from Britain, the Americans continued to adopt this ideal of a two-nation state, but in practice the notion soon collapsed as

they pushed the Indian line westward past the Appalachians to the Mississippi River and into the Missouri River valley and other western lands. Nearly all the Indians in the east were displaced to the west and into special zones in Oklahoma, the Great Plains, and the intermontane basins. Even there, their land and their way of life were not respected, as ranchers, railroaders, and homesteaders opened the West to settlement.

The Indian "territories" soon were reduced to isolated "reservations." As a result, most of the Indian population in the United States is now found west of the Mississippi River, usually in drier areas unsuited to productive agriculture. At times the U.S. government has encouraged Indians to leave the reservations and mix with the general population in the large cities of the Midwest and West, a process of acculturation that some—including many younger and ethnically conscious Indians—would claim poses as many dangers to the individual and social well-being of Indians as do the communal misfortunes already brought upon them. Counteracting the forces of assimilation have been increasingly energetic programs to defend and strengthen aboriginal identity.

Canadian reservation system

In Canada the reservation system was adopted at a relatively early date; it protected Indian settlements throughout the east, even in such agriculturally rich areas as the Montreal plain or peninsular Ontario. As the Europeans moved west, care was taken to retain Indians on at least part of their own lands, including such fertile areas as the valley of the Red River of the North and the Fraser River delta. Intermarriage between whites and Indians was much more common than in the United States and produced a sizable community of the French and Indian métis, who in 1869–70 unsuccessfully attempted to set up a separate state in the Canadian prairies.

In both Mexico and Central America, racial admixture has gone much farther. In Mexico, the mestizo population—of mixed Indian and white descent—accounts for some three-fifths of the population, while pure-blooded Indians amount to less than a third, and whites constitute nearly all the rest (a tiny fraction are Mexicans of African descent). European immigration to Mexico and Central America since the original Spanish conquest has been negligible. When Velasco made his tally of 5,000,000 Indians within his jurisdiction, there were only 150,000 Spaniards in the New World.

The policies of the colonizers. *Spanish policy.* Colonial policies strongly affected the evolving human patterns of North America. It often is stated that Spanish interests centred around God and gold—the Christianizing of the Indians and quick wealth from precious metals—but this is an overstatement. The Spanish also were deeply involved in the land, which they developed into huge haciendas (estates) that were worked by tenants or by direct labour in the form of serfs or peons. As a result of this policy, few European settlers were drawn to the lands ruled by Spain, although it did introduce a competent entrepreneurial and professional group into North America—mine owners and operators, proprietors of the haciendas, merchants, administrators, and priests—but few members of the middle and working classes. Little manufacturing was established; and, even though towns were important, they functioned mainly as centres for trade and services. Descendants of the Spanish remain as an elite class in the area colonized by their ancestors.

French policy. The policy of France was much the same, even though the physical conditions of their territories prevented creation of large estates or mining operations. The first Frenchmen on the continent were mostly entrepreneurs interested in the lucrative fur trade who hired Indians to collect and carry furs from the hinterland to the French trading posts. The French opposed, sometimes forcefully, extensive European agricultural settlement. The royal government, however, believed it essential to have a strong European population base in its new holdings. Consequently, it gave large seigneuries, or grants, to landed proprietors who promised to bring in settlers, clear the forest, and develop the country. The seigneurs arrived with the traditional French ideas of tenant farming, a system under which the seigneury was divided into small parcels, each paying rent for the land. Like the Spanish, few of the French wished to live in the New World under Old World conditions. As a consequence, when the British took over from the French in Canada in 1763, there were only about 80,000 French settlers in Acadia and Quebec, whereas the British on the continent then numbered between 2,000,000 and 3,000,000. The French, however, had been there for more than 150 years; and, since their language, religion, school system, and laws were tolerated by the British, the French Canadians were able to retain their identity. The people of French origin now account for about one-fourth of Canada's population and are firmly entrenched in the province of Quebec, with sizable communities in New Brunswick and Ontario and smaller outliers in the western provinces. They form a distinctly Latin element within the Anglo-American realm, and, indeed, many Québécois yearn for an independent French-speaking nation based in Quebec.

The Quebec French community

British policy. British policy promoted, with considerable success, the large-scale settlement of its colonies in North America by freemen seeking land of their own, businessmen trying to found new enterprises, mill owners, craftsmen, professionals, and workers eager to make the most of their own skills, as well as political and religious refugees and landlords intent upon exploiting their grants. The British colonies, therefore, attracted many settlers from the British Isles (including the Irish) with a wide range of competence. The British also opened their colonies to non-British Europeans, notably the Dutch and Swedes and such religious minorities as the French Huguenots and the Mennonites and other dissenting groups from Germany. Under the Hanoverian regime in Britain, many German mercenaries also were settled. In the 19th century the British opened the Canadian west to Germans, Scandinavians, Ukrainians, and Poles on a large scale and later accepted Chinese, East Indians, and other settlers.

U.S. policy. The newly independent United States continued and expanded British colonial immigration policy. Provisions for landownership were even more generous, and—especially after the Southern plantation system and chattel slavery were abolished—opportunities for capitalist manufacturing and trade increased dramatically. The nation welcomed virtually all immigrants from Europe in the belief that the United States would become, at least for whites, the "melting pot" of the world and thus in a sense develop what the historian Frederick Jackson Turner called a "new race of men." A major influx did not materialize until the 1830s, when massive numbers of British, Irish, and Germans began entering, to be joined after the Civil War by streams of Scandinavians and then groups from eastern and southern Europe and the Russian Empire; in addition, small numbers came from the Middle East, China, and Japan.

A decline in immigration from northwestern Europe and concerns over the problems of assimilating so many people from other areas prompted the passage in the 1920s of legislation restricting immigration. Since 1970, however, there has again been a liberalization in immigration policy and a striking change in the demographic makeup of the new immigrants, with large numbers now coming from Latin America, the West Indies, and East and South Asia; significant numbers also come from Europe, Canada, and the Middle East. The number of documented (legal) and undocumented (illegal) immigrants may approach 1 million per year, the great majority of whom are destined for urban centres. In total, somewhat more than 50 million people have migrated to the United States in the span of two centuries, which far outnumbers population movements to any other part of the world.

THE AFRICAN HERITAGE

The slave trade and its consequences

North Americans of African descent originally were brought to the continent involuntarily as slaves. The entire question of the transatlantic slave trade and its turbulent legacy is still fraught with deep emotions—a not unexpected development—since this tragic episode set in motion forces and counterforces that molded much of European and African, as well as North American, society over the course of nearly four centuries. Slaves were not

widely used in Canada or in most sections of New England and the Middle Atlantic states, areas where plantation agriculture never developed, or in Mexico or Central America, where Indian labour could be coerced; but slaves were imported in great numbers to the Caribbean islands and to the Southern states of the United States, where they toiled on tobacco, cotton, sugar, and rice plantations. The importation of slaves to the United States became illegal in 1808, but illicit traffic and natural increase produced a steady growth in the black population. These people lived under conditions that not only were physically difficult but also created social and psychological problems for families and individuals.

The abolition of slavery in 1865 gave blacks, in theory if not in practice, freedom to work and live where they chose. Many, however, saw no alternative to staying on plantations as impoverished tenants or sharecroppers. Economic and technological developments in the 20th century—notably the mechanization of farming—sent large numbers of blacks to the Northern cities, where they became concentrated in ghettos and had to face new problems of racial discrimination in addition to those present in the South. The resulting social and racial polarization struck at the very roots of American society and challenged the validity of its professed egalitarianism. Although the struggle to win full equality made some progress, especially from the 1950s, the cause of black Americans remains far from won. Schooling, housing, social services, and, above all, equitable access to employment opportunity remain major areas of concern. Partly because of this systematic exclusion from the mainstream American society, the African contribution to the life of the nation has given rise to a rich and unique African-American culture.

Black Americans have been the usual and longest-standing victims of racial prejudice in America; but they have not been its only victims. Racism has complicated relationships with peoples from other cultures and continents as well. Hawaii, nevertheless, has become something of a model as a multiracial society; and attitudes on the mainland have matured as the influx of Mexicans, Chinese, Koreans, Southeast and South Asians, and others has continued. The United States increasingly continues to become a polyglot nation. The resulting rich ethnic mix, while generating certain problems, also is one of that nation's greatest assets.

DEMOGRAPHIC PATTERNS

Favourable and unfavourable regions. As an area of late exploitation, North America does not have the high settlement densities of Europe and Asia. The continent's population, however, continues to grow and is concentrated in regions of comparative advantage, such as the coasts, lowlands, and humid and temperate zones. The enormous expanses of the Canadian Shield and of mountainous terrain have discouraged continuous settlement in nearly half of the continent. Settlement is even more problematic in the frost-ridden areas of the Arctic coastal plain and the Mackenzie and Hudson Bay lowlands. Similarly, drought conditions in much of the western parts of the continent limit their use, while the disease-ridden, wet, tropical lowlands of Central America remain relatively empty. Furthermore, some of these sparsely populated areas are becoming emptier, as those who seek better economic and social opportunities move to already crowded regions.

These more densely populated areas include the Atlantic Coastal Plain from Nova Scotia to Florida; the humid, cool temperate belt of southern Canada, with its warm summers; the vast warm temperate zone of the United States centred in the Mississippi-Ohio drainage basin; the mild, moist Pacific Coast from southern British Columbia south to California; and the temperate, yet warm, and well-watered Mexican Plateau and similar portions of Central America. Within these privileged areas, growth is concentrated still further in the large cities, especially those associated with the Atlantic coast from Maine to Virginia, the Hudson-Mohawk gap, the Great Lakes–St. Lawrence system, the Ohio River basin, the middle Mississippi basin, Puget Sound and the Fraser River delta, and the California coast.

Geographic distributions. *The role of Canada.* Canada's share of the total continental population is small (less than 10 percent); and, with some two-fifths of the continent's land area, its overall population density is low. Most of Canada—the shield, the northern Appalachians and Cordilleras, and the tundra and boreal forest zones—is almost devoid of inhabitants. Population is concentrated toward the south, around the Bay of Fundy, the St. Lawrence River and lower Great Lakes, the southern prairies, and the Columbia and Fraser valleys. Wealth is still based on iron, nickel, and other metals; oil and natural gas; hydroelectric resources; and grains, livestock, fish, and forest products. Much of its manufacturing industry depends on these resources. Mechanization and automation give a high per capita production, and it produces far more food and various raw materials than it can consume and thus sells much abroad.

The makeup of Canada's population

A member of the Commonwealth, Canada's population is still nearly half British in ancestry and more than three-fifths English-speaking. The fact that about a quarter of the population is French-speaking reflects Canada's origin from the two founding nations of France and Great Britain. Although most Canadians are native-born, immigration is still a major factor, with the non-British (including U.S. citizens) outnumbering the British among the new settlers. Canada is thus a bilingual, multicultural nation, with strong attachments to Britain and other western European countries. It is dependent, economically, on the United States, the source of the great majority of foreign investment and of some 70 percent of Canada's imports. Ontario is the leading destination for immigrants and internal migrants, but Alberta and British Columbia also are attracting new residents. Some three-quarters of the national population lives in urban areas, with about a quarter in the metropolitan areas of Montreal and Toronto, the leading industrial and business centres.

The role of the United States. The United States dominates the continent, with considerably more than half the total continental population. Unlike the other countries of North America, most of its area is habitable, even though the many mountainous and arid regions are almost unpopulated. The average density is much higher than that of Canada, though still low compared to Europe or Asia. Nonetheless, more than half of the nation's people are clustered in less than one-tenth of the country's area.

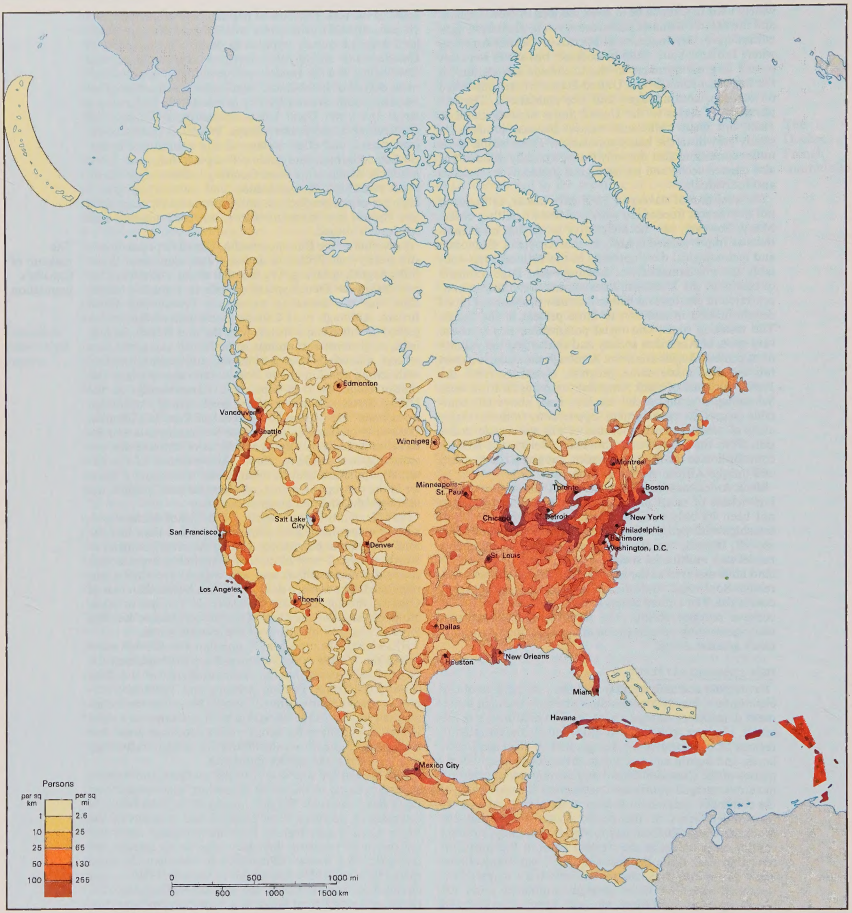
Historically, the most heavily populated section has comprised the Middle Atlantic states, New England, and the Great Lakes states; but in the second half of the 20th century California, Florida, Arizona, and Texas have undergone rapid relative growth rates. This influx can be attributed in part to the attraction such amenities as a mild winter climate have for people retiring to those areas, but it also has resulted from the flourishing of high-technology manufacturing and service industries.

Even though the strong shift to the southern and western states has come to dominate migration, other population flows have emerged. Notable among these have been the increases in northern New England and portions of the upper Great Lakes region. Most metropolitan areas still receive more migrants than they lose—both foreign and domestic—but overall urban growth rates have lessened markedly since 1950. Indeed, since the late 1960s a near equilibrium has existed in the exchange of migrants between urban and rural areas, and nonurban environments have become increasingly appealing to many Americans.

The United States has developed its service sector more fully than any other New World nation, with more than two-thirds of its working population thus employed. About one-quarter of all workers are in manufacturing and construction, and the remainder are engaged in primary production, such as farming, mining, fishing, and lumbering. The per capita consumption of material goods in the United States is among the highest in the world.

Immigration

Although only a small fraction of the American population now is foreign-born, immigration is supplying an increasingly large share of the nation's population increase; the birth rate has dropped below the replacement level. Among native-born groups, fertility has been highest among American Indians, Hispanics, blacks, and such religious groups as the Mormons. Less than one-



Population density of North America.

fifth of all black Americans remain in the rural South, as most now live in the larger cities, predominantly in overcrowded inner-city areas. Blacks now constitute the largest single group in most large American cities and represent a majority population in many of them. The inner-city concentration of blacks and Hispanics, one of the more conspicuous features of urban life in North America, has been paralleled by a strong white population shift to the suburbs. About two-thirds of the U.S. population growth has been in metropolitan suburbs, thus often exacerbating the problems of the inner city.

Despite the leveling effects of modern means of communication and travel and the impact of large national and multinational firms, the United States retains much regional diversity in its culture. Even though new regional patterns may emerge—as in southern California or the Hispanic-influenced Southwest—the five principal traditional culture areas of New England, the Midland, the South, the Midwest, and West remain recognizable in a variety of ways. Such cultural complexes are the products of differences in the ethnic identity and social backgrounds of their inhabitants, the date and place of their arrival, and the interaction with physical habitats and historical circumstance that vary from place to place. Perhaps the most closely studied of the relevant phenomena have been the various dialects of a rapidly evolving American English, a language that is clearly distinct from British English and subtly different from Canadian English; and these di-

alects—and subdialects, such as the speech of New York City, New Orleans, or Philadelphia—tend to coincide with other markers of regional identity. Enough also has been learned about the regional aspects of building construction—including barns, fences, farmsteads, cemeteries, and the layouts of towns and villages—to affirm the existence of the older and newer culture areas. A striking 20th-century development has been the emergence of what are called "voluntary regions"—*i.e.,* places to which people of similar tastes or aptitudes tend to gravitate. Some of these regions are relatively large (such as southern Florida, the Ozarks retirement region, or the Kentucky Bluegrass region), but much smaller localities (such as cities in Nevada and Arizona, certain college communities, winter-sport developments in the Rockies, or research complexes in places like North Carolina's Research Triangle) have acquired their unique populations and distinctive ways of life.

American religious diversity

In one major cultural respect the United States has become unique: the sheer number and diversity of its religious denominations. All the world's major religions and sects are represented, and other groups are constantly appearing. Many of these churches were imported from the Old World, but a large number are domestic in origin. Although Protestantism accounts for a large majority of denominations and population, Roman Catholicism is by far the largest single religious community; it accounts for nearly 30 percent of all church members in the United States, but many of its adherents and parishes tend to practice the faith in their own ethnic fashion. There remain significant minorities of Americans professing other faiths—notably Eastern Orthodoxy, Judaism, Islām, and Buddhism—as well as less familiar ones; and, like Protestants and Catholics, these groups often are split along ethnic or doctrinal lines. Certain denominations are closely identified with general culture areas. This is true for the Southern Baptists, the Lutherans of the Upper Midwest, and, most prominently, the Mormons of Utah and portions of neighbouring states. Other denominations that were once localized have become national in scope, such as the Presbyterians who once were clustered in western Pennsylvania and other zones of Scotch-Irish settlement and the Unitarians who were most closely identified with portions of New England.

The role of Mexico, the West Indies, and Central America. The combined areas of Mexico, the West Indies, and Central America have a substantial population, which has been growing rapidly. Although birth rates have been reduced somewhat in Mexico and Costa Rica, overall birth rates remain high, and death rates have dropped to an all-time low; thus, a population explosion has been under way for some time. As in other developing areas, the existing economy can scarcely support the present population, despite the considerable expansion of manufacturing and service industries in Mexico. American capital investment and government aid have been aimed at helping Central America and the Caribbean countries to become self-sufficient; and, although the assistance has been helpful, it also has created problems, such as the massive foreign debts owed by many of these countries. In addition, the impact of such development assistance tends to be concentrated in the capital cities, with little discernible benefit to the rest of the countryside.

If Canada has something approaching the diversity of religions found in the United States, the situation is relatively simple in Mexico and Central America, where the overwhelming majority of inhabitants are at least nominally Roman Catholic or—in the case of many mestizos and aboriginal people—profess a version of Christianity that has become hybridized with preconquest indigenous faiths. As might be expected, the Spanish language also is strongly dominant in these lands, except in those less accessible portions of Mexico and Guatemala where a multiplicity of aboriginal tongues are still spoken. The Spanish spoken in these regions has undergone a transformation from its mother tongue similar to the process that gave rise to American English. Regional dialects have emerged, and the language has been enriched through the adoption of words from indigenous languages.

Dominance of Spanish

The economy

Few episodes in human history have been more remarkable than the economic transformation of North America since about 1700. During the pre-Columbian period, the territories that became the United States and Canada (sometimes called Anglo-America) were areas thinly settled by an aboriginal population that just had begun to practice agriculture on a local scale. In contrast, comparatively old and complex agrarian and urban civilizations had arisen in portions of Mexico and Central America, where relatively elaborate economies and dense populations had developed.

The revolutionary changes occurring after European contact and occupation were the result of an extraordinary combination of circumstances, at least in the United States and Canada. The large numbers of energetic immigrants from a rapidly modernizing western Europe, who brought with them the newest technological advances, encountered a habitat that afforded them ample opportunity to create considerable wealth. Many of the vast regions they encountered were well watered, covered by rich, exploitable forests and productive soils; underlain by considerable mineral resources; and blessed with a climate tolerable to Europeans. Moreover, the configuration of ocean shorelines, rivers, lakes, and landforms rendered feasible the construction of a dense and efficient transportation system for both domestic and foreign commerce. In addition, throughout nearly all of this economic transformation, the huge expanse of the continent north of Mexico has been controlled by two remarkably compatible nations—the United States and Canada—which, in their political orientations, have actively promoted aggressive economic development. The outcome of all of these circumstances has been a level of physical well-being for their citizens that ranks among the highest in the world. Finally, during much of the 20th century the United States has been the world's dominant power in terms of financial resources and economic influence—as well as in agricultural, mineral, and industrial output—and in general it has been the locus of an inordinate share of worldwide production and consumption.

Development in Latin America

Since the time of the Spanish conquest, the economic development in Mexico, Central America, and the Caribbean region—which constitute the northern portion of what often is called Latin America—has been much less pronounced. The failure to attract large numbers of immigrants (aside from African slaves and East Asian labourers in the West Indies), the fragmentation of Central America and the Caribbean into small colonies or sovereign nations, and the perennial political instability throughout the region have all inhibited development. The quantity or quality of natural resources has been less crucial than social and political factors in relegating these lands to peripheral or so-called underdeveloped status within the world economy. (New England, for example, prospered despite distinctly mediocre physical resources.) Whatever economic well-being these Latin American and West Indian countries now enjoy depends to a large extent on the export of minerals and the products of plantations, forests, and the sea and on the infusion of foreign capital and expertise. This has given rise to an economic system in which only a small number of individuals in certain advantaged areas of the region have benefited from the wealth generated by economic development, while the great majority of the region's population has remained impoverished and little affected.

This so-called core-periphery model of development also is evident—though to a lesser extent—in the United States and Canada. Large disparities in social and economic attainment exist between such generally affluent areas as the northeastern Atlantic Seaboard of the United States, the California coast, and the more urbanized areas of Ontario and Quebec and such economically depressed regions as the southern Appalachian Mountains, the lower Mississippi River valley, and Newfoundland. On a smaller scale, notable differentials can be discerned among neighbourhoods in individual cities and among communities within urban areas.

RESOURCES

North America has rich and varied resources. Although it contains less than 10 percent of the world's population, it has an extraordinarily high proportion of the world's resource wealth. It produces a substantial percentage of the world's oil, iron ore, steel, copper, lead, and zinc. With a large percentage of the world's coal and oil output and electrical power production, it possesses the critical elements of modern industry.

Metallic minerals. *The shield.* With a large shield area and mountains strongly intruded by igneous rocks, the continent is well endowed with metals. Its vast interior lowlands and some long stretches of coastal plain are areas of major fossil-fuel formation. Metal-bearing regions include shield structures affected by mountain building or trough development, together with the intensely folded ridges that rose from the eugeosynclines (narrow subsiding troughs that fill with debris) on the periphery. The shield has four main metal-bearing areas: the iron of the Adirondack Mountains and Superior Upland in the United States; the iron-nickel-copper and gold belt of Ontario and Quebec, along the old fold zones north of Lakes Superior and Huron; the iron of the Ungava Peninsula; and the copper, nickel, gold, and uranium of the fault and fold systems of the shield's western rim. Three areas are of special importance: the taconite hematite ores of Mesabi and Ungava, mined with relative ease by opencast, or open-pit, methods; the world's largest deposit of nickel in the norite ore body at Sudbury, Ont.; and the large copper and gold bodies associated with the greenstone intrusions in northern Ontario and Quebec.

The marginal mountains. The Appalachians also are endowed with significant metallic deposits, especially in the median mass between the Caledonian and the Acadian folds, where lead and zinc are found in Newfoundland and New Brunswick; and also in the eastern or outer intensively folded rocks, with iron deposits in Belle Isle (Nfd.), the Trenton (N.J.) prong, and the Birmingham (Ala.) basin.

Deposits in the Cordilleras

The Cordilleras are rich in ores, mainly because of the immense igneous intrusions that underlie many of their structures. The median mass between the Laramie–Rockies and the Sierra Nevada–Cascade systems has major gold, silver, copper, and iron ores in the old plateau of Colorado and Utah. Large lead, zinc, and copper ore bodies occur in the Selkirk Mountains and adjacent ranges of British Columbia. Famous silver, lead, zinc, and gold deposits dot the Cassiar Mountains and upper Yukon River in the north; and, far to the south, the Mexican Plateau holds iron, lead, and silver ores. To the east of this long, north-south line of plateaus lie the Rockies, which were not intensively folded and hence are not as rich in metals



Basic structural regions and principal mineral and hydroelectric sites of North America.

as other mountainous regions of the continent; but the vast intruded mass of the Idaho Batholith and the igneous bodies in the Dome and Peak region were associated with copper, silver, and lead ores of great importance. The Western Cordilleran ore deposits are widespread. They are found linked with intensively folded and intruded rocks of the Sierra Nevada–Cascade–Pacific Coast systems, notably the copper and gold ores of southern and western Alaska. They also include the copper, lead, zinc, and iron ores of the enormous Coast Batholith of British Columbia; the gold, copper, and iron deposits in Arizona and in the Sierra Nevada, where the discovery of gold touched off the famous gold rush of 1849; and the copper, gold, and silver of the Sierra Madre Occidental of Mexico.

Other metallic minerals. With the exception of iron, copper, lead, zinc, nickel, gold, and silver, North America has a mixed endowment of the metals needed for advanced industrial production. Of the various ferroalloy metals that have become essential for industrial and military purposes, only molybdenum is abundantly available, while chromium, manganese, vanadium, tungsten, titanium, cadmium, and cobalt are imported and stockpiled. Domestic reserves of mercury, barites, and uranium may be adequate, but the continent is deficient in tin, platinum, and bauxite (the principal ore of aluminum).

Nonmetallic minerals. The nonmetallic mineral wealth of the continent also is great, particularly in coal, natural gas, and oil. These fuels accumulated as carbon deposits in the lakes and shallow seas of the great lowlands stretching between the shield and the marginal mountains. They also underlie portions of the coastal plains and the continental shelf, particularly in the Atlantic and Arctic oceans.

Coal deposits. Coal deposits were preserved in basins between gentle upwarps in the buried extensions of the shield beneath the Interior Lowlands and also in mildly folded rocks in the miogeosynclines of the inner, less disturbed parts of the Appalachians and Cordilleras. Below the Mississippi-Ohio lowlands and the Great Plains, the outer edge of the shield was depressed and buried, after which it buckled into basins and warps. The Cincinnati Anticline created a vast elongated basin between the middle Ohio River and the Appalachians, in which the western Pennsylvania, West Virginia, and Kentucky coalfields were preserved—probably the single largest coal reserve in the world—together with the Lima (Ohio) oil field. The Kankakee Rise, south of the Great Lakes, has preserved coal and oil in the Michigan (Saginaw) Basin, to the north of it, and the Indiana and Illinois basins, to the south. The last-named basins, also called the Eastern and Western Interior fields, are separated from each other but kept close to the surface by the La Salle Anticline. The Llano uplift similarly has helped to form the Southwest Interior field in Texas.

Coal reserves of the Cincinnati Anticline

An enormous mid-continental arch, the stem of the ancient Y-shaped structure connecting the Canadian Shield with the Colorado Plateau, separates the interior from the western coalfields lying in basins in front of the Rocky Mountains. Seams of bituminous coal occur in the Raton Basin, which is cut off from the Denver Basin by the Las Animas uplift. The huge Williston Basin extends farther north, but it contains rather low-grade coal. Beyond it lies the vast Alberta Basin, with coal exposed in the foothills of the Rockies; this basin also contains one of the largest coal deposits in the world.

Oil and natural gas deposits. The same coal-containing "rises" and basins in the buried shield also have controlled the distribution of oil and natural gas. The Appalachian oil and gas basin, in Pennsylvania on the western flanks of the Appalachians, was the first to be developed. The Illinois, Kansas, and Oklahoma basins lie in the huge quadrilateral formed by the Cincinnati Anticline and mid-continental arch to east and west and by the Kankakee rise and Ozark Dome to north and south. Between the Ozark Mountains and the Sierra Madre Oriental of Mexico are the tremendously productive fields of West and East Texas and the Gulf Coast. Northward, between the mid-continental arch and the Rockies, are found a number of important fields, including the Denver, Big Horn, and western Alberta fields, close to the Rockies, and the Williston, eastern Alberta, and Mackenzie River valley areas, halfway toward the shield. Small fields of oil and gas lie on the flanks of folded mountains within the intermontane zone, as at Paradox, Utah, and San Juan, N.M. The western basins, bordering the Pacific Coast Ranges of California, are of moderate size but very rich. In the extreme north, the Prudhoe Bay basin of Alaska and Mackenzie delta oil have proved that the potentialities of the Arctic shore are real; domes—very much like the salt and sulfur domes of the Gulf Coastal Plain, associated with Louisiana's oil and gas—go with oil on the plains sloping away from the Innuitian fold mountains in the Canadian Arctic Archipelago. Large, though unexploited, oil reserves also occur in the form of oil sands in Alberta and oil shales in Utah and Wyoming.

Arctic oil reserves

Other nonmetallic minerals. In general, North America contains ample supplies of nearly all the more economically important nonmetallic minerals. Few populated places are far from sand and gravel deposits of commercial quality and quantity. Several regions have essentially unlimited amounts of excellent clays for the ceramic industry; limestone for fertilizers, cement, road building, and other uses; and nitrates for farms and the chemical industry. Southeastern Quebec is a principal source of the world's asbestos; the United States—Florida and North Carolina in particular—accounts for a third of the world's phosphate production and dominates the helium market (mainly because of wells in Kansas and Texas); while immense tonnages of borax are mined in California, and North Carolina has substantial mica resources. A fifth of the world's sulfur comes from Texas and Louisiana, areas which together with Ohio, western New York, and lower Ontario account for virtually unlimited amounts of salt. Among the sources of high-quality building stone are Vermont and northern Georgia for marble, Pennsylvania and New York for slate, and southern Indiana for limestone. Mexico and the United States also produce many semiprecious stones, while Mexico is second only to Australia in opals.

Water resources. Considered as a resource, water and waterpower are also abundant, although supplies are rather unevenly distributed. The average rainfall in North America is 30 inches a year, which produces some 15 billion acre-feet of water. About half of this is lost through evapotranspiration, which is direct evaporation plus transpiration from plants. A further sixth is lost through rapid runoff, while yet another sixth percolates down into the groundwater. The amount available from rivers and lakes is thus relatively limited, a fact of growing concern as demand for water grows. It takes 16,000 gallons of water, for example, to produce one ton of steel, while an average steam-generated power plant requires 4,000 cubic feet of water per second. The gap between use and availability is widening, although such measures as tapping artesian water have increased considerably—at least for a time—the overall supply.

The water resources of the continent vary with regions. In northern Alaska, the Canadian North, and Greenland, they are low, mainly because they are locked up in ice most of the year; when the summer melt comes, runoff is high. Central Alaska and mid-northern Canada have a moderate precipitation of from 12 to 15 inches per year, but again much of this is locked up in winter ice. The spring melt leads to extensive flooding, which makes the control of water difficult. Late summers are dry, but evaporation is low. Though rivers dwindle, they generally carry enough water to meet demand.

The Great Plains area also has marked high- and low-water periods, the latter posing serious problems. Most rivers rise in mountains to the west, where usually there are extensive snows. Meltwater gives an early spring flush, and high flow is continued into early summer through storms generated by the tropical gulf air. In late summer and fall, however, the storms cease, and the rivers drop. Streamflow originating within the region may dry up, while bigger rivers may sink into braided channels between bars of sand. Evapotranspiration also exceeds precipitation, a loss not made up again until early winter with the return of polar-front storms. Surface water therefore is scarce for

Water problems in the Great Plains

four to five months and often needs to be supplemented from groundwater.

The intermontane basins stretching from southern British Columbia to central Mexico exhibit a strikingly unequal pattern, with areas of water surplus in the mountains lying adjacent to areas of marked deficit in the basins. Major rivers like the Columbia, Colorado, Rio Grande, and Guadalajara rise in snowy or rainy mountains and supply enough water, especially where their waters are trapped by dams, to serve the basins through which they flow. Lesser rivers, however, often cease flowing and are intermittent or ephemeral. Groundwater supply in areas with artesian wells alleviates the situation.

The eastern parts of southern Canada and the United States have ample water, with rainfall in most months, as the southern movement of polar continental air and the northern expansion of tropical gulf air draw storms regularly across the area. Rainfall is from 30 to 60 inches a year, and evapotranspiration does not exceed precipitation except in late summer. Streamflow is perennial, averaging more than 10 inches in depth per stream each year.

Finally, the tropical areas in the trade-wind belts in Central America are well supplied with water, yet less is available than might be expected owing to swift runoff after heavy rains and high evaporation. Rivers are relatively short and steep and are prone to flash flooding.

Biological resources. The coming of Europeans and their activities over a period of some five centuries have vastly transformed the plant and animal life of North America. Paradoxically, it is the creatures of the ocean—the earliest biological resources to be heavily exploited—that have undergone the least change qualitatively. Because of a favourable conjunction of ocean currents, the waters off Labrador, Newfoundland, Nova Scotia, and New England have maintained rich marine populations; and, despite heavy, often excessive fishing since the late 15th century, such sought-after species as cod and haddock are still available in some abundance. More recently, the waters and estuaries farther south in the Atlantic, Gulf of Mexico, and Caribbean Sea and off the Pacific coast have become economically important for their fish and crustaceans. Overfishing and pollution have reduced considerably the significance of major inland rivers and the Great Lakes, although sport fishing is popular in many of the more sparsely settled areas of the United States and Canada. On the other hand, pond-raised catfish and other species have become increasingly important, and promising experiments have begun in cultivating oysters, crabs, shrimps, and other varieties of seafood.

Loss of original vegetation

The most striking changes to North America's flora have been in the magnificent forests that once covered much of the eastern half of the United States and those sections of eastern Canada south of the shield and in the formerly luxuriant grasslands that fanned out westward in a large triangular shape from central Ohio. A combination of extensive clearing for fields and pastures; exploitation for fuel, construction, and industrial uses; and the impact of various introduced pests on species of elm, oak, and chestnut have reduced the original vegetation to only scattered patches of virgin woodland and a few tiny remnants of the original prairies. A similar retreat of forests has occurred in Mexico and Central America because of strong pressure for space and resources by a rapidly expanding population. Change has been less noticeable in the subarctic boreal forest (taiga) of Canada and Alaska because of its remoteness and the thinness and poor quality of the trees, but the southern third of this forest is a major base for pulp and paper industries. The much reduced northern mixed and eastern hardwood forests have lost most of their former value, as the original stands have been replaced by commercially marginal second- and third-growth trees; these woodlands have become attractive, however, for recreational purposes. Some forests of the Pacific Coast and Cordilleras still contain some excellent stands, and, with controlled use, growth usually is rapid enough to produce a steady yield. The Southern Pineries, long neglected by farmers because of sandy soils, have become a major source of timber and pulpwood for the United States. The tropical hardwood forests are also important for timber, but much has been cut down and replaced by banana plantations or poor second growth. Oak and pine forests above 3,300 feet in the *tierra templada* ("temperate land") remain a useful resource.

Early European explorers and settlers in North America were delighted by the abundance and variety of its endemic wildlife; and the various mammals, birds, and fish were important as sources of raw materials as well as food for aborigines and European pioneers. For many years, hunting and fur trapping were dominant activities throughout much of Canada and the wooded tracts of the United States. Excessive exploitation and changes in land-use patterns brought about the near extinction of some species (such as the beaver and bison) and the disappearance of others (such as the once superabundant passenger pigeon), so that the harvesting of wild creatures has become minor in significance. On the other hand, recreational hunting—for deer, bears, turkeys, geese, ducks, and other such controlled populations—is a large industry in many areas of Canada and the United States. It is important to note that the introduction of Old World domesticated animals has changed considerably North America's plant cover, especially where overgrazing has occurred in much of Mexico and the western United States.

MINING, FORESTRY, AND FISHING

Essential though they were to the continent's economic development, three of North America's primary industries—mining, forestry, and fishing—now account for only a small share of total continental economic output and nonagricultural employment. Part of the explanation lies in the depletion of resources, especially within the United States, and an increasingly heavy reliance on imports. The advent of mechanization also has lowered demand for labour while keeping productivity at a high level, at least locally. The relatively minor role of fish in the American diet has kept the domestic fishing industry from flourishing as it might have otherwise, although Japanese, Russian, and Scandinavian vessels intensively exploit the rich North Atlantic and North Pacific fisheries for their home and export markets. The inland and upland concentration of so much of the Mexican and Central American population has inhibited development of marine resources except for export to other lands.

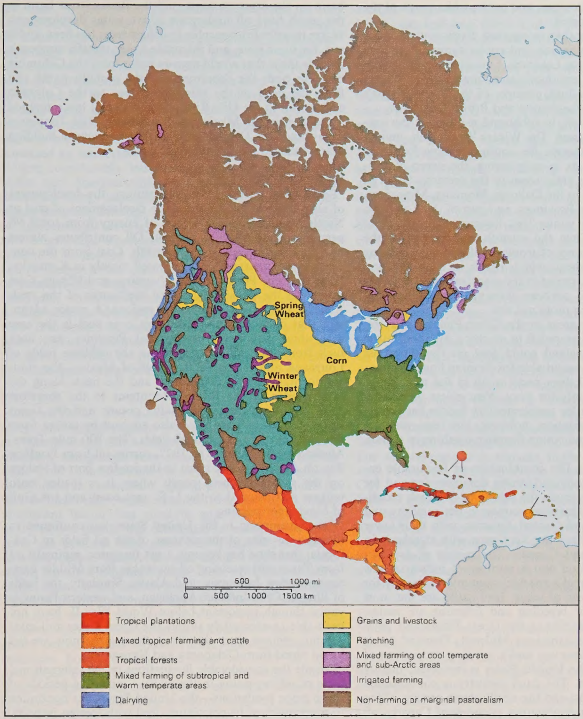
Local fisheries

Despite the relative insignificance of these industries in the total economy, they are crucially important in certain localities. Thus, fishing is still a dominant activity in much of Newfoundland, Labrador, and sections of the Maritime Provinces. Within the Gulf of Mexico and Pacific coast fisheries (from which most of the catch goes into animal feed and industrial products), many coastal towns are economically dependent on their fishing fleets, as is also true for some communities along Chesapeake Bay and the New England coast. Despite drastic reductions in the work force in the bituminous and anthracite fields of the Appalachians, coal still dominates the economy of much of West Virginia and eastern Kentucky, and strip-mining is now a major economic factor in Montana and Wyoming. Oil and gas extraction, which accounts for most American mining employment, is of central importance to the welfare of Texas, Oklahoma, and Louisiana. The fortunes of Alberta rise and fall with the price of petroleum, while the production and export of oil is of great importance to the economy of Mexico. Similarly, the cutting of trees for lumber, plywood, pulpwood, and fuelwood is a major source of income for much of the Pacific Northwest and the Gulf and South Atlantic coastal plains and dominates large portions of Quebec and Ontario. Although Canada remains one of the world's principal exporters of wood and wood products, the United States must import a large share of its overall needs.

AGRICULTURE

The various peoples who developed North America have made it a world economic leader and, in general, a well-used and productive continent. Agriculture, though no longer the principal economic activity (except in some of the southern Latin nations), is still important.

Tropical regions. In tropical areas, the Spaniards made



Agricultural regions of North America.

the most of the strong altitudinal zonation by raising sugarcane in rainy parts of the low *tierra caliente* ("hot land"), wheat and cattle in the middle levels of the *tierra templada* ("temperate land"), and sheep on the upper slopes in the *tierra fría* ("cold land"). Later, orange groves and coffee, cocoa, and banana plantations were established on the coastal plains and wet windward slopes of the tropical areas; and cotton and hemp were grown in the warmer and drier basins of the intermediate zone. These remain important export crops for Central American countries and Mexico, being shipped mainly to the United States and Europe.

Subtropical and warm temperate regions. An enormous extension of fruit, winter vegetable, cotton, and tobacco farming has occurred in the subtropical and warm temperate areas of the United States and northern Mexico. Citrus fruits do well in Florida and the Rio Grande valley of Texas, where the Gulf of Mexico brings warm tropical air with early rain but much late-summer sun. The Central Valley of California—guarded from frosts by the Sierras, with winter rain for growth and prolonged summer sun for ripening—also is a prime area for growing fruit and vegetables. Drought is a challenge, however, and has been met only by extensive irrigation. Winter vegetables are widely grown on the sandy soils of the Gulf Coastal Plain and the southeastern parts of the Atlantic coast, which have a long frost-free season and ample rain. Cotton has proved a success in areas with less than 60 inches of rain and more than 200 days free of frost. Tobacco is concentrated on the sandy soils of old shores and deltas from Virginia to Kentucky. Many tobacco and cotton fields are now alternately planted with rye, corn (maize), soybeans, and winter wheat grown as fodder for cattle or as additional cash crops. These help to maintain the fertility of the soil, which long has been threatened by the practice of monoculture.

Cool temperate, humid regions. Crops of the continent's cool temperate, humid regions include hardy fruits grown on the valley sides of the Appalachians and the Piedmont from Georgia through Virginia, in the Finger Lakes region of New York, in the Niagara Peninsula of Ontario, on the eastern shore of Lake Michigan, and in parts of the Columbia River basin in Washington and British Columbia. In all these areas, aspect, frost, and drainage are important factors.

The Corn, Dairy, and Wheat belts

The zone known as the Corn Belt derived its name from the preponderance of corn grown in the warm-summer region that extends westward from the Ohio River to the lower Missouri River, although soybeans have come to rival corn as the leading field crop. In this region winter snowmelt, rains from the northward springtime surge of tropical gulf air, and early summer convection showers bring on the plants, while strong late-summer sun and high temperatures ripen the cobs and bean pods. Most of

the corn is fed to fatten pigs and cattle, while much of the soybean crop is exported.

The Dairy Belt, another recognized division, makes use of a shorter growing season and cooler summers in New England and the Great Lakes–St. Lawrence region, where clover, timothy hay, and hardy small grains thrive. Dairying also exploits the lush pastures of the Pacific Coast's equable climate in Washington and British Columbia.

West of the Corn Belt, in subhumid regions, lie the continent's vast wheat areas. The Winter Wheat Belt, mainly in Kansas and Oklahoma, lies south of killing frosts. As the polar front retreats in early spring, the sweep of rainstorms brings on the grain sown in the previous fall. The Spring Wheat Belt—in the Dakotas, Montana, Minnesota, the Canadian Prairie Provinces, and part of the Columbia basin—has a severe winter that forces postponement of sowing to spring. Then the warmth and wetness of the sudden northward surge of tropical gulf air quickly bring on the new-sown wheat, which ripens in a usually dry, sunny fall. Wheat farming takes place on an ever larger scale than corn and soybean farming, using more machines and producing more per acre.

Dry regions. Dry areas in the Great Plains and intermontane basins long were left to ranching. Hereford cattle brought in from England could feed on the shortgrass prairies, which were unsuitable for farming homesteaders. Sheep, raised in still drier parts or up in the mountains, have been bred mainly for wool. Near rivers or in artesian areas, irrigation for supplementary fodder has greatly helped ranching. Irrigation, however, has been used increasingly for fruit and cotton farming, resulting in a drain on water supplies.

Livestock raising. The combination of favourable environmental conditions and strong domestic demand for animal products has made the raising of livestock prominent in the North American economy; but quantity and quality in Mexico and Central America, with their lower purchasing power, have not kept pace with standards in the United States and Canada. The raising of domesticated animals for food and a number of industrial raw materials has generated a specific economic geography for each species. In terms of value, beef cattle are the most important, and their breeding and fattening are major, often dominant activities in the Great Plains and adjacent sections of the American Midwest. Demand tends to outrun supply, however, and a growing proportion of beef consumed in the United States is imported, mainly from Latin America. The dairy industry is concentrated in the Upper Midwest and the northeastern section of the United States and neighbouring portions of Canada, all areas that provide the appropriate habitat and are near major markets. The production of hogs and pigs may be widespread, but some three-fifths of North America's commercial output is concentrated in five Midwestern states. Mutton and lamb never have figured significantly in North American diets (although kid meat is highly esteemed in Mexico), and so a relatively small number of sheep are raised primarily for wool; sheep ranching is limited to a few tracts in the Great Plains, the intermontane basins, and California. Since about 1970 the consumption of red meat has declined as awareness of potential health risks associated with it has grown, and there has been a subsequent increase in the consumption of poultry; large-scale poultry production has expanded sharply in Southern states from Arkansas to Maryland, where land and labour for a factory-like industry are cheap and abundant.

Poultry production

WATER DEVELOPMENT

Water development is crucial both to circumvent drought and to prevent flooding. Roughly 50 million acres of irrigated land have been developed in the United States, with large dam projects and conduits in the Columbia and Snake river valleys, the Central and Imperial valleys of California, the Salt and Gila tributaries of the Colorado River, the upper Rio Grande, and the upper Missouri and the upper Platte rivers. In western Canada a vast scheme has been under development on the Bow and South Saskatchewan rivers; while in Mexico the lower Rio Grande (shared with the United States), the Fuerte River basin on the dry west coast, and the Balsas River basin in the south have all undergone active water development. Water transfer from surplus to deficit areas has been under way for some time, and interstate water-transfer proposals include those that would convey water from the Columbia basin to both the Sacramento and Colorado rivers and from the head of the Missouri system to the Colorado and thence to the Gila River. Flood control has remained a problem in the Mississippi River basin. The Tennessee valley and the Ozarks schemes have involved building many dams to redistribute river water.

ENERGY DEVELOPMENT

Fossil fuels. During the 20th century, the development of new fuels caused the dramatic displacement of coal as North America's major source of energy from some 90 percent to less than 25 percent. Oil contributes almost half, and natural gas about a fourth. Coal from the continent's vast reserves is concentrated mainly in Kentucky, West Virginia, Pennsylvania, Wyoming, and Illinois. Coal is sent to the power plants and steelworks of the mid-Atlantic and lower Great Lakes regions. A major advantage that oil and natural gas have over coal is the ease with which they can be transported. Pipelines carry both fuels from their remote sources in the offshore fields of Louisiana and Texas in the Gulf of Mexico, the mid-continental fields of Oklahoma, and the fields along the eastern edge of the Rocky Mountains to the shoreline cities of the Atlantic and Pacific oceans and the Great Lakes. Large amounts of oil also are sent by tanker from the ports close to the gulf oil fields. The 800-mile Trans-Alaska Pipeline, opened in 1977, carries oil from Prudhoe Bay on Alaska's Arctic coast to the ice-free port of Valdez on the state's southern coast, where it is loaded onto tankers and shipped to the U.S. west coast and the Gulf of Mexico for refining.

Oil consumption in the United States has continued to increase. In spite of the richness of the oil fields in California, that state has become a net importer, piping in oil from Texas and receiving oil by tanker from Middle Eastern countries, Indonesia, and Alaska. Similarly, the fields of Illinois, Ohio-Indiana, Michigan, and western Pennsylvania, though important before World War II, have not been able to adequately supply the Great Lakes and mid-Atlantic regions since that time; those areas now are fed by oil piped from Oklahoma and Kansas.

Despite the considerable fluctuations in the international price of oil beginning in the 1970s—including periods of sharp price escalations—the United States has continued to meet much of its petroleum need with foreign imports. In Canada the industrial regions in Vancouver, B.C., and the lower Great Lakes–St. Lawrence area are fed oil and natural gas by pipe from Alberta; and in Mexico, oil is supplied to Mexico City by pipe from the Gulf Coast oil fields around Reynosa and Tampico-Tuxpan, and natural gas is piped to Monterrey from gas fields around Reynosa.

Oil pipelines

Hydroelectricity. Hydroelectric development has been immense in the United States and Canada. The rivers of the Canadian Shield, fed from lakes and falling abruptly over the edge of the plateau, provide many sites, especially in Quebec and Ontario. These are linked to such Great Lakes–St. Lawrence sites as Niagara Falls and International Falls, which, in turn, tie in to a power grid developed from Appalachian rivers. The north-central and northeastern areas are thus well supplied.

The snow-fed rivers from the high Cordilleras, where impounded (as at the Grand Coulee, Hoover, Glen Canyon, Fort Peck, and Garrison dams), also provide an immense amount of power. Yet, in the United States, hydroelectric power represents only a small percentage of the total electricity generated, nearly all the rest coming from coal-, gas-, or oil-fired thermal plants and from nuclear-power stations.

Nuclear and other sources. Since the 1950s the United States has put more than 100 nuclear power plants into operation in more than 30 states—the largest total for any country—while Canada has built close to 20. Nevertheless, nuclear-generated electricity accounts for a relatively modest share of North America's total energy budget:

less than 20 percent of all electricity generated in the United States and only about 1 percent of all the energy the nation consumes. The initial predictions that nuclear technology would assume a much larger role in the energy economy have not been realized for several reasons: costs of construction and operation have been higher than anticipated; it has been difficult to find plant sites that are technically and politically acceptable; plant operation and maintenance have been subject to frequent problems; and the safe, long-term disposal of radioactive wastes has remained an intractable problem.

Other considerably less complicated technologies that utilize such inexhaustable resources as solar and wind power for energy production have been making slow but steady progress, although they supply only a tiny fraction of the continent's energy. Tens of thousands of homes and commercial structures have installed rooftop solar collectors for heating and cooling purposes; and research and development has continued to enhance the efficiency of photoelectric cells that convert sunlight directly into electricity, which has potential for widespread use in the sunnier sections of the continent. More limited geographically is the potential exploitation of geothermal and wind power, but experimental projects in some favoured localities have confirmed the practicality of technologies created to utilize these energy sources.

INDUSTRY

The role of ports in industry

Coastal sites. The industry of North America is its chief contemporary source of wealth. It first developed at Atlantic coast and Mississippi River ports, where raw materials transported from abroad or brought by coastal trade from other colonies could be made into goods for distribution in the interior. Inland products also could be transformed before being exported from such ports, where immigrant labour was plentiful and capital brought in or developed locally was abundant. In many respects the ports still perform these roles. New England ports bring in wool, leather, hardwoods, and metal from abroad and cotton from the Southern states; New York City imports coffee, cacao, sugar, timber, pulp, and oil; the Philadelphia region brings in great quantities of iron from Canada and Venezuela and oil and petroleum coke from the Gulf of Mexico; together these cities manufacture textiles, leather goods, petrochemical products, iron and steel, ships and machines, books, clothes, and foods not only for their own dense populations but also for the interior United States. In spite of the enormous development of the interior, coastal sites (including those on the Great Lakes and Pacific coast) have remained paramount. From Buffalo, N.Y., to Chicago, the movement of coal from the Appalachian and eastern interior fields up to the lakeshore, combined with the shipment of iron ore from Lake Superior and Ungava to the lake ports, has led to a vast and dynamic belt of ironworks and steel mills, transport facilities, and machine-making cities. The Pacific ports of Seattle, Wash., San Francisco, and Los Angeles have developed from an outpouring of forest, fish, farm, mine, and oil-well products, partly shipped abroad and partly sent by the Panama Canal to the eastern United States.

Similarly, Canada imports oil, wool, cotton, leather, and food-based raw materials into the St. Lawrence–Great Lake ports such as Montreal and Toronto and exports iron, nickel, copper and other metal-based goods, wood products, and flour from the eastern ports and from Vancouver. These trade activities have resulted in concentrated population at the gateways in and out of the country. Mexico's gateway district, at Vera Cruz, is also industrialized.

Inland sites. Sites in the interior, however, are not without importance. The first to develop were the fall-line power centres, strung out from the falls of the Merrimac River at the edge of the New England Upland, then southward along the eastern front of the Piedmont, to the Coosa River south of the Appalachians. Later, with the advent of steam and electric power, these sites continued as major textile, pulp and paper, and engineering locations. A major shift inland occurred with the use of coal for power in the eastern and western Pennsylvanian coalfields around Wilkes-Barre and Pittsburgh, in the Birmingham (Ala.) coal and iron fields, and in the Saginaw Bay, Indiana, and Illinois coalfields. Pittsburgh soon used up its local iron ore but was sufficiently near the Great Lakes to bring in Mesabi Range iron ores, which, in combination with the vast amounts of high-quality coking coal at hand, formed the basis for a great iron and steel industry. Except where coking coal is used in the steel plants, the lower-grade Western coal has been used primarily for electricity generation. Oil and natural gas, however, have become the base of active petrochemical industries in areas such as Alberta, Louisiana, Oklahoma, and Texas. Since oil and gas can be easily piped, they have not stimulated the development of industry on a large scale near their sources but have fueled the northeastern and Pacific Coast industrial areas. Modern industry has become less tied to sites where fuel and raw materials are available and more oriented toward the market. Service industries especially have concentrated in the highly populous areas of Boston–New York City–Philadelphia, Pittsburgh-Detroit-Chicago, and San Francisco–Los Angeles. Space-age developments have been supported by science-based industries from Texas through Louisiana to Florida. Industries to meet the immense demand for travel and recreation have sprung up on the major highways and in the tourist areas in the Appalachians, in the Cordilleras, and along the seacoasts. Though industry is more free to disperse—and has done so to a significant degree—it nevertheless continues to centre on areas of existing urban agglomeration. In the United States, industrial concentrations are greatest in the New York–Washington, D.C., Cleveland-Chicago, and Los Angeles regions; in Canada, in the Montreal-Toronto and Vancouver districts; and in Mexico, in the Mexico City basin. The major cities of these regions also are the focus of critical social and economic problems.

Service industries

More generally, automation is everywhere creating a major problem of technological unemployment, met in part by reducing working hours and retiring people earlier. These trends, in turn, have given rise to the problem of the use of leisure time, which has become the target for much of America's fastest-developing industries.

TRADE

North American trade patterns offer noteworthy contrasts. Canada, with a small population but with immense resources and high productivity, has a low home consumption and depends on foreign trade more than any other developed country on the continent. The United States, on the other hand, with a vast internal market and the highest per capita consumption of goods in the world, depends mainly on internal trade, although external trade has risen considerably since World War II and now accounts for about one-fourth of its total trade. Mexico and Central America, by contrast, still have large areas where people live at a subsistence level and produce little more than goods for local trade. Production of certain metals, oil, and tropical crops, however, has expanded rapidly for sale in foreign markets.

The Canadian segment. Canada's internal trade is dominated by the provinces of Ontario and Quebec. Together they account for three-fourths of the nation's manufactured goods, which they ship across Canada in exchange for fish, lumber, and fruit from British Columbia, wheat and meat from the Prairie Provinces, and pulpwood, iron ore, and fish from the Atlantic provinces. Most of Canada's trade abroad consists of raw or semiprocessed materials, including pulp, paper, lumber, iron ore, nickel, lead and zinc, uranium, and asbestos, sent to Britain, the United States, and Japan; and wheat, exported to Britain, China, and Japan. Some oil and natural gas are sold to the United States.

Until World War II, Canada traded mainly with Britain; during that time, the United States still produced a surplus of most of the things Canada raised and thus was not a major customer. Canada, in fact, bought far more from the United States than it sold to it. By the late 20th century, however, the United States had become short of metals, wood, pulp and paper, power, and water and was importing these items from its neighbour on an increas-

ing scale. It has thus replaced Britain as Canada's chief market. The European Economic Community and Japan also are important customers for Canada's metals, wood products, and wheat.

Role of internal trade

The United States segment. Internal trade in the United States is enormous, often surpassing that among sovereign states on other continents. It is dominated by New England's need for fuel, cotton and wool, leather, wood products, and metals; by the mid-Atlantic states' demand for coal, oil, natural gas, iron ore and other metals, and food products; by the Pittsburgh region's need for iron, copper, oil, and gas; by the lower Great Lakes–Lake Michigan area's need for coal, oil, gas, iron, pulp and paper, and wood; and by the Los Angeles–San Francisco region's demand for steel, aluminum, cellulose products, oil, and chemicals.

Most of the other areas of the United States trade their raw materials or semifinished goods to these major manufacturing regions, though of course there are local industrial centres of importance. Trade is concentrated in servicing, or in being served, by such large metropolitan centres as New York City, Los Angeles, Chicago, Houston, and Philadelphia. These cities also handle a great deal of American foreign trade. Southeastern ports send out cotton, tobacco, and wood products; and the mid-Atlantic coast ports send out wheat, corn, meat, and a wide range of manufactured products.

Since the development of the St. Lawrence Seaway, the major cities along the Great Lakes have been directly exporting the steel products, cars, airplanes, agricultural machinery, cereals, and meat for which the northern Midwest is famous. New Orleans continues as an exporter of cotton, corn, and other agricultural products from the vast Mississippi hinterland, although oil and grain now are more important; while trade from Houston's port is based on oil and chemical products. Los Angeles dominates the West, with its sales of aircraft, ships, motion pictures, and chemicals. Seattle is important for its trade in fish and forest products and in aircraft. American imports include a wide variety of products: tropical fruits, woods, fibres, and vegetable extracts, mainly from Latin America, West Africa, and Southeast Asia; oil from Saudi Arabia, Mexico, Nigeria, Indonesia, and Great Britain; tin from Bolivia and Malaysia; wool from Australia and South America; and a wide range of motor vehicles, machines, textiles, instruments, and books from Japan and western Europe.

American trade has a worldwide distribution and impact: of its export total, about one-third goes to western Europe; more than one-fifth to Japan, Southeast Asia, Australia, and New Zealand; almost one-fifth to Canada; one-tenth to Mexico, Central America, and the West Indies; and one-twelfth to South America. Of almost equal importance has been the widespread influence of American foreign aid: while initially this helped American trade by being tied to the use of domestically manufactured equipment, it has become much freer and enables countries to develop their own agriculture or industry in the most satisfactory way.

The Mexican and the Central American segments. The Latin American portion of the continent includes some highly sophisticated regions, along with many as yet undeveloped areas. In Mexico's internal trade the capital region predominates, producing most of the nation's manufactures, which are then distributed through regional cities. Mexico City consumes much of the domestically used oil piped up from the coast, the metals of the Cordilleran mines, the cotton of the irrigated central and western basins, and hemp from Yucatán. Petroleum exports became a steadily growing part of Mexico's external trade following the discovery of vast oil reserves in the Bay of Campeche in 1972. Within a decade, petroleum sales represented by far the greatest portion of Mexican export earnings. The oil exports have given Mexico higher income, but they also have placed the country in danger of becoming overly dependent on a commodity that is subject to market fluctuations. In an effort to avoid the consequences of such dependence, the government has attempted to diversify the country's export economy. This effort has involved expanding Mexico's industrial base, increasing the export of manufactured goods, and augmenting the export of agricultural goods and metals.

Mexican petroleum exports

Imports consist predominantly of manufactured goods and of parts and materials needed for Mexican industries. Machinery, vehicles, and consumer goods are the chief items. The United States has the greatest share of Mexico's foreign trade, providing the greatest portion of the imports and exports. Since 1960, however, more of Mexico's trade has been oriented toward Latin America. Mexico is also trying to send more winter fruits and vegetables, textiles, and leather goods to Canada.

Central America has developed a limited amount of trade. By far the greatest exports are tropical fruits, fibres, and minerals (especially from the Caribbean), which are sent to the United States in exchange for American manufactured goods. Increasingly, virtually the whole of North America is being integrated in its economic development with the growth of the United States.

TRANSPORTATION

Waterways. Industry has been strengthened by the ease of movement in North America. Waterways, widely used by the Indians and early Europeans, are still important. In spite of the barriers of the Canadian Shield and the Appalachians, the routes up the Gulf of St. Lawrence, the Hudson Strait, Chesapeake Bay, and the Gulf of Mexico permitted the swift development of coastal ports and allowed the continental interior to be opened up. The Mississippi-Ohio and the Great Lakes–St. Lawrence waterways drew navigation into the heartland. Connecting these two systems, the Chicago Sanitary and Ship Canal, linking the Illinois River with Lake Michigan, and various Ohio River–Lake Erie canals provided a tremendous network, extended by the Erie Canal to the Mohawk-Hudson waterway and by the Intracoastal Waterway to river ports of the Gulf of Mexico. The St. Lawrence Seaway, which overcame the Lachine and International rapids and Niagara Falls, has made ocean ports of inland cities.

Railways. Railways soon offered the challenge of more direct and speedy access than the waterways. Developed principally from bases along the Atlantic Seaboard, they made the most of gaps through the Appalachians, debouched on the Great Lakes or Ohio River at Buffalo and Chicago and Pittsburgh, and pushed on to the Mississippi River at St. Louis, Mo., and St. Paul–Minneapolis, Minn. Other lines were then laid across the Great Plains and, utilizing passes through the Cordilleras, the railways built terminals at San Francisco, Seattle, and Los Angeles. Most of the Western railways were given large land grants to encourage immigrants to settle along them, while low promotional rates on long-haul traffic developed transcontinental trade. In Canada the transcontinental railways linked up the Maritime Provinces with the St. Lawrence–Great Lakes, and thence, from Montreal and Toronto, they crossed the shield to converge at Winnipeg; there, reinforced by large land grants, they fanned out across the prairies, to be drawn together by the Fraser River down to Vancouver.

Development of Canada's railway system

Mexico overcame difficult grades in building a railway from Vera Cruz to Mexico City and added extensions north and south along the Gulf Coast, with lines into Monterrey and to Mérida. Eventually lines were pushed through the Sierra Madre Occidental at Guadalajara to the Pacific coast.

Railroads had a tremendous impact on urban development. Among the major railroad cities are New York City, Chicago, St. Louis, and Los Angeles in the United States, and Montreal, Winnipeg, and Vancouver in Canada. Mexico City dominates the network in Mexico. Railroads led to the rise of east-west over north-south lines and rapidly displaced most waterways, particularly the Mississippi. The main economic axis in the United States lies along the railway belt from New York to Chicago. Inadequate overall planning in major metropolitan regions has resulted in crucial transportation problems, however, and inner-city rapid-transit systems often have fared no better.

Roads. North America's road network first began to offer serious competition to the railways after World War I. The U.S. government has since financed more than 300,000 miles of transcontinental highways, including

more than 40,000 miles of limited-access, multilane roads. In Canada the Trans-Canada Highway offers a coast-to-coast through route, while from Mexico the Pan-American Highway links the countries of Central America. These highways have enabled trucks to take over short-haul routes from railways, and the railways have concentrated on long-haul, low-cost routes. Truck and train, however, have been integrated in the "piggyback" containerized carriage. The automobile, meanwhile, has displaced commuter trains in many cities, and radial and ring routes have helped draw the cities far out into the countryside. The attendant problems of congestion and pollution have approached the critical stage in many cities.

Air transport. Air transport has taken most of the long-distance passenger traffic from the trains, and airfreight has cut into truck-freighting trade. Intense overall competition is thus a recurrent feature of North American transportation systems. Airways have tended to centre on the larger cities and to magnify their importance, although the rise of the "hub" system of air transport has helped to diversify air routes. Links with Europe and Asia make North America the chief crossways of air routes in the world. The United States alone accounts for some two-fifths of all the world's passenger air traffic, and several of the chief airports in the world are in the United States, including those in Chicago; Dallas–Fort Worth, Texas; Atlanta, Ga.; Los Angeles; Denver, Colo.; San Francisco; New York City; Miami, Fla.; Boston; and Washington, D.C. Montreal and Mexico City are also major air hubs.

(J.W.W./W.Ze.)

NORTH AMERICAN GEOGRAPHIC FEATURES OF SPECIAL INTEREST

Landforms

ALASKAN MOUNTAINS

The mountain ranges of Alaska give their state a rugged and beautiful terrain across its entire expanse. They include the highest peak in North America and are characterized by glaciers, earthquakes, and continuing volcanic activity. Structurally, the ranges are northwestward continuations of the Rocky Mountains and the Pacific mountain system of North America. Still little explored for vast stretches, Alaska's mountains contain, or lie close to, largely untapped mineral resources.

The most northerly of the three major Alaskan mountain groups are the Brooks Range and the Arctic foothills, which extend the Rocky Mountains in an east-west arc from the Canadian border across northern Alaska. Central Alaska is characterized by highlands and basins drained by the great Yukon and Kuskokwim river systems.

Alaska's southern coast and adjoining southeastern panhandle are dominated by an arc of mountain ranges that demark the Gulf of Alaska and make the state's Pacific coast one of the most spectacular on Earth. This Pacific mountain province is subdivided into several groups. The interior Alaska Range merges southwestward into the Aleutian Range and the Aleutian Islands. Separated from the Alaska Range by the Talkeetna and Wrangell mountains, the main mountains of the southern coast lie in the Kenai and Chugach mountains. These heavily glaciated ranges border the Gulf of Alaska, the Chugach Mountains adjoining, to the south and east, the St. Elias Mountains at the Canadian border. The St. Elias Mountains, in turn, merge to the southeast into the mountains of the coastal Boundary Ranges, which, with the mountainous islands of the Alexander Archipelago, constitute the Alaskan panhandle.

Physical features. *Physiography of the northern ranges.* The Arctic northward-sloping foothills, just north of the Brooks Range and along Alaska's Arctic Ocean coast, consist of low east–west-trending ridges and rolling plateaus with irregular isolated hills. They rise from 600 feet (180 metres) in the north to 3,600 feet in the south. Except for the east-flowing upper portion of the Colville River, most drainage is northward. This tundra-covered area, called the North Slope, is underlain by permafrost, a permanently frozen, rock-hard soil; only a shallow surface zone thaws during the short summer, producing a vast number of small ephemeral lakes and ponds. This region is geologically complex, as is the higher Brooks Range to the south, but the layered bedrock is of less-resistant lithologies, some of which are oil-bearing. The rocks in the Arctic foothills consist of sediments that are folded, faulted, and overthrust toward the north.

Brooks Range

The Brooks Range, situated just south of the Arctic foothills, is the highest mountain range within the Arctic Circle. It includes groups of subranges extending some 600 miles (1,000 kilometres) from the Canadian border westward to the Chukchi Sea. Average elevations range from 3,000 to 4,000 feet in the west to 5,000 to 6,000 feet in the east, with a high point of 9,060 feet in Mount Isto. Except for some higher ridges, the entire area has been glaciated and has exceedingly rugged topography. Several small glaciers are still present in the east, fewer in the west. The Brooks Range forms the drainage divide between waters flowing northward across the North Slope into the Arctic Ocean, those flowing westward into Kotzebue Sound, and those flowing southward into the Yukon River drainage system, which empties into the Bering Sea. Several major rivers have eroded headward into the range to form low passes, the best-known being Anaktuvuk Pass, at an elevation of 2,200 feet in the central part of the range. Atigun Pass, at the head of the Dietrich River, connects the oil-producing areas of the North Slope with interior Alaska and the south.

The backbone of the range is composed of sedimentary and metamorphic rocks dating from the early Paleozoic Era (540 million years ago). Younger sedimentary rocks flank the range. The mountains were uplifted by major compressional foldings (orogenies) in the Earth's crust. Folding, faulting, and major overthrusting toward the north during these orogenies were accompanied by erosion and glaciation. Most of the area now is characterized by permafrost.

Physiography of the central ranges. The mountains of central Alaska are lower than the ranges to the north and south. They are drained almost entirely by two river systems, the Yukon and the Kuskokwim. The intricately dissected uplands are divided into three areas: the eastern highlands, the western highlands, and the Seward Peninsula. The great sweep of ranges extends south of the Yukon from the Canadian border to the Bering Sea; north of the river the ranges are discontinuous.

The eastern highlands consist of several separate mountain chains (*e.g.*, the White Mountains), with average elevations of 4,000 to 5,000 feet and a few ridges rising 1,000 to 2,000 feet above these uplands. No glaciers are present in the region, and permafrost is discontinuous, occurring only at the higher elevations. Underlying rocks are highly deformed metamorphic and metasedimentary, with some older volcanic material. The higher parts are commonly composed of small segments of resistant granite that intruded into the other rocks while in a molten state.

The Kuskokwim Mountains

The western highlands are subdivided into several smaller groups, notably the Kuskokwim Mountains. These ranges are somewhat lower and more rolling than the eastern highlands, with ridges trending southwest-northeast. Numerous isolated, nearly circular groups of mountains rise above these ridges. No glaciers are now present, but the Ahklun Mountains at the sector's southwestern extremity are the largest formerly glaciated area in central Alaska.

To the west and north is the upland area of the Seward Peninsula, the western tip of which is some 50 miles from Russia, across the Bering Strait. Much of the peninsula consists of broad, convex hills and ridges with an average elevation of about 2,000 feet surmounted by more rugged



The Alaskan mountain ranges and the Mackenzie and Yukon river basins and their drainage networks.

mountain groups. A few peaks rise above 3,000 feet; the highest, at 4,714 feet, is Mount Osborn in the Kigluaik Mountains in the southwestern part of the peninsula. The entire area is characterized by permafrost.

Physiography of the southern ranges. The Alaska and Aleutian ranges—together with the Talkeetna, Chugach, and Wrangell mountains, the interior part of the St. Elias Mountains, and the Boundary Ranges of southeastern Alaska and flanking interior sectors of northwestern British Columbia—constitute the most massive and spectacular mountain system in North America.

The Alaska and Aleutian ranges extend in a great belt from the Canadian border, at first northwestward and then south- and westward to the Aleutian Islands. The oceanic Aleutians comprise a chain of mountainous volcanic peaks, the crest of a huge submarine ridge 1,500 miles long and 20 to 60 miles wide that rises 11,000 feet above the seafloor. Separating the Bering Sea from the Pacific Ocean, the archipelago stretches in a 1,100-mile-long arc from the Alaska Peninsula to Attu Island at the western end of the chain. With the Aleutian Range on the southeast side of the peninsula, they form a long, narrow belt of storm-whipped, often fog-shrouded peaks for 1,600 miles from Attu to Mount Spurr just west of the city of Anchorage. Some 80 volcanoes have been mapped in this chain, more than half of which have been reported active since 1760. Marine sedimentary rocks and granitic intrusions, as well as volcanic rocks, form this range. Pavlof and Shishaldin volcanoes rival Japan's Mount Fuji in the beauty of their symmetrical cones. In 1912 one of the most spectacular of recent historic eruptions occurred when a volcano in the Aleutian Range erupted, forming the Valley of Ten Thousand Smokes, in what is now Katmai National Park and Preserve. Mount Spurr erupted in 1954 and remains active, as do Mounts Redoubt (1968) and Augustine (1976).

The Alaska Range merges on its western end with the Aleutian Range between Iliamna Lake and Mount Spurr and extends in a great arc some 600 miles to the Canadian border at the southeastern end. This great mountain wall is about 120 miles wide near Mount Spurr and about 60 miles wide in the vicinity of Mount McKinley, gradually narrowing to about 30 miles near the Canadian border. The range is extremely rugged and glaciated. The crest of most of the range averages between 7,000 and 9,000 feet in elevation, with a number of peaks exceeding 10,000 feet. The heavily glaciated massif of Mount McKinley (Denali), at 20,320 feet (6,194 metres), is the highest point in North America. Four great individual mountain masses dominate the Alaska group, divided by a number of low passes and river valleys. Great valley glaciers radiate from these mountain masses, except in the relatively low eastern sectors, where the few glaciers are small. The Alaska Range is the drainage divide for rivers flowing north into the Yukon system and those flowing south into the Gulf of Alaska.

Mount McKinley

Most of the Alaska Range is underlain by large granitic intrusions (batholiths) into sedimentary rocks that have been metamorphosed and deformed. The youngest sedimentary sequences can contain large deposits of coal. Long valleys and low passes follow the course of geologic faults, some extending almost the entire length of the range.

Between the Alaska Range and the coastal ranges lie the Talkeetna Mountains and, to the east of them, the Wrangell Mountains. The Talkeetnas occupy a rugged oval area about 100 miles from north to south and 70 miles from east to west. They consist of a compact group of radial ridges averaging from 6,000 to 8,800 feet in elevation. There are only a few low passes. The higher ridges are sharp-crested, but on the western flank, as elevation decreases, the ridge tops have been rounded and subdued by overriding glaciers during the Pleistocene Epoch (1,600,000 to 10,000 years ago). Small glaciers 5 to 15 miles long are still present at the heads of many valleys in the Talkeetnas.

The Wrangell Mountains, covering an area 100 by 70 miles, lie near the Pacific between the Alaska Range to the north and the Chugach Mountains to the south. The high, glaciated massifs rise more than 10,000 feet above the Copper River basin. Extensive local ice caps cover most of the highest mountains and feed large valley glaciers. This oval-shaped range consists of composite volcanic mountains that rest on metamorphosed sedimentary and igneous rocks. Several peaks are at elevations higher than 12,000 feet; the highest is Mount Bona, at 16,421 feet.

Encircling the Gulf of Alaska, from Kodiak Island in the west to Baranof Island in the southeast, is another arcuate (bow-shaped) mountainous belt, 800 miles long and 20 to 110 miles wide. Mountainous Kodiak Island and the Kenai and Chugach mountains form a rugged barrier along the northeast margin of the Pacific Ocean. The mountains of the Kodiak Island group, at average elevations of 2,000 to 4,000 feet, trend southwest-northeast. Pleistocene glaciation over most of the island produced a highly irregular coastline.

Kodiak Island

The average elevation of the Kenai Mountains is 3,000 to 5,000 feet, whereas the Chugach group to the north and east average 7,000 to 8,000 feet. The highest peaks are in the sharp bend of the arc, where Mount Marcus Baker rises to 13,176 feet. The mountains are extremely rugged and heavily glaciated, resulting in the Sargent and Harding ice fields in the Kenai Mountains (on the Kenai Peninsula) and the Bagley Ice Field in the eastern Chugach Mountains. Numerous long and spectacular glaciers descend from the crests of these mountains. The St. Elias Mountains and the Kenai-Chugach mountain system have the most extensive system of highland and valley glaciers in North America.

The St. Elias Mountains straddle the border between Alaska and Canada. The Alaskan part of the range is topographically continuous with, and geologically similar to, the Chugach Mountains and joins the southeastern panhandle to the rest of the state. The St. Elias chain, composed of many glacier-fed ranges, is one of the highest coastal mountain groups in the world. It is about 200 miles long and has a maximum width of about 100 miles. The chain merges with the Chugach group near the Alaska-Yukon border and with the Wrangells and parts of the Alaska Range to the northwest.

The massive, blocklike St. Elias Mountains rise from a myriad of narrow ridges and spectacular peaks at 8,000–10,000 feet (2,400–3,000 metres) in elevation to numerous ice-armoured summits over 14,000 feet high. Mounts Logan (19,524 feet) and St. Elias (18,008 feet) are the two highest peaks. The St. Elias chain contains the largest ice field in North America, with about half of its glacial cover in Canada and the rest in Alaska. The average elevation of the ice fields blanketing the lower regions is 3,000 to 7,000 feet. Because of difficulty of access and extensive ice cover, the geology is still little known.

At the southern end of the St. Elias Mountains, on a peninsula south of the Alsek River where it enters Dry Bay, rises the unique and spectacular fault-block mountain system of the Fairweather Range. At the southern end of this range is the Brady Icefield, and east of the range is world-renowned Glacier Bay, with its largely receding tidal glaciers. The Chilkat Range, east of Glacier Bay, is flanked by Lynn Canal, the northern extension of Chatham Strait. Together they represent one of the longest and deepest fjords in North America.

Along the north-south axis of this fjord is the trace of a great, inactive fault system known as the Lynn Canal–Chatham Strait trough. West of the St. Elias Mountains and Fairweather Range is the still-active Fairweather Fault, a northward extension of California's coastal San Andreas Fault. This fault system has been the locus of many major earthquakes in Alaska since the 1850s, including the large quake of March 1964.

The mountains of southeastern Alaska tie in the Canadian Coast Mountains to the south and east with the St. Elias range to the north and west. As such, they are a northward continuation of the Pacific mountain system that extends southward into the western United States. The heavily glaciated Boundary Ranges along the Alaska-Canada border extend between the Skagway River at the northern end of Alaska's Inside Passage southward to the Portland Canal southeast of Ketchikan. They rise to 5,000 to 7,000 feet above sea level, with the higher peaks

reaching 10,000 feet. These mountains are underlain by the intruded granitic rocks of the Coast Range Batholith. To the northeast and southeast of Juneau, respectively, are the Juneau and Stikine ice fields that feed numerous valley glaciers, some of which extend to the sea.

Lying to the west of the Boundary Ranges on the mainland is the rugged and scenic island complex of the Alexander Archipelago. The mountains of the archipelago range in elevation from 2,000–3,500 feet in the southern Prince of Wales Mountains to more than 4,000–7,500 feet in the Chilkat Range and the mountains of Admiralty, Baranof, and Chicagof islands. These islands have small glaciers and rugged coastlines indented by fjords.

Climate. On a regional scale the Alaskan mountains span all the climatic zones found in the state. The northern slopes of the Brooks Range fall within the Arctic zone, while its southern slopes and the Alaska, Talkeetna, and Wrangell ranges all fall within the continental zone. Both zones are characterized by long cold winters, short cool summers, moderate summer rainfall, and light snowfall during the winter. The continental zone is generally more arid, with clearer skies and more extreme temperatures.

The Chugach Mountains, the western Aleutian Range, and the Alaska Peninsula fall within the transitional zone. The mountains of the Aleutian Islands and the remaining southern mountains, in particular those of the panhandle, lie within the maritime zone, the climate being influenced by the warm waters of the Kuroshio (Japan Current). These two zones have relatively small temperature variations and much cloudiness and precipitation, although these conditions are all less pronounced in the transitional zone. Mean January temperatures range from −20° F (−29° C) in the Brooks Range to between 14° and 32° F (−10° and 0° C) in the Boundary Ranges of the panhandle. Winter temperatures at or below −50° F (−46° C) are not unusual, however, in the mountains of the interior and at higher elevations in the Boundary Ranges. Mean July temperatures range from about 60° F (16° C) on the lower slopes of the Brooks Range (and lower still at higher elevations) to about 68° F (20° C) in the lower Talkeetnas. With less than 20 inches (500 millimetres) of annual precipitation, the Brooks Range is the driest of the Alaskan ranges, while the coastal mountains from the Copper River delta area southward through the Alexander Archipelago are the wettest, with precipitation sometimes reaching 200 to 300 inches annually.

Plant and animal life. Vegetation at the higher elevations of the mountain ranges, when they are not barren or covered by ice, is usually a ridge type of tundra, or treeless plain. Above the timberline, vegetation consists of lichens, grasses, sedges, and heather. Dwarf species of willow and alder also are found, while extensive grasslands occur in the Aleutians, on the Alaska Peninsula, and on the southern slopes of the Alaska Range. The interior forests, consisting of white spruce and birch or aspen, with mixtures of balsam poplar, occur mostly on the lower slopes of the larger river valleys north of the Alaska Range.

The timberline

The Tongass National Forest encompasses southeastern Alaska, and the Chugach National Forest covers the lower parts of the Chugach, Kenai, and Kodiak mountain areas. Vegetation in the lower elevations is a hemlock-spruce coastal forest. Western hemlock and Sitka spruce extend to about 1,500 feet above sea level, and subalpine species to at least 2,500 feet. The Tongass National Forest is composed largely of western hemlock, with a much smaller proportion of Sitka spruce and a sprinkling of western red cedar, Alaska cedar, and alpine fir. On the continental flank of these ranges, white spruce and lodgepole pine dominate. The Chugach National Forest is predominantly a hemlock forest with some Sitka and white spruce and occasional cottonwood and paper birch.

Several large mammals are native to the Alaskan mountains. Brown and grizzly bears and wolves inhabit the Boundary and St. Elias ranges, the Alaska Range, and the interior. Black bears, absent from the Alaska Peninsula, are found in most of the state. Dall bighorn sheep live high in the mountains from the Kenai Peninsula to the Brooks Range and southeastward in the interior St. Elias and Boundary ranges. Mountain goats are in the Chugach, Kenai, Talkeetna, St. Elias, and Boundary ranges. Moose, though living mostly in the lower elevations, range into high country from the Alaska Peninsula to the Brooks Range. Barren-ground caribou and foxes range over high plateaus and mountain slopes from the Alaska Peninsula to the Arctic. Sitka deer are abundant in southeastern Alaska and in parts of the Prince William Sound region. A number of smaller fur-bearing animals—including lynx, martens, and weasels—are native to all the mountains.

The people and economy. As a marginal environment in a mostly harsh climatic region, the Alaskan mountains have few areas suitable for settlement. Where they occur, settlements are limited to lower elevations or intermontane valleys. Only the coast mountains of southern Alaska and the panhandle support sizable populations. Anchorage is the most populous urban area. Commercial fishing, forestry, some mining, and tourism are the major economic activities in settled coastal areas. The Trans-Alaska oil pipeline, from Prudhoe Bay on the North Slope, crosses the Brooks, Alaska, and Chugach ranges, terminating at the ice-free port of Valdez, east of Anchorage.

Mountain landscapes in the interior have soils underlain by permafrost and only short frost-free periods in summer,

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Exit Glacier in the Harding Icefield of the Kenai Mountains, Alaska.

both of which inhibit agriculture. Moreover, solifluction—the downslope flow of waterlogged soil over subsurface permafrost—prohibits building construction and road development in many areas. Inhabited mostly by Alaskan Indians and Eskimos, interior settlements are isolated and depend largely on subsistence-level activities such as hunting, fishing, and fur trapping, with some farming. Arts and crafts are economically important in some areas. The major commercial activities in the mountain interior are metal (zinc, platinum, gold, and silver) and coal mining and forestry. There are some gold and silver mining operations in the mountains of the panhandle.

Mapping

Study and exploration. Alaska has been fully mapped topographically from aerial photographs; the underlying geology of large areas, however, remains incompletely mapped. The U.S. Geological Survey, as part of the general reconnaissance mapping program from the late 19th century to the 1960s, did most of the geologic work, with some fieldwork also by the U.S. Bureau of Mines and the Alaska Department of Geological and Geophysical Surveys. Since 1950, areas of potential mineral and transportation value have been mapped on a more detailed basis by these state and federal agencies. Various university research parties also have contributed to the data, while some local site assessments and geologic mapping have been done by private mining and petroleum companies.

Detailed glaciological studies in the Alaskan mountains began with the Harriman Alaska Expedition (1899), funded by the railroad magnate Edward Henry Harriman. This was followed by expeditions of the National Geographic Society in the early and mid-20th century and field studies by the American Geographical Society, the Office of Naval Research, the Arctic Institute of North America, and the U.S. Geological Survey. The longest continuous glaciological study in the Alaskan mountains has been conducted since 1946 by the Juneau Icefield Research Program in the Coast Mountains. (R.Sc./M.M.M.)

APPALACHIAN MOUNTAINS

The Appalachian Mountains are one of the great highland systems of North America, the eastern counterpart of the Rocky Mountains. Extending for almost 2,000 miles (3,200 kilometres) from the Canadian province of Newfoundland to central Alabama in the United States, they form a natural barrier between the eastern Coastal Plain and the vast Interior Lowlands of North America. As a result, they have played a vital role in the settlement and development of the entire continent. They combine a heritage of natural beauty and a distinctive regional culture with contemporary problems of economic deprivation and environmental deterioration.

Physical features. *Physiography.* The system may be divided into three large physiographic regions: northern, central, and southern Appalachia. These include such mountains as, in the northern area, the Shickshocks (French: Chic-Chocs) and the Notre Dame ranges in Quebec; the Long Range in Newfoundland; the great monadnock (isolated hill of bedrock) of Mount Katahdin in Maine; the White Mountains of New Hampshire; and Vermont's Green Mountains, which become the Berkshire Hills in Massachusetts, Connecticut, and eastern New York. New York's Catskill Mountains are in central Appalachia, as are the beginnings of the Blue Ridge range in southern Pennsylvania and the Allegheny Mountains, which rise in southwestern New York and cover parts of western Pennsylvania, western Maryland, and eastern Ohio before merging into the third, or southern, region. This area includes the Alleghenies of West Virginia and Virginia; the Blue Ridge range, extending across Virginia and western North Carolina, the northwestern tip of South Carolina, and the northeastern corner of Georgia; the Unaka Mountains in southwestern Virginia, eastern Tennessee, and western North Carolina (of which the Great Smoky Mountains are a part); and the Cumberland Mountains of eastern Kentucky, southwestern West Virginia, southwestern Virginia, eastern Tennessee, and northern Alabama.

Elevations

The highest elevations in the Appalachians are in the northern division, with Maine's Mount Katahdin (5,268 feet [1,606 metres]), New Hampshire's Mount Washington (6,288 feet), and other pinnacles in the White Mountains rising above 5,000 feet, and in the southern region, where peaks of the North Carolina Black Mountains and the Tennessee–North Carolina Great Smoky Mountains rise above 6,000 feet, and the entire system reaches its highest summit on Mount Mitchell (6,684 feet [2,037 metres]).

A distinctive feature of the system is the Great Appalachian Valley. It includes the St. Lawrence River valley in Canada and the Kittatinny, Cumberland, Shenandoah, and Tennessee valleys in the United States; the latter is the site of the world-famous Tennessee Valley Authority (TVA), a government agency for natural resource conservation, power production, and regional development.

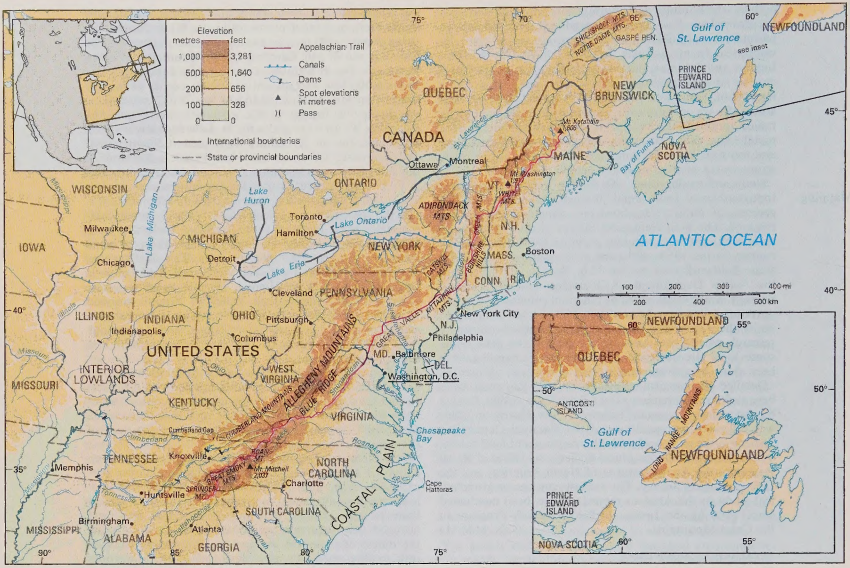
In the area known geologically as "New" Appalachia, especially where there are softer limestone rocks that yield to the constant erosion by water, numerous caves are a distinctive feature of the physiography. The chief caverns lie within or border the Great Valley region of Pennsylvania, Maryland, West Virginia, Virginia, and Tennessee. Caverns of the Shenandoah Valley in Virginia provide well-known and dramatic examples of underground passages, rooms, watercourses, formations, and decorations that honeycomb much of the land below central and southern Appalachia.

Geology. The Appalachians are among the oldest mountains on Earth, born of powerful upheavals within the terrestrial crust and sculpted by the ceaseless action of water upon the surface. The two types of rock that characterize the present Appalachian ranges tell much of the story of the mountains' long existence.

First there are the most ancient crystallines. Between about 1.1 billion and 540 million years ago, during Precambrian time, long periods of sedimentation and violent eruptions alternated to create rocks and then subject them to such extreme heat and pressure that they were changed into sequences of metamorphic rocks. Among the oldest of these are the gneisses. Limestone changed into marble, shales became slate and schist, sandstones were transformed into quartzite, and intrusions of magma formed bodies of granite. These ancient rocks antedated most plant or animal life; in addition, the intense pressure and heat destroyed any traces of primitive life—so that the Precambrian crystallines contain no trace of fossils. They make up what is known as "Old" Appalachia in Canada, New England, and a belt east of the Great Valley with the Blue Ridge at its heart. To west the Great Valley, the Valley Ridges, and the Appalachian Plateau (including the Alleghenies) are characterized by the second type of rocks, the Paleozoic sediments. These make up "New" Appalachia—the shales, sandstones, and coals that were created by sediments deposited, stratified, and solidified over a vast range of geologic time. During the Carboniferous Period (360 to 286 million years ago), this long process included the formation of some of the richest coal beds in the world. During the Permian Period, near the end of the Paleozoic Era (*i.e.,* about 250 million years ago), a great mountain folding occurred. This was the Appalachian Revolution, a vast interior crumpling resulting from the stress placed on huge masses of subterranean rock. As parts of the Earth buckled into folds, cracked, and faulted, other parts were uplifted—sometimes in the parallel ridges distinctive of the Appalachians—and thrust faults served to move one rock mass atop another. Thus, the ancient crystallines were lifted in places above more recent sedimentary rock deposits.

The Appalachian Revolution

In addition to the massive folding of the Appalachian Revolution, however, two other agents—ice and water—have carved the steep ridges and pinnacles and gouged out the deep ravines and valleys of the Appalachians. This building, eroding, uplifting, and shaping of the Appalachians has been a continuous process throughout the ages. Many of the major rivers are older than the mountains. This accounts for the fact that northeast of the New River in Virginia the major Appalachian rivers flow into the Atlantic Ocean, often through dramatic passages called water gaps, while southwest of the New the rivers, with few exceptions, flow to the Ohio River. When the mountains were thrust up, blocking their westward course to



The Appalachian Mountains.

the ancient sea that once covered the American Midwest, these old rivers cut out their own routes, creating those spectacular canyons, gorges, and "narrows" that are part of Appalachian scenery.

The northern Appalachians were also affected by glacial forces. During the Pleistocene Epoch (1.6 million to 10,000 years ago), continental ice sheets flowed down over North America, covering New England but reaching no nearer the southern Appalachians than the Ohio River valley. These moving tongues of ice stripped topsoil, ground and polished certain peaks, and elsewhere scattered rock debris and random boulders, all the while driving plants and animals farther south where they could survive. Thus, the southern Appalachians became the refuge for northern life forms, a giant bed for reseeding when the glaciers retreated and the plants moved slowly north again, leaving behind a rich botanical variety thriving in northern and southern latitudes.

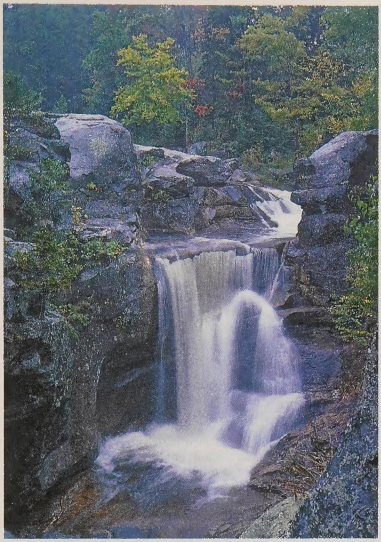
Drainage. The New River, rising on the Blue Ridge in North Carolina, runs northward and then turns westward across the Appalachian Valley and the Alleghenies (where it becomes the Kanawha River) and empties into the Mississippi River basin. The larger mountain streams to the south, dominated by the Tennessee River, follow this example. Exceptions are the rivers rising southeastward on the Blue Ridge, which flow into the Atlantic, and the Chattahoochee, rising in the northeastern corner of Georgia, which runs southwestward into the Gulf of Mexico.

The entire Appalachian system is laced with an intricate network of springs, streams, waterfalls, and rivers. Water is most abundant in the southern Appalachians. Certain areas of the Blue Ridge receive an annual rainfall of 69 inches (1,750 millimetres) during an average year. Elsewhere precipitation is even higher—the western slopes of the Great Smoky Mountains, for example, often receive as much as 90 inches per year—being exceeded in the United States only along the northwest Pacific coast. Much of this rainfall comes in extremely heavy downpours during short periods. Since this region does not have the natural storehouses of numerous lakes and glacial deposits of sand and gravel spread over hills and valleys, such as are found in the northern Appalachian region, sudden rainfalls bring rapid rises and falls in the southern Appalachian stream flows. Under certain conditions (as when the forest cover, which serves as a storage sponge, has been destroyed) destructive floods have characterized much of the hydrologic history of this part of the Appalachians. To contain these floods and harness the might of an entire river system for purposes of navigation, power production, land reclamation, and watershed development, the Tennessee Valley Authority was established in 1933, and it quickly became one of the chief factors influencing the ecology of the Southern Appalachian region. Its system of dams turned a river that rampaged and often destroyed into a river that flows gently and productively. The TVA created a series of spacious reservoirs (the majority of which are in or adjoining the Appalachian region) called "the Great Lakes of the South." These lakes, in turn, have altered the natural and human resources of the region, using Appalachian water power to produce electrical power that has expanded industrial and agricultural and recreational opportunities.

The Tennessee Valley Authority

Waterfalls are common throughout much of the Appalachian system. Most of those in the northern Appalachians, especially from New York to Maine, were created when glacial moraine or debris, scraped from surrounding peaks by the melting ice cap, solidified into shelves along creeks or river valleys over which the water must plunge as over a terrace. Southern Appalachian waterfalls generally were formed by the action of water on alternating layers of soft and hard rock.

Climate. Generally temperate and humid, the climate of the Appalachians presents sharp contrasts. In the Canadian ranges and the Presidential Range of the White Mountains, Arctic and subarctic conditions prevail. Altitudes below 2,000 feet usually have milder weather in the



Screw Auger Falls in the Mahoosuc Range, northern Appalachian Mountains, Maine.
© George Wuerthner

hills of northwestern Georgia and northeastern and north-central Alabama. Snowfall is heaviest in the Shickshocks, Newfoundland's Long Range, and the White Mountains, but Mount Mitchell in North Carolina has recorded more than 100 inches in a single year. Unique in climatic severity is barren, boulder-strewn Mount Washington, which is lashed by some of the world's strongest winds (a gust of 231 miles per hour was recorded there in 1934); temperatures recorded on its summit have never risen above 71° F (22° C). Heavy clouds and haze are common throughout the Appalachians, often frustrating recreational activities and sightseeing but nourishing the abundant plant life and the river system.

Plant and animal life. From Maine to Georgia, the Appalachian Mountain system was once almost totally covered with forest. Today some of the best and most extensive broad-leaved deciduous forests in the world still flourish in the Appalachians and bordering areas, notably in southern Appalachia. To the north are the conifers (red spruce and balsam fir, which grow at the highest elevations and distinguish the Canadian and Maine woods) and the northern hardwoods (sugar maple, buckeye, beech, ash, birch, and red and white oak). Farther south are hickory, poplar, walnut, sycamore, and at one time the important and—before they were destroyed by blight—plentiful chestnuts. All of these, plus other of the 140 species of trees of Appalachia, are found in the southern mountain region. Lofty elevations nurture representatives of the Canadian forest, while the western slopes of the Great Smokies, with their abundant rainfall, produce trees that have reached record maximum height and diameter. Among these are the tulip tree (yellow poplar), buckeye, eastern (Canadian) hemlock, and chestnut oak.

Forests

The interdependent system of southern plant growth known as the "Appalachian forest" is highly complex. It forms one of the great floral provinces of the Earth. There are the trees that bear luxuriant bloom, such as serviceberry, redbud, hawthorn, tulip tree, dogwood, locust, sourwood, and many others. Among the numerous shrubs with particularly showy flowers are the rhododendron, azalea, and mountain laurel. Certain summits of the southern Appalachians are called heath balds—open meadows or grasslands interspersed with thick growths of heath. Roan Mountain in the North Carolina–Tennessee Unakas is one of the most extensive of these, with some 1,200 acres of natural gardens sprawling vivid rose and pink and purple rhododendron across its high pinnacle and down its slopes. It is estimated that, of some 2,000 species of Appalachian flora, perhaps 200 are native and wholly confined to the southern Appalachians. Ferns, mosses, and mushrooms of many species also are part of the complex Appalachian plant life.

Bison, elk, and wolves, once common to the Appalachians, disappeared long ago, although elk subsequently have returned to the northern mountains; caribou and moose are still found in the northernmost corners of the region. Scattered through other areas are the black bear, white-tailed deer, wild boar, fox, raccoon, beaver, and numerous other small animals. All areas of Appalachia, from the Gaspé Peninsula to Georgia, support an abundant birdlife. In the Great Smoky Mountains alone some 200 varieties of game birds and songbirds have been recorded.

The people and economy. *Settlement and expansion.* Various Eastern Woodland Indian groups, including the Pennacook, Mahican, and Susquehanna, inhabited the northern half of the Appalachians for centuries before European settlement. In the southern mountains, the Cherokee were predominant. Warfare and eviction had driven most of the Indian populations from the mountains by the mid-19th century. The so-called Trail of Tears, the forced march of the Cherokee to Oklahoma in the fall and winter of 1838–39, is perhaps the best-known episode of Indian removal.

Obstacles to settlement

The long blue wall of the Appalachians thrust up a mighty barrier to colonial expansion. Exploration and settlement was further discouraged by the size and complexity of the lateral mountain ranges, the rugged courses of many of the streams and rivers, and the ubiquitous dense forest. The central Appalachians, with their more spacious water gaps affording easy passage, attracted the largest number of early settlers. Many of these were Germans and Scotch-Irish who went into the interior of Pennsylvania and subsequently migrated down the Great Appalachian Valley in Virginia and Tennessee. In the New England Appalachians the narrow notches, often blocked by glacial debris, and the steepness of the mountains discouraged early settlement—as did the massive ruggedness of the successive ranges in the southern Appalachians—so that each of these regions remained a wilderness long after the American frontiersman Daniel Boone had forged his pioneer route through the Cumberland Gap. During the French and Indian War (1754–63), trails to the Ohio country and Great Lakes led through central Appalachia, and these, with their scattered lonely forts of the interior, became brutal battlegrounds of border warfare. Indian allies of the British waged bloody skirmishes against Appalachian settlements during the American Revolution (1775–83), but the Appalachian Mountains confined most of that struggle for independence to the Eastern Seaboard.

Economic growth. The diversity that characterizes Appalachian plant and animal life also exists in the system's mineral resources. As the immense stands of timber throughout the Appalachians brought into existence important lumber and wood-pulp industries, so rich coal beds, veins of iron ore, salt springs and licks, and deposits of granite and marble created major American industries in the region. Each of these has been attended by its own peculiar problems, especially in the field of conservation. There is, for instance, pollution of Appalachian waterways by the pulp and chemical industries and the devastation of land and human resources brought on by certain coal-mining operations. Air pollution, especially in the form of acid rain, has taken a toll on Appalachian forests from North Carolina to Canada. The pinnacle of the Appalachians, Mount Mitchell, once called Black Dome because of its blanket of virgin evergreens, is now a ghost forest of dead trees.

Despite the early arrival of the lumber industry and the opening of the coal mines, some areas of Appalachia remained isolated until early in the 20th century, notably those mountain areas of the southern region where rough terrain hindered road building. As a consequence, Southern Appalachian highlanders developed a distinctive culture characterized by handicrafts, ballads, folklore, and mores that reflect both the massive problems and the rich potential of the region.

Recreation and tourism. The Appalachian region has developed into one of the premier recreational areas of North America. One unique feature of a large portion of the system is the 2,100-mile Appalachian Trail. This footpath, stretching from Mount Katahdin in Maine to Springer Mountain in Georgia, provides a hiker's grandstand on the varied ranges of the Appalachians. Overnight shelters are scattered along the way. A noncommercial motor route, the Blue Ridge Parkway, stretches 469 miles from the Shenandoah National Park in northern Virginia to the Great Smoky Mountains National Park and is the most popular area administered by the U.S. National Park Service.

The Appalachian Trail

The springtime profusion of flowering wild azalea, rhododendron, and laurel is a major tourist attraction in the Appalachians, beginning in the south in April and spreading northward. In autumn the pattern is reversed, as the brilliant coloration of the foliage moves from north to south. Motoring, hiking, camping, fishing, skiing, whitewater rafting, and spelunking are encouraged throughout the Appalachians, as are visits to numerous craft centres and historic sites. Famous spas are reminders of more leisurely days in both the northern and southern mountains, while conference facilities and theme parks reflect a growing emphasis on tourism, with its attendant benefits and its problems of environmental stress.

Study and exploration. The ruggedness of the Appalachians, the transverse ranges by which they are crossed, their maze of streams and rivers, and their lack of natural passes created a formidable barrier to early explorers and settlers. The Spanish conquistador Hernando de Soto was probably the first European to enter southern Appalachia, in 1539–40. In 1716 Governor Alexander Spotswood of Virginia led the first organized body of English colonists across the Blue Ridge Mountains. During the 1760s and '70s Daniel Boone became America's frontier folk hero through his exploits in exploring and settling the Blue Ridge and Cumberland Mountain country. Historical figures associated with the opening of northern Appalachia include the French explorer Samuel de Champlain, who sighted the mountains in 1605 as he sailed along the Maine coast; the American Darby Field, who made the first climb up Mount Washington (1642); Timothy Nash, discoverer of the Crawford Notch (1771), which made possible communication between the coast and the Connecticut River valley; and Sir William Logan, first director of Canada's geologic survey, who made a cross section of the geologic formation of the Gaspé Peninsula in 1844 and became the first European to cross the Shickshock Mountains. During the mid-19th century the first extensive scientific studies of Appalachia began when in 1849 the Swiss geographer Arnold Guyot commenced mapping the eastern mountains. Starting with the White Mountains, he spent five years in northern Appalachia, then moved south to the Great Smoky Mountains area. He mapped, measured elevation, and made the first methodical effort to name mountains. The highest peak in the eastern United States was named for another pioneer explorer-scientist, Professor Elisha Mitchell, who fell to his death in 1857 while establishing the fact of this mountain's preeminence. It remained for Horace Kephart, a St. Louis, Mo., librarian turned naturalist who came to the southern mountains in 1904, to bring the isolated and scenic region to national attention. From his writings grew the interest and impetus that led to the establishment of the Great Smoky Mountains National Park. (W.D.)

GREAT PLAINS

A major physiographic province of North America, the Great Plains lie between the Rio Grande in the south and the delta of the Mackenzie River at the Arctic Ocean in the north and between the Interior Lowland and the Canadian Shield on the east and the Rocky Mountains on the west. Their length is some 3,000 miles (4,800 kilometres), their width from 300 to 700 miles, and their area approximately 1,125,000 square miles (2,900,000 square kilometres), roughly equivalent to one-third of the United States. Parts of 10 states of the United States (Montana, North Dakota, South Dakota, Wyoming, Nebraska, Kansas, Colorado, Oklahoma, Texas, and New Mexico) and the three Prairie Provinces of Canada (Manitoba, Saskatchewan, and Alberta) and portions of the Northwest Territories are within the Great Plains proper. Some writers have used the 100th west meridian as the eastern boundary, but a more precise one is an eastward-facing escarpment that runs from Texas to North Dakota, generally somewhat east of the 100th meridian. In the Canadian portion the line dividing the Great Plains from the Canadian Shield runs east of the Red River of the North, cuts through Lake Winnipeg, and then curves northwestward, crossing Lake Athabasca, Great Slave Lake, and Great Bear Lake; in the far north, the plains reach the Arctic Ocean in a narrow strip just west of the Mackenzie delta.

Extent of the Great Plains

For map coverage of the Great Plains, see below *Mississippi River*.

Physical features. *Relief and drainage.* Once known as the Great American Desert, the Great Plains are a vast high plateau of semiarid grassland. Their altitude at the base of the Rockies in the United States is between 5,000 and 6,000 feet (1,500 and 1,800 metres) above sea level; this decreases to 1,500 feet at their eastern boundary. The altitudes of the Canadian portion are lower, and near the Arctic Ocean the surface is only slightly above sea level. Some sections, such as the Llano Estacado (Staked Plains) in western Texas and eastern New Mexico, are extremely flat; elsewhere, tree-covered mountains—the Black Hills of South Dakota and the Bear Paw, Big Snowy, and Judith mountains of Montana—rise 1,500 to 2,000 feet above the general level of the plains.

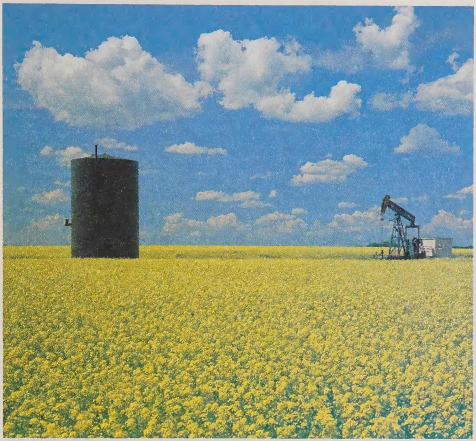
In the United States the Great Plains are drained by the Missouri River and its tributaries (the Yellowstone, Platte, and Kansas) and the Arkansas, which flow eastward from the Rockies in broad, steep-sided, shallow valleys. In Canada the Saskatchewan River and its tributaries constitute the main drainage system.

Soils and climate. The soil groups of the Great Plains are correlated with rainfall and natural grass cover. In the more humid region with heavier grass cover, deep, black soils with much organic matter developed. Sections with less moisture have lighter, shallower soils with less organic matter, while in the most arid regions the soils are even thinner, lighter in colour, and less organic in composition.

The Great Plains have a continental climate. Over much of their expanse, cold winters and warm summers prevail, with low precipitation and humidity, much wind, and sudden changes in temperature. The major source of moisture is the Gulf of Mexico, and the amount falls off both to the north and west. Thus, the southern plains have 15 to 25 inches (380 to 640 millimetres) of rain annually, the northern plains 12 to 15 inches, the eastern margin in Nebraska 25 inches, and the western margin in Montana less than 15 inches. The southern parts of the Canadian Great Plains receive 10 to 20 inches and have a growing season of 70 to 110 days. The growing season averages 240 days in Texas, 120 days at the U.S.-Canadian boundary, and from 70 to 110 days in the Prairie Provinces. A distinctive winter phenomenon of the western Great Plains is the chinook, a warm wind that blows down the eastern slope of the Rocky Mountains and can raise temperatures by as much as 30° to 40° F (17° to 22° C) in a short period.

Plant and animal life. Natural vegetation in the Great Plains is dominated by grasses—tallgrass and medium grass prairie in the east and shortgrass steppes in the west. These grasslands include larger plants such as the yucca and the prickly pear cactus in marginal areas. Much of the natural grass cover, however, has been removed to create agricultural land. Gallery forests are found along the rivers and include hardy xerophytic (drought-tolerant) trees such as box elder and cottonwood. Coniferous evergreens (pri-

Dominance of grasses



Pumping oil from a well in a field of mustard on the Great Plains, in western Saskatchewan, near Maidstone.
© E. Otto/Comstock

marily Ponderosa pine) dominate the mountain islands, such as the Black Hills. Between Edmonton, Alta., and Winnipeg, Man., a transition zone trending northwest-southeast and known as the "Parklands" is found, where the grasslands gradually give way to forest; and north of 54° N latitude coniferous forests dominate the vegetation.

Before European settlement, the Great Plains were the home of immense herds of grazing mammals: the buffalo (bison) and the pronghorn. The buffalo were nearly eliminated, but the pronghorn continued to thrive. Other grassland-adapted animals that thrive together with agriculture include prairie dogs, coyotes, and rattlesnakes. In the northern coniferous forests are found moose, woodland caribou, Canada lynx, and timber wolves.

The people and economy. The Great Plains were sparsely populated until about 1600. Spanish colonists from Mexico had begun occupying the southern plains in the 16th century and had brought with them horses and cattle. The introduction of the horse subsequently gave rise to a flourishing Plains Indian culture. In the mid-19th century, settlers from the eastern United States began to supplant the Indians, the latter being relegated to marginal agricultural areas set aside as reservations. European immigrants also played an important role in settling the plains; by 1910, foreign-born immigrants and their children constituted nearly half the population of the six northern plains states (Montana, North Dakota, South Dakota, Wyoming, Nebraska, and Kansas), with the British, Germans (many of them from Russia), and Scandinavians the leading ethnic groups. The Prairie Provinces were settled by British, German Russians (many of them Mennonites), Ukrainians, and Scandinavians.

Many of the immigrants were religious, thrifty, hard-working people who developed a strong attachment to the land. Kinship and nationality ties drew the plainsmen together, and they would travel long distances to visit and exchange work. Class differentiation was less and the status ladder shorter than in Europe or parts of North America that had been settled longer.

Although there are still few large cities, some three-fifths* of the population is urban. The largest cities are Edmonton and Calgary in Alberta and Denver in Colorado; smaller cities include Saskatoon and Regina in Saskatchewan and Amarillo, Lubbock, and Odessa in Texas. The rural population also has remained sparse.

Life-styles of the plains

Ranchers traditionally enjoyed their remoteness and looked upon their rangeland as the last remaining trace of the Old West, with its vast expanse of plains and untamed wilderness. Not generally a gregarious kind of people, they were highly individualistic in politics. Farmers, more inclined to social interaction, made economic cooperatives strong on the plains. Since the end of World War II, ranchers and farmers alike have valued horsemanship and rodeos as symbols of a tradition and style of life that evolved from the natural habitat.

The need for larger farms and ranches to produce viable economic units has led to a heavy migration from the rural areas. This exodus has been demoralizing for the farmers, ranchers, and businessmen who remained, and it has made survival more difficult for churches, schools, and the rural trading centres. The low density of population has concentrated services increasingly in a few centres, necessitating long trips to attend school and church, to do business, and to find recreation. To meet these difficulties, some farmers have moved into town to live and commuted back to their land to work, a revival of a centuries-old pattern.

Indians on horseback exploited the buffalo herds for some two and a half centuries; but in the 1870s cattle replaced the buffalo, and cowboys replaced the Indians. In the 1880s and '90s farmers began to crowd the ranchers, and wheat began to replace cattle. Settlement came in years of good rains, so the Great Plains were overpopulated in the first rush. A heavy emigration followed the twin blows of drought and economic depression in the 1930s. Many grain farmers left because their farms were too small and more vulnerable to drought than the cattle ranches. Those who stayed built up the size of their holdings, saved against hard times, and added livestock to grain farming. These people were aided considerably by the construction after World War II of numerous dams in the Missouri River basin, which provided flood control, hydroelectric power, and irrigation. In addition, an immense source of groundwater, the Ogallala Aquifer, was tapped for irrigation water for an area extending from Nebraska to the Texas Panhandle.

Thus, the Great Plains have remained basically an agricultural area producing wheat, cotton, sorghum, and hay and raising cattle and sheep. Eight of the leading U.S. wheat states (Kansas, North Dakota, Texas, Montana,

Nebraska, Colorado, Oklahoma, and South Dakota) lie within the Great Plains, and the Prairie Provinces are the leading wheat producers in Canada. Of increasing importance are crops of such oilseeds as sunflower and canola. Livestock accounts for a large percentage of farm income in most of the plains states.

The Great Plains states also produce much mineral wealth, with Texas leading the nation and four other plains states (Oklahoma, New Mexico, Wyoming, and Kansas) ranking high. Four of the plains states have the largest coal reserves in the nation (Wyoming, North Dakota, Montana, and Colorado) but, except for Wyoming, rank low in actual production. Texas leads the United States in production of petroleum and natural gas, and several other plains states are substantial producers. Alberta leads Canada in petroleum and natural gas.

Study and exploration. European knowledge of the Great Plains began with the expedition of the Spanish explorer Francisco Vázquez de Coronado in 1539–41. American interest in the region was sparked by the Louisiana Purchase (1803), which gave rise to the great Lewis and Clark Expedition in 1804–06. Two subsequent expeditions are of note: the first, led by Zebulon Pike (1805–07), explored the Arkansas and Red rivers; and the second, led by Stephen Long (1820), concentrated on the Platte and Arkansas river basins and caused Long to characterize the region as the "Great American Desert." Fur trappers and then settlers traveling through the region on the Oregon, Mormon, and Santa Fe trails completed the basic knowledge of the plains.

Expeditions of Pike and Long

Study of the Great Plains in the 20th century has concentrated on their agricultural and mineral potential, as well as on their natural history. Since World War II more emphasis has been placed on ecological studies of the soils, groundwater, and effects of the use of agricultural chemicals. Research also has been undertaken on the effects of rural depopulation and on the impact the region's natural grass cover—particularly its restoration—may have on global climatic conditions, including the greenhouse effect. (E.B.R./J.L.Di.)

NORTH AMERICAN DESERT

A vast, irregular belt of inhospitable terrain stretches north to south down the western side of the North American continent from southern Oregon and Idaho to northern Mexico, roughly corresponding to the sheltered, and hence rain-starved, intermontane region lying between the soaring barrier of the Rocky Mountains to the east and the fertile coast ranges fringing the Pacific Ocean to the west. Estimates of the size of this region vary from about 500,000 to more than 730,000 square miles (1,300,000 to 1,900,000 square kilometres). The physical geography and human utilization of this huge area exhibit great internal variety, but its overall aridity—associated with an excess of evaporation over precipitation, great temperature extremes, frequent winds, localized storms, and a predominance of starkly eroded sun-beaten landscapes—give it an unquestioned unity. Scientists, in naming this whole ecological complex, or biome, the North American Desert, are merely echoing the legend of a "Great American Desert" established as early as the 1820s by the vivid reportage of an expedition led by the American pioneer explorer and engineer Stephen H. Long.

All forms of life, from lowly plants and insects to people, have had to struggle to survive in the region, and the North American Desert thus has had enormous importance in the development of the continent. Descendants of the earliest inhabitants, the desert-culture Indians, are still found in the area. Their ranks were swollen in the 19th century by tribes thrust westward in the great dispossession that followed the advance of European settlement from the Eastern Seaboard into the continental interior, and the region is now the home of most of the U.S. Indian population. The legacy of much earlier population movements from farther south has lent a distinctly Spanish element to the area, while modern American settlement has added its own contribution in the form of sheep and cattle grazing, military installations, and small but often rapidly expanding oases of mining and manufacturing.

All the peoples of the North American Desert, whatever their origin, have their lives molded by the basic and all-pervading lack of water.

Physical features. *Physiography.* Differences in latitude, elevation, climate, topography, vegetation, soil, and human use have allowed the North American Desert to be subdivided into regions of cold mid-latitude and hot mid-latitude desert. All the continent's major deserts are associated with the intermontane Basin and Range Province of the western United States and northern Mexico.

The basic divisions of the desert

Classified as a cold mid-latitude desert is the Great Basin Desert, which lies in the physiographic Great Basin that covers nearly all of Nevada, western Utah, and portions of surrounding states. It constitutes the largest section of the Basin and Range Province and includes the Great Sandy Desert of southeastern Oregon, the Snake River Plains of southern Idaho, the volcanic Black Rock Desert of northwestern Nevada, and the Great Salt Lake Desert of western Utah. Although they are not usually assigned to the physiographic Great Basin, the Red Desert of southern Wyoming and the Painted Desert of northern Arizona are sometimes considered as extensions of the Great Basin Desert.

To the south the Great Basin Desert merges with the Mojave (Mohave) Desert and the hotter mid-latitude desert regions. In California near the undefined Great Basin–Mojave border are the sun-scorched landscapes of Death Valley; the valley's maximum depth of 282 feet (86 metres) below sea level is the continent's lowest point. The Mojave merges in the southeast with the Sonoran Desert, which covers much of Baja California and runs along the Gulf of California coast to the Mexican state of Sonora. Its subdivisions include the Yuma and Colorado deserts. To the east lies the huge Chihuahuan Desert, extending from southern New Mexico (where the dazzling gypsum dunes of White Sands National Monument are found) and western Texas to the highlands of central Mexico.

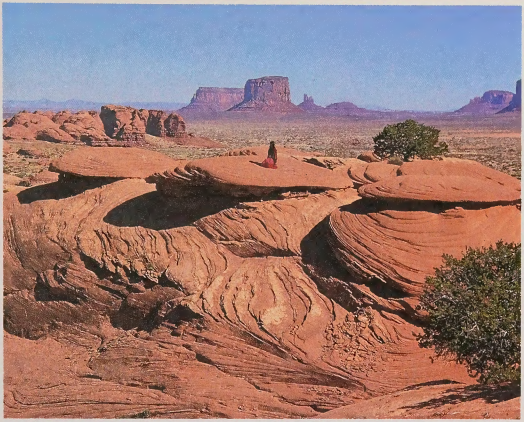
Geology. Most of the North American Desert—and all the salty-lake remnants—occupies areas covered by geologically recent Quaternary deposits (*i.e.,* those less than 1.6 million years old) and mountains thrust up and folded by movements in Tertiary time (or about twice as old, with some plains and plateaus consisting of sediments up to 225 million years old).

Through long periods of erosion, the landforms produced from these rocks are characteristically sharp and angular (except in the heavily eroded badlands regions) and contain, in their harsh but breathtaking beauty, some of North America's finest scenery. The action of wind, temperature changes, ephemeral streams, and floods have all been involved in this molding process. The individual deserts are characterized by plateaus, gorges, ravines, and alluvial fans washed out at the feet of mountains. Deserts of the bolson types contain playas (dried-up lake remnants) and mud and salt lakes and flats. Deserts of the hammada type are characterized by extensive rocky surfaces with boulder or gravel coverings, sometimes blackened and wind-scoured, with magnificent buttes, mesas, and other isolated mountain remnants rising high above the flat landscape. Stretches of shifting sands known as ergs—the extensive Algodones Dunes of the Colorado-Yuma desert are a notable example—are found at lower elevations, with the shallow troughs of arroyos carrying intermittent streams from surrounding uplands to be lost in the sands.

The Algodones Dunes

Soils. The soils of the North American Desert have origins similar to those of more humid regions, but they are less enriched by organisms and less leached of constituents. Most belong to the dry-soil order called aridisols, but local variations occur, reflecting differing salt and mineral composition and presence or absence of organic matter. With proper management, the more fertile soils can be productive. The youngest, least developed soils belong to the order known as entisols.

Climate. Regardless of the latitude, longitude, and elevation, a harsh and extreme temperature regime exists in the North American Desert, with a high frequency of cloudless days and intense solar radiation, infrequent and intense storms, winds carrying dust and sand, low relative humidity, and rapid evaporation or sublimation



Sandstone formations rising above the desert floor of Monument Valley Navajo Tribal Park, which straddles the boundary of Utah and Arizona.
© Brian A. Vikander/West Light

of snow. Regionally specific climatic zones exist, ranging from temperate in the Great Basin and Painted Desert to subtropical in the western Sonoran and northern Chihuahuan sections to tropical in the Sonoran gulf coast. Average annual temperatures range from approximately 49° F (9° C) in the northern deserts (Black Rock) to 73° F (23° C) in the Sonoran Desert and 77° F (25° C) at the bottom of Death Valley. Average annual rainfall varies from 6 to 12 inches (150 to 300 millimetres) in the Great Basin Desert, 2 to 6 inches in the Mojave Desert (a low of 2 inches in Death Valley), 10 to 11 inches in the Red and Painted deserts, 8 to 18 inches in the Sonoran Desert, and 12 to 14 inches in parts of the Chihuahuan Desert. Precipitation may be seasonal and characteristically is erratic, scattered, or intense. Snowfall of 12 to 24 inches occurs in most of the northern deserts, decreasing to only a trace in the Sonoran Desert. Winds are directional, with speeds averaging seven to nine miles per hour. Average relative humidities are generally less than 50 percent (20 percent for Death Valley), but 10 percent or less is not uncommon. The growing season varies from 90 to 140 days in the northern deserts to more than 300 days along the Sonoran gulf coast and in the Baja Peninsula.

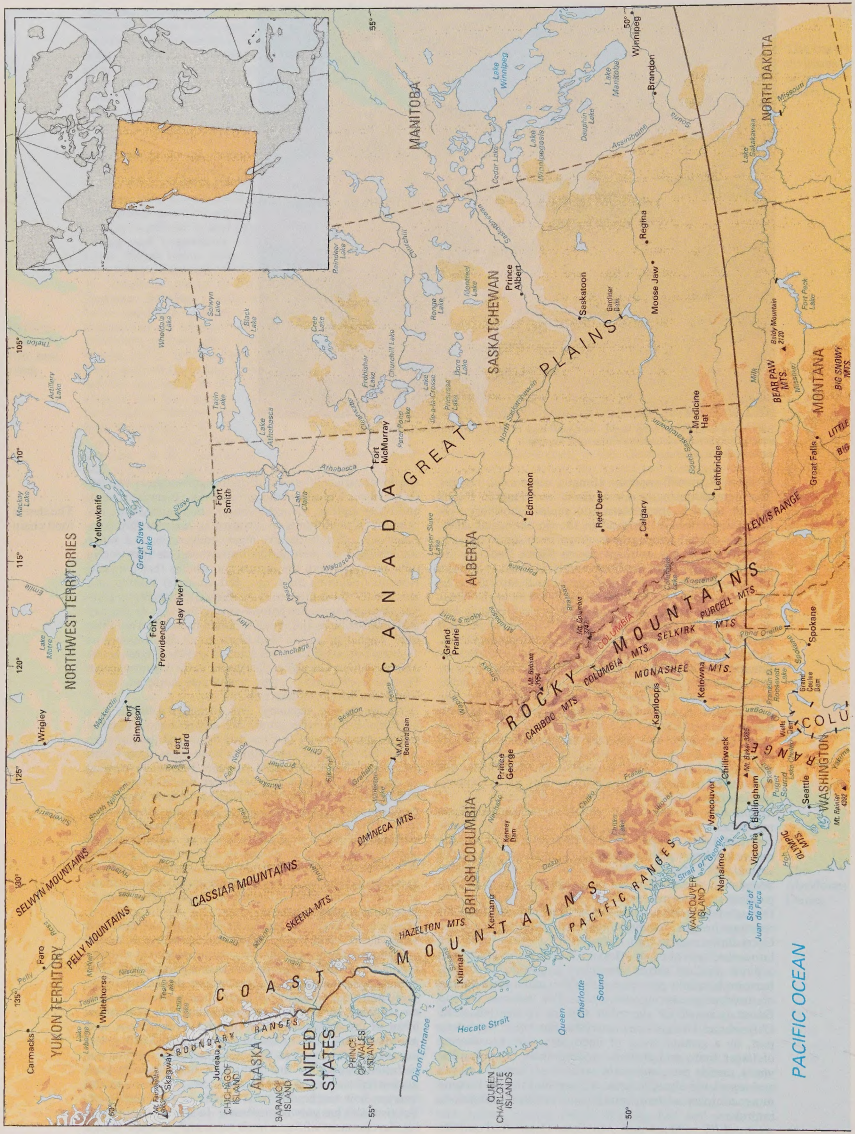
Plant life. In the North American Desert, available moisture is the most critical factor for life. Local environmental factors also are significant in determining the nature of desert plant communities and their dependent animal life. Most desert plants are xerophytes (plants adapted to arid conditions) or phraetophytes (plants dependent on a permanent water supply) and survive only through their root systems and adaptive mechanisms for resisting drought. Sagebrush and saltbush characterize the Great Basin region, with Joshua trees, creosote bush, and burroweed typical of the Mojave. The Sonoran Desert has a thorn scrub of shrubs (mesquite, paloverde, ironwood, burrobush, smoke tree, and cat's claw) and a great variety of moisture-preserving succulents. The Arizona Upland Desert is noted for the giant saguaro cactus, while the Chihuahuan Desert is characterized, notably in its eastern part, by a ground cover of open mesquite, a scattering of larger trees, and shrubby undergrowth, including the yucca, prickly pear, and other varieties of cactus. Plant life and associated algae, lichens, mosses, and insects become more complex as temperature and moisture conditions improve.

Animal life. The North American Desert harbours an abundant variety of insects, including grasshoppers that occasionally reach destructive proportions. Lizards, snakes, and other reptiles, the most conspicuous animals, are dependent on plant fluids or devoured animals for moisture. Likewise, desert birds are largely independent of water sources (and are seen almost everywhere), as they derive their moisture from the insects and spiders that they eat. Rodents (including mice, rats, and squirrels), rabbits, and bats are the most numerous mammals; essentially nocturnal, they remain underground during the heat of the day and, like the birds and reptiles, obtain moisture from their food. Higher up in the food chain are such carnivores as coyotes, bobcats, foxes, and skunks; and the largest desert mammal, found at higher elevations, is the bighorn sheep. Protective coloration, often remarkably complex, is an important feature of desert life.

The desert food chain

The people and economy. As ancient dwellings, rock paintings and carvings, and other archaeological remains testify, desert-culture Indians had developed a distinctive way of life within the approximate boundaries of the North American Desert thousands of years before the coming of Europeans. Spanish explorers were the first Europeans to penetrate the southwestern area, and their legacy has molded much of the character of the region. It was only in the 19th century that a great wave of settlement, often attracted by the lure of mineral wealth, swept westward over the whole area on its way to the more fertile regions of the Pacific coast; left behind was a scattering of settlements focused on mineral wealth and irrigated regions and, even more sparsely, in the vast areas given over to sheep and cattle grazing.

Large areas of the contemporary landscape are occupied by Indian reservations, a legacy of America's continental expansion. Military installations, some associated with the testing of nuclear weapons, also take up vast areas. The various types of agriculture encompass dryland farming, sheep and cattle grazing, and more intensive developments on irrigated oases. Mineral exploitation has continued, often to the detriment of the natural environment, and manufacturing industry has become associated with growing urban settlement in the more favoured regions. Air pollution, caused by the burning of fossil fuels in population centres along the Pacific coast as well as in the interior, now reaches the most remote areas of the desert. Tourism also has grown immensely. In spite of the increasing development of dams, reservoirs, and canals, the lack



Physical features of western North America.



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of water has remained a severe limitation to agricultural, urban, and industrial expansion.

Study and exploration. The Indians of the region accumulated a rich natural lore during the thousands of years of their adaptation to the desert environment, but it was left to Francisco Vázquez de Coronado and other 16th-century Spanish explorers to provide the first written descriptions of the region, particularly of the southwestern portion. Although Stephen H. Long never saw the true North American Desert, his depiction of the "Great American Desert" fired the American public's imagination. John C. Frémont's mapping of the region in the 1840s foreshadowed a host of reports, often generated by the huge land grants made to railroads and land companies and written by 19th-century surveyor-engineers. In 1878 the geologist John Wesley Powell made a significant report on the arid West, accurately forecasting the detrimental consequences of imposing on arid regions ways of life more appropriate to humid lands. More diversified studies followed—the first arid-lands research laboratory was founded at Tucson, Ariz., in 1903—and contemporary studies have included the important International Biological Program of ecological investigation. (R.E.C.)

Report of Powell

PACIFIC MOUNTAIN SYSTEM

The Pacific mountain system is a general term for the series of mountain ranges that stretches along the Pacific coast of North America from northern British Columbia (Canada) to northwestern Mexico. These ranges may be divided into eight sections. Roughly from north to south they are the Coast Mountains of British Columbia, the mountains of Vancouver Island and the Queen Charlotte Islands, the Cascade Range (itself divided into North, Middle, and South ranges), the Olympic Mountains, the Coast Ranges of Washington and Oregon, the Klamath Mountains, the Coast Ranges of California, and the Transverse Ranges. Although the Sierra Nevada often are considered to be part of this system, they are not included in this discussion (see below *Sierra Nevada*).

Physical features. *Geology.* In general, the movement of tectonic plates has been responsible for the development of the Pacific mountain system. The coastal mountains from the Queen Charlotte Islands southward to southern California have been folded, faulted, and intruded with molten rock as a result of this movement. The most significant activity has been the lateral, northerly movement of the Pacific Plate (west) relative to the North American Plate (east) along transform faults. To the north, in British Columbia, this movement has been along the offshore Queen Charlotte Fault, while in California it has been along the San Andreas Fault. Subduction (crustal sinking) is not currently occurring in these two areas. Seismic activity, particularly in California, is considerable along the transform faults. After Alaska, California is the most earthquake-prone area in North America.

To the west of the coasts of Oregon and Washington the Pacific Plate is spreading along the Gorda and Juan de Fuca oceanic ridges. The Juan de Fuca Plate, east of this spreading centre, is subducting under the North American Plate. The molten mantle rock produced by this subduction is responsible for the major volcanoes in the Cascade Range. All the Cascade composite cones are of the explosive type, their molten rock being high in silica. Until the eruption of Mount St. Helens in 1980, Lassen Peak had been the most recently active volcano (1914–17) in the coterminous 48 United States. The Mount St. Helens eruption, which blew off the top of its cone, was of greater magnitude than any other eruption in the region since the eruption and collapse of Mount Mazama 6,600 years ago, which formed the caldera now occupied by Crater Lake.

Because the subduction process is not continuous—it is impeded as huge quantities of materials accumulate on plate boundaries—enormous stresses develop. The release of these stresses creates shock waves of a larger magnitude than any other known earthquakes (*i.e.,* greater than 9 on the Richter scale). It is thought that for the past 4,000 years such subduction-related earthquakes have occurred at intervals of 300 to 1,000 years.

Earthquakes related to subduction

Physiography. The arrangement of the ranges in the system can be visualized as being in the shape of an extremely elongated H with a closed base. From north to south the west side of the H is made up of the ranges of the Queen Charlotte Islands and Vancouver Island, the Olympic Mountains, and the Washington, Oregon, and California Coast Ranges. From north to south the east side of the H consists of the Canadian Coast Mountains, the Cascade Range, and the Sierra Nevada. The Klamath Mountains of southern Oregon and northern California make up the east-west cross in the centre of the H, while the Transverse Ranges bend eastward from the California Coast Ranges to form the closed base of the H.

Inside the H north of the Klamath Mountains are the drowned inside passage of British Columbia, the Puget Sound Lowland of Washington, and the Willamette Valley of Oregon. Inside the H south of the Klamath Mountains is the Central Valley of California.

Coastal plains are either narrow or nonexistent along the entire north-south extent of the coastal ranges. Offshore a narrow continental shelf drops abruptly into ocean depths. In places waves have cut notches and terraces. More resistant igneous rocks stand as sea cliffs with undercut notches. Softer sedimentary rocks have been eroded to form embayments.

The ranges of Vancouver Island and the Queen Charlotte Islands have been heavily glaciated. Stream valleys have been deepened by glaciers to produce a fjordlike coast, with relatively short streams draining the interior. Southward, across the Strait of Juan de Fuca, the Olympic Mountains rise to almost 8,000 feet (2,440 metres). They consist of folded sedimentary and metamorphic rock and also have been heavily glaciated. Drainage is radial from the highest peaks; among the major streams are the Hoh, Quinault, and Elwha.

The Canadian Coast Mountains and North Cascades differ structurally from the Middle and South Cascades. These northern ranges consist of a dissected upland of late Paleozoic rock (*i.e.,* about 300 million years old) that has been folded, metamorphosed, and intruded by granites. Ridges in the North Cascades rise to elevations between 6,000 and 8,000 feet; above these ridges stand the composite volcanic cones of Glacier Peak and Mount Baker. The Coast Mountains of British Columbia are considerably

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Coast Mountains along the Torres Channel, an arm of Atlin Lake, northern British Columbia.

lower, with the highest elevations reaching 3,000 to 4,000 feet in the south. The higher peaks, however, often are glacier-covered. All the ranges have been heavily dissected by running water both before and after the Pleistocene Epoch (1,600,000 to 10,000 years ago). During the Pleistocene they were covered by a cordilleran ice sheet, the glaciers of which occupied and deepened many existing stream valleys. On the east side of the North Cascades, Lake Chelan is in a glacially formed valley, and its deepest points are more than 1,500 feet below the surface. In the Coast Mountains glacial action has produced a spectacular fjord coast. Farther south in southern British Columbia and Washington are deep glacial valleys opening out onto the Fraser River delta and the Puget Sound Lowland.

The Middle Cascades

The Middle Cascades, which extend southward from west-central Washington into Oregon, are an uplifted and faulted region consisting of volcanics of Tertiary and Quaternary age (*i.e.*, from the past 66.4 million years). These volcanics consist of successive layers of tuffs, breccias, and mudflows, covered by basaltic flows. The range can be divided into eastern and western sections, the western being the oldest. Capping the higher, eastern part of the range is a more recent layer of Tertiary and Quaternary andesites and basalts. Elevations reach 4,000 to 6,000 feet, with a number of volcanic peaks—such as Mounts Rainier and Hood—standing high above the general surface relief; Rainier, at 14,410 feet (4,392 metres), is the highest peak in the Pacific mountain system.

The Columbia River cuts through the Middle Cascades in a magnificent gorge. On the southern (Oregon) side are numerous hanging valleys with streams that plunge in spectacular waterfalls into the gorge. Multnomah Falls, at 620 feet, is second in height in the United States only to Yosemite Falls in California. During the latter part of the Pleistocene (10,000–12,000 years ago), a large lake (Lake Missoula) was impounded by an ice dam in western Montana. On several occasions the dam gave way and released enormous quantities of water, which then rapidly drained to the sea. These floods deepened and widened the existing Columbia River valley and are responsible for the present profile of the gorge.

The South Cascades, extending from southern Oregon into northern California, differ from the Middle Cascades in that they were not uplifted. Even so, two of the major volcanoes in the western United States, Lassen Peak and Mount Shasta, surmount the range. The Pit River provides a low-elevation passage across these mountains.

The Klamath Mountains are the oldest of the Pacific coastal mountains, dating to the early Paleozoic Era (*i.e.*, about 500 million years ago). They are extremely complex, probably resulting from the collision of tectonic plates in the Early Triassic Period (245–240 million years ago). Later they were intruded by granite batholiths. The Klamath Mountains have been glaciated in their higher elevations and have been heavily dissected by streams; the major watercourse crossing them is the Rogue River.

Both the Coast and the Transverse ranges were formed by plate collisions. The Washington and Oregon Coast Ranges consist of folded gray mudstones and siltstones oriented in a north-south direction. The major streams are antecedent to the uplift and have been drowned in their lower courses, producing estuaries. In addition to the Columbia[1] these include the Umpqua and Siuslaw rivers. The California Coast Ranges also are made up of folded and faulted sedimentary rocks. The major faults trend northwest-southeast, however, and the rivers tend to follow these lines of weakness. North of San Francisco Bay are the Napa, Russian, Eel, and Klamath rivers, while the Salinas River is the major coastal stream south of the bay. The eastern section of the Transverse Ranges consists of granites and metamorphic rocks, while the western portion resembles the sedimentary structure of the Coast Ranges; streams draining them include the Santa Clara and Santa Ana rivers.

Three most abundant orders

Soils. In the Pacific mountain system are found all of the 11 orders of soils, of which three are most abundant. Inceptisols dominate in the coastal ranges from the Queen Charlotte Islands south to San Francisco Bay and in the Cascade Range. They have weakly differentiated horizons (layers), are little altered from their parent material, and occur where summers are cool. The California Coast Ranges south of San Francisco and the Transverse Ranges have dark-coloured mollisols rich in organic material. Much of the Klamath Mountains area is characterized by ultisols, leached reddish soils that develop where winters are mild and moist and summers are warm and dry.

Climate. The orientation of the Pacific mountains has a profound effect on the climate of the western United States and Canada. Regionally, they act as a barrier to storms from the Pacific Ocean, which especially in winter bring large quantities of precipitation to the western slopes of the ranges. For example, the highest annual precipitation levels in the 48 coterminous states (more than 150 inches [3,800 millimetres]) occur on the southwestern slope of the Olympic Mountains, while the greatest annual precipitation total in Canada (more than 200 inches) occurs along the British Columbia coast north of Vancouver Island. Inland precipitation decreases on the east side of the coastal ranges and increases again on the western slopes of the Cascades, in some places exceeding 100 inches; much of this is in the form of snow. Immediately east of the Cascades the annual precipitation decreases drastically to only 8 inches at Yakima, Wash. In California more than 50 inches falls on the windward side of the Coast Ranges, decreasing to 30 inches in the higher parts of the Transverse Ranges.

Plant life. Climate is the major influence on vegetation type. Conifers predominate and can grow to enormous size, especially on the moister, western slopes. The Sitka spruce is dominant along the coast from southern British Columbia to northern California. The largest standing mid-latitude rain forest in the United States is on the west side of the Olympic Mountains. Inland and up into the Cascades, Douglas fir and western hemlock dominate. They give way at high elevations to trees such as Pacific silver fir and mountain hemlock. On the eastern slopes of the Cascades, ponderosa pine is the major tree.

Along the coast from southern Oregon to the Monterey Peninsula of California, the redwood is dominant, occurring with Sitka spruce, Douglas fir, and hardwoods such as alder. Farther from the coast, the Coast Ranges are characterized by mixed forests of bigleaf maple, madrone, various oaks, and pines and other conifers. On the eastern slopes is an oak-grassland association. In the drier Transverse Ranges is found the bigcone Douglas fir, as well as pines and oaks.

Animal life. The anadromous (river-spawning) salmon is the most distinctive creature of the coastal ranges. Five species—pink, chum, coho, sockeye, and chinook—are found in the streams draining the mountains, each with its own distinctive range and environmental conditions. The pink and chum spawn in coastal streams near the ocean, while the sockeye usually spawns in upstream lakes. The chinook (or king) favours large rivers such as the Columbia and Sacramento and travels hundreds of miles inland. The coho also favours larger rivers. The American shad, another anadromous fish and originally native to the Atlantic coast, was introduced in the late 19th century and has adapted to streams of the Pacific coast.

Mammals

The larger land mammals include Roosevelt elk in the coastal ranges from British Columbia to northern California and black bears in the coastal ranges and Cascades. Three species of deer are found: mule deer on the eastern slopes of the Cascades, black-tailed deer in the coastal and Cascade ranges, and, locally in the Coast Ranges of Oregon, white-tailed deer. Three members of the cat family—lynx, bobcat, and mountain lion—are found throughout the Pacific mountain system. The beaver, a mainstay of the 18th- and 19th-century fur trade, is found as far south as northern California.

The people. The Pacific mountain region had a large American Indian population before the arrival of white explorers and settlers. Hunting, the gathering of berries, roots, and nuts, and fishing were the major economic activities. Trade and barter were common among tribes, especially in the north, where peoples from the interior traded hides, meat, and roots for salmon caught by the coastal peoples.

The Spanish were the first Europeans in the region. They moved northward, establishing missions throughout California to just north of San Francisco Bay. The first whites in the northern areas were fur trappers and traders. These early contacts had profound effects on the lives of the native peoples. Many of the California Indians were put on missions, where they became farmers and pastoralists. The fur trade introduced a number of useful manufactured goods, notably firearms and blankets. Contact with whites, however, introduced such European diseases as smallpox, scarlet fever, and measles, for which the Indians had little immunity: much of the Indian population was wiped out in a short period of time.

From the 1830s an increasing flood of whites poured into the region, many of them farmers who settled in the Fraser River valley, Puget Sound Lowland, and Willamette Valley. By the end of the 19th century, the region's modern settlement pattern had been established, with most of the Indians on reservations and the economy dominated by the logging and lumber industry.

The economy. *Resource exploitation.* The abundant precipitation and deep, weathered soils of the coastal ranges from the Queen Charlotte Islands through the Klamath Mountains and into northern California produce the largest softwood lumber trees in the world. The completion of railroads into the region in the 1880s, giving it access to other parts of the country, made possible the large-scale commercial exploitation of these forests. The opening of the Panama Canal in 1914 stimulated the movement of lumber by ship. Wholesale cutting of these lands ensued. The coastal ranges, most of which were privately owned, were virtually cleared of their old-growth (virgin) forests. The Canadian Coast Mountains and the Cascade Range were the last areas to be logged, because their greater inaccessibility made it more difficult to cut and transport the timber.

Mining and the extraction of oil and natural gas are of some economic importance. Sand and gravel are now the major minerals mined.

Although the Columbia River basin is the main focus of hydroelectric development in the region, the abundant precipitation, large drop in elevation, and deep, wide glacial valleys for water storage also have made possible hydroelectric development in the Canadian Coast Mountains and North Cascades. Two notable schemes are the harnessing of the Skagit River northeast of Seattle, Wash., and the generating station at Kemano, on the coast of British Columbia, that supplies power for an aluminum smelter at nearby Kitimat.

Hydroelectric schemes

Agriculture and fishing. Agriculture is important in some of the valleys within the ranges. From southern British Columbia to northern California, dairying and egg production are leading activities. Some of California's most important vineyards are in the Coast Ranges near San Francisco, notably the Napa and Sonoma valleys to the north. The Salinas Valley south of San Francisco and the Central Valley to the east are two of the leading vegetable-producing areas in the United States.

Fishing once was a major activity along the entire Pacific coast. Salmon fishing was dominant from British Columbia to northern California, while tuna and sardines were important in southern California. Overfishing, pollution, and (for the anadromous salmon) the destruction of the natural spawning habitat have seriously depleted fish stocks and reduced the importance of commercial fishing. Salmon farming has become significant, however, especially in British Columbia.

Recreation. The Pacific mountain system is one of North America's great playgrounds. Large numbers of tourists and outdoors enthusiasts are attracted to the region's magnificent scenery and its varied, year-round recreational opportunities. More than a dozen national parks, monuments, and recreation areas are scattered throughout the ranges, as well as dozens of provincial, state, and county parks. Some of North America's best Nordic and Alpine skiing facilities are found in the region, often in close proximity to large urban areas.

Environmental concerns. The almost rainless summers in all but the most northerly part of the region make fire a constant threat. Although some fires are started by natural causes (mainly lightning), many are caused by human carelessness, as, for example, with the great Tillamook Burn in Oregon in 1933.

The logging practice of clear-cutting left millions of acres of denuded mountainsides. Exposed hillsides were subject to heavy erosion, and one result was the deposition of sediment on the gravel spawning beds used by salmon. The removal of forest cover also eliminated habitat for many species, although as ground cover was reestablished it provided grazing for such large mammals as deer and elk. Reforestation often was successful on more accessible, privately owned lands in the coastal ranges, but such efforts frequently met with difficulty in areas (often public lands) with poorer soils and steeper, more rugged terrain.

Beginning in the late 19th century, concerns about timber depletion led to the creation of government-protected lands. These formed the core of the present-day system of crown lands in Canada and national forests in the United States and the government supervision of logging. A growing environmental movement was instrumental in the enactment of increasingly stringent logging regulations; those that restricted habitat destruction, such as the old-growth forests inhabited by the northern spotted owl, sparked a bitter dispute between environmentalists and logging interests.

Logging regulations

Study and exploration. Juan Rodríguez Cabrillo, a Portuguese explorer in the service of Spain, probably was the first European to explore the coast of California. He is thought to have sailed north in 1542, and his pilot, Bartolomé Ferrelo, may have reached as far as the present southern border of Oregon. Sir Francis Drake sailed the coast in 1579 and may have landed in Oregon. Juan Pérez landed on the west coast of Vancouver Island in 1774, and the following year Bruno Hezeta reached the Washington coast and claimed the area for Spain. Captain James Cook charted the coast from Oregon to the Arctic in 1778.

The first overland explorer was Alexander Mackenzie, who in 1793 traveled westward until he reached the British Columbia coast. In 1805 the Lewis and Clark Expedition reached the Pacific Ocean after following the Columbia River. The last of the great overland treks was by the Canadian explorer Simon Fraser, who followed the river later named for him and reached its mouth (near present-day Vancouver, B.C.) in 1808.

The first geologic studies of the ranges were carried out in the late 19th century. The great San Francisco earthquake of 1906 precipitated a thorough investigation of the California Coast Ranges. Present-day scientific research focuses on restoring wild stocks of salmon, finding evidence of the periodicity and magnitude of subduction-caused earthquakes, and improving methods of forest management.

(J.G.A.)

ROCKY MOUNTAINS

The Rocky Mountains form the backbone of the great upland system that dominates the western North American continent. Generally, the ranges included in the Rockies stretch from northern Alberta and British Columbia southward to New Mexico, a distance of some 3,000 miles (4,800 kilometres). In places the system is 300 or more miles wide. Limits are mostly arbitrary, especially in the far northwest, where mountain systems such as the Brooks Range of Alaska are sometimes included. The Rockies are bordered on the east by the Great Plains and on the west by the Interior Plateau and Coast Mountains of Canada and the Columbia Plateau and Basin and Range Province of the United States.

The Rocky Mountains include at least 100 separate ranges, which are generally divided into four broad groupings: the Canadian Rockies and Northern Rockies of Montana and northeastern Idaho; the Middle Rockies of Wyoming, Utah, and southeastern Idaho; the Southern Rockies, mainly in Colorado and New Mexico; and the Colorado Plateau in the Four Corners region of Utah, Colorado, New Mexico, and Arizona. These four subdivisions differ from each other in terms of geology (origin, ages, and types of rocks) and physiography (landforms, drainage, and soils), yet they share the physical attributes

Four broad groupings

of high elevations (many peaks exceeding 13,000 feet [4,000 metres]), great local relief (typically 5,000 to 7,000 feet in vertical difference between the base and summit of ranges), shallow soils, considerable mineral wealth, spectacular scenery from past glaciation and volcanic activity, and common trends in climate, biogeography, culture, economy, and exploration.

For map coverage of the Rocky Mountains, see above *North American Desert.*

Physical features. *Physiography.* The Canadian Rockies include the Mackenzie and Selwyn mountains of the Yukon and Northwest Territories (sometimes called the Arctic Rockies) and the ranges of western Alberta and eastern British Columbia. The Northern Rockies include the Lewis and Bitterroot ranges of western Montana and northeastern Idaho. These ranges formed along the eastern edge of a region of accumulated carbonate sediment some 17 miles thick. This structural depression, known as the Rocky Mountain Geosyncline, eventually extended from Alaska to the Gulf of Mexico and became a continuous seaway during the Cretaceous Period (144 to 66.4 million years ago). The ranges of the Canadian and Northern Rockies were created when thick sheets of limestones were thrust eastward over younger rocks during the mountain-building episode called the Laramide Orogeny (65 to 35 million years ago). Some of these thrust sheets have moved 20 to 30 miles to their present positions. The western margin of the Canadian Rockies and Northern Rockies is marked by the Rocky Mountain Trench, a graben (straight, flat-bottomed valley) up to 3,000 feet deep and several miles wide that has been glaciated and partially filled with deposits from glacial meltwaters.

The Columbia Icefield is situated on the continental divide in the Canadian Rockies at elevations of 10,000 to 13,000 feet above sea level. It includes the large Athabasca Glacier, which is nearly five miles long and about a mile wide. Glaciers in this ice field, while continuing to move, are thinning and retreating. The Canadian Rockies are about equally divided between drainage to the east (Atlantic and Arctic oceans) and west (Pacific Ocean).

The Middle Rockies

The Middle Rockies include the Bighorn and Wind River ranges in Wyoming, the Wasatch Range of southeastern Idaho and northern Utah, and the Uinta Mountains of northeastern Utah; the Absaroka Range, extending from northwestern Wyoming into Montana, serves as a link between the Northern and Middle Rockies. While the massive deposition of carbonates was occurring in the Canadian and Northern Rockies from the late Precambrian to the early Mesozoic, a considerably smaller quantity of clastic sediments was accumulating in the Middle Rockies. Mountain building there resulted from compressional folding and high-angle faulting, except for the low-angle thrust-faulting in southwestern Wyoming and southeastern Idaho. The granitic core of the anticlinal mountains often has been upfaulted, and many ranges are flanked by Paleozoic sedimentary rocks (*e.g.,* shales, siltstones, and sandstones) that have been eroded into hogback ridges. Most mountain building in the Middle Rockies occurred during the Laramide Orogeny, but the mountains of the spectacular Teton Range attained their height less than 10 million years ago by moving more than 20,000 vertical feet relative to the floor of Jackson Hole along an east-dipping fault.

The Bighorn, Wind River, and Uinta ranges all form sharp ridge lines that rise above surrounding basins. The Wind River Range supports a large area of glaciers, including the Dinwoody Glacier. These glaciers, however, are retreating fairly rapidly.

Geologic events in the Middle Rockies strongly influenced the direction of stream courses. A special feature of late Cenozoic time (*i.e.,* the past 10 million years) was the creation of rivers that flowed from basin floors into canyons across adjacent mountains and onto the adjacent plains. This phenomenon resulted from superposition of the streams. The stream courses were initially established in the Late Miocene Epoch (11.2 to 5.3 million years ago), when the basins were largely filled by Tertiary deposits (*i.e.,* those between 1.6 and 66.4 million years old) that locally extended across lower segments of mountain axes. During the subsequent regional excavation of the basin fills—which began about five million years ago—the streams maintained their courses across the mountains and cut transverse canyons.

The Yellowstone-Absaroka region of northwestern Wyoming is a distinctive subdivision of the Middle Rockies. A large magma chamber beneath the area has filled several times and caused the surface to bulge, only to then empty in a series of volcanic eruptions of basaltic and rhyolitic lava and ash. Three such cycles have occurred in the past two million years, the most recent of which occurred about 600,000 years ago. The magma chamber is currently filling again, and the land surface in Yellowstone is rising or tilting a slight amount each year.

The Southern Rockies

The Southern Rockies include the Front Range and the Wet and Sangre de Cristo mountains along the eastern slope and the Park, Gore, and Sawatch ranges and the San Juan Mountains along the western slope. The eastern and western ranges are separated by a series of high basins: from north to south they are North Park, the Arkansas River valley, and the San Luis Valley. The Southern Rock-



Forested slopes of the Beartooth Mountains, Mont., in the northern Rocky Mountains.

ies extend northward into southern Wyoming in three prongs: the Laramie and Medicine Bow mountains and the Sierra Madre.

Only about 5,000 feet of sediment accumulated during middle Mesozoic times (about 200 to 150 million years ago) in the region now occupied by the Southern Rockies. Mountain building in these ranges resulted from compressional folding and high-angle faulting during the Laramide Orogeny, as the Mesozoic sedimentary rocks were arched upward over a massive batholith of crystalline rock. Some 10,000 vertical feet of the sedimentary rocks were then eroded; otherwise the Front Range would be approximately twice its present height.

The ranges of the Southern Rockies are higher than those of the Middle or Northern Rockies, with many peaks exceeding elevations of 14,000 feet. Colorado has 53 peaks over this elevation, the highest being Mount Elbert in the Sawatch Range, which at 14,433 feet (4,399 metres) is the highest point in the Rockies. These ranges were heavily eroded by several episodes of glaciation—the most recent ended about 7,500 years ago, and no active glaciers remain—resulting in spectacular alpine scenery. River valleys have been deepened in the past two million years, first from the direct action of glacier ice and subsequently by glacial meltwaters. Moraines occur in most valleys, marking the downslope extent of past glaciations.

The physiographic province called the Colorado Plateau in southeastern Utah, southwestern Colorado, northern Arizona, and northwestern New Mexico is another high-elevation region of the western United States, although it lacks the history of folding, faulting, and volcanic activity of adjacent regions. The uplifts in the Colorado Plateau are not as great as those elsewhere in the Rockies, and therefore less erosion has occurred; Precambrian rocks have been exposed only in the deepest canyons.

The plateau is actually a series of plateaus at different elevations arranged in a stairstep sequence through faulting. The horizontal sedimentary rocks have been dissected by the Green and Colorado rivers and their tributaries into a network of deep canyons. Some of these canyons are deeply entrenched meanders, such as the dramatic Goosenecks section of the San Juan River near Mexican Hat, Utah, where erosion through the canyon walls separating opposite sides of a meandering river loop has created a natural bridge.

The Grand Canyon

The Grand Canyon of the Colorado River cuts across the southern end of the Kaibab Upwarp in the southern plateau region. The canyon is up to 6,600 feet deep and exposes a remarkable sequence of sedimentary rocks. Weak rock types, such as shale and softer sandstone layers, form low-sloping benches, while more resistant rock types, such as limestone and harder sandstone layers, comprise cliff-forming units. Because of the alternating sequence of weak and resistant rocks in the canyon walls, a cliff-and-bench topography has formed that is typical of much of the Colorado Plateau region. The headward erosion of streams into the plateau surface eventually isolates sections of the plateau into mesas, buttes, monuments, and spires. Bedrock that has been fractured into series of parallel joints can weather into high rock walls known as fins. Subsequent weathering leads to the creation of natural arches. The same weathering processes on cliffs can create niches, which have been exploited by cliff-dwelling Indian cultures in the past.

Four mountain groups—the La Sal, Henry, Abajo, and Carrizo—are notable. From a central pipelike intrusion reaching deep into the Earth's crust, magma has been injected between layers of sedimentary rock, causing the overlying beds to bulge up in domes about one mile across. These domes are called laccoliths, and each of these mountain massifs is made up of a group of laccoliths.

Soils. Mountain soils in the Rockies are poorly developed, being extremely thin and young and too deficient in nutrients for most types of agriculture. High-valley soils are sometimes suitable for irrigation, depending on texture, steepness of slopes, length of snow cover, and the presence of trace elements (*e.g.*, selenium) that limit suitability for crop cultivation. Rangeland grazing is a more common pursuit. Soils of the Colorado Plateau also are generally shallow and stony, and they contain a high percentage of salts. In some locales, they can be made fertile if sufficient water is available to flush excess salts.

Climate. Along the great north-south extent of the mountains, the climate of the Rockies extends from the northern fringe of the subtropical zone in the far south to the Arctic in the far north. In the south, however, the continentality and high elevation of the mountains tend to reduce the advantages of latitude. Two vertical zones prevail throughout much of the range. The lower is characterized as cool temperate, with cold winters and relatively cool summers. This zone occurs between elevations of 7,000 and 10,000 feet in the south, with upper and lower limits decreasing proportionally with increasing latitude. The higher zone is alpine and tundralike in character, with severe winter conditions and short, cold summers; in the south the highest peaks may remain snow-covered until August, while in the north many of the high valleys sustain permanent glaciers.

Precipitation

Precipitation generally increases from south to north, with the north receiving about three times that of the south. In the south the climate tends to be dry. The San Luis Valley in Colorado, for example, has a mountain-desert climate and is one of the driest areas of the Rockies. Much of the total annual precipitation in the south falls as snow in winter, although characteristic of the summer are local, sometimes violent, afternoon thunderstorms. The Northern Rockies tend to receive precipitation more evenly throughout the year from Pacific cyclonic storms. Almost everywhere in the Rockies the growing season is short; some places are susceptible to frosts even in summer.

Plant life. The plant communities of the Rockies vary markedly according to elevation, latitude, and exposure. On the eastern slopes in Colorado and New Mexico, strong winter winds off the arid plains stunt and deform the scattered cedars and piñon pines. The lower elevations at this end of the system are predominantly treeless, except along watercourses, where cottonwoods and other broad-leaved, deciduous species cluster. Sagebrush occurs in valleys and basins as far north as southern Alberta.

Trees of the middle-elevation montane forest include aspen, yellow pine, and Douglas fir. The subalpine forests comprise western hemlock, lodgepole pine, western red cedar, white spruce, and Engelmann spruce. The tree-line elevation descends as latitude increases, and alpine tundra, characterized by low flowering plants, spans nearly the full length of the range. So-called elfin woodland, consisting primarily of dwarfed willows, occurs in the most northerly mountains. The myriad wildflowers of the forests and high meadows include columbine, bunchberry, larkspur, gentian, and Indian paintbrush.

Animal life. The fauna of the Rockies is varied and abundant. Among the large mammals emblematic of the rugged backcountry are the black bear, grizzly bear, mountain lion, and wolverine. Bighorn sheep and mountain goats inhabit the high crags in summer and migrate to the lower slopes for the winter months. Members of the deer family, such as the caribou, elk (wapiti), mule deer, and white-tailed deer, also migrate vertically between alpine meadows and subalpine forest cover; the solitary moose frequents northern lakes, streams, and marshy areas, feeding on willow foliage and aquatic plants. Yellowstone National Park in Wyoming is home to one of the largest herds of bison in North America. Wild horses and burros inhabit the surrounding plains, while coyotes roam the lower valleys and along roads and rail routes. Wolves, brought to near extinction by human predation, remain rare but have resurged since 1970 as their importance in the wilderness ecosystem has come to be appreciated. Smaller mammals of the lower elevations include the least chipmunk, red squirrel, Columbian ground squirrel, black-footed ferret, and marmot. The pika dwells on talus slopes, and the prairie dog inhabits the drier valleys and plateaus. Wildlife of the arid southern mountains comprises the pronghorn, jackrabbit, peccary, rattlesnake, and other desert species. Beavers and river otters can be found in watercourses throughout the region. Amphibians include several species of frogs, toads, and salamanders that are indigenous to the region.

Birds

Birdlife is comparably diverse. In summer such raptors as the bald eagle, golden eagle, osprey, peregrine falcon, and turkey vulture nest throughout the range. Several owl species are found, including the great horned owl. Woodland and meadow birds include species of grouse (ruffed, sage, spruce, and blue), ptarmigan, wild turkey, ring-necked pheasant, Clark's nutcracker, gray jay, and Steller's jay. Among wading birds are species of egret, crane, great blue heron, curlew, and avocet. An abundance of waterfowl—such as teal, snipe, numerous duck species, and the endangered trumpeter swan—spend the warm season on mountain lakes. Canada geese and white pelicans also spend a portion of the year in the region. The numerous hot springs of the Rockies provide a winter haven for many birds that would otherwise migrate southward.

The rainbow trout, while perhaps the most celebrated fish of the region, is largely introduced from California. The arctic grayling is a prominent denizen of high northern lakes.

The people. The human presence in the Rocky Mountains has been dated to between 10,000 and 8,000 BC. American Indian peoples inhabiting the northern mountains in modern times include the Shuswap and Kutenai of British Columbia, the Coeur d'Alene and Nez Percé of Idaho, and the Flathead of Montana. The traditional lands of the Shoshoni in Idaho and Wyoming and the Ute in Utah and Colorado extended into the west-central ranges. Southwestern groups include the Navajo, Hopi, and Pueblo. Nomadic Plains Indians who once ranged into the eastern Rockies included the Blackfoot, the Crow, and the Cheyenne.

Incursions by Europeans began in the Southwest in the 16th century. By the early 19th century, exploration and economic exploitation brought them into contact, and often conflict, with virtually all the indigenous mountain peoples. These encounters, along with shifting food supplies and intertribal territorial wars, generated extensive migration and attrition among some groups. Many Indians now live on the reservations established throughout the region. Although settlement is now widespread throughout most of the Rockies, population is concentrated in urban areas generally located at the base of mountains, along railways, or in river valleys.

The economy. *Water resources.* The Rocky Mountains in Canada and the United States are a region of water surplus, where precipitation exceeds losses from evaporation, runoff, and transpiration. The lands on either side of the mountain front, however, experience a water deficit. The people living in these areas have looked to water-storage projects in the Rockies for irrigation, domestic and industrial use, navigation, and hydroelectric power generation, as well as for flood control. Most of the potential sites for large dams already have been utilized, and smaller dams in the headwater regions are now being constructed.

The Colorado project

One of the most ambitious of these projects is in the Colorado Rockies, where a complex network of reservoirs, tunnels, and pipelines diverts water from the western slope of the Front Range to the large urban area centred on Denver along the eastern slope. This scheme, opposed by residents of the range's western slope, is the first in a series of projects extending downstream in the Colorado River system that may eventually utilize the entire flow of the river.

Mineral resources. Minerals have been of economic significance since the mid-19th century, although worldwide market fluctuations often have caused mine closures. Copper, easily the most valuable of the many metallic resources of the Rocky Mountains, has been extracted from large mines in British Columbia, Montana, Utah, and Arizona. The Rockies are more noted for their many underground mines for silver, gold, lead, and zinc, found in British Columbia, Colorado, Montana, Idaho, Utah, New Mexico, and Arizona. The Rockies also have produced large quantities of molybdenum, beryllium, and uranium.

Sapphires are mined in Montana, while great reserves of other nonmetallic minerals occur in various places in the mountains. These include phosphate rock, potash, trona, magnesium and lithium salts, Glauber's salt, gypsum, limestone, and dolomite. The large basins between the uplifts of the ranges contain many petroleum and natural gas fields. Alberta, Wyoming, New Mexico, Montana, Colorado, and Utah are all substantial producers, with the Powder River basin of Wyoming proving to be one of the leading regions.

The Rockies also hold extensive shale deposits containing a solid hydrocarbon material that can be driven off as crude oil by heat treatment. These oil shales occur principally around the Uinta Mountains in Wyoming, Colorado, and Utah. Immobile oil also is located in certain sandstones in various places. These deposits are called bituminous, oil, or tar sands. In both cases, the amounts of potential oil are vast, although the costs involved in extracting the oil have not made exploitation profitable.

The Rocky Mountains and the adjacent Great Plains to the east contain the Western Hemisphere's most abundant and accessible coal reserves. These consist largely of bituminous, subbituminous, and lignitic deposits and constitute a tremendous energy source. Most of this coal is mined using surface strip-mining techniques.

National parks, forests, and recreational areas. Many of North America's finest national parks, national monuments, and wilderness areas are in the ranges of the Rocky Mountains and in the Colorado Plateau. To these areas of natural beauty have been added such large recreation facilities as the Glen Canyon National Recreation Area, located on either side of Lake Powell in Utah and Arizona, and Flaming Gorge National Recreation Area, in Wyoming and Utah. The area in and around Yellowstone National Park represents one of the largest relatively intact temperate-zone ecosystems on the planet. More than 10,000 hot springs, along with the large populations of elk, bison, and moose and high-quality trout fisheries, draw large numbers of tourists.

Park accessibility

The construction of roads over high mountain passes have made recreational areas more accessible, especially Jasper and Banff national parks in Alberta and Glacier, Yellowstone, Grand Teton, and Rocky Mountain national parks in the United States. An increasing number of the high mountain roads, while closed to automobiles during winter, are used by snowmobile enthusiasts. High-speed highways facilitate long-range trips to the Rocky Mountain region from other sections of North America. Although transcontinental Canadian rail travel has been discontinued, Banff and Jasper national parks can still be reached by rail from the larger cities in Alberta and British Columbia. Small commuter airlines also have increased access to the parks.

Most of the land in the Rockies has been designated as national or provincial forests. In the United States the principle of multiple use governs management of these forests, with lumbering, mining, oil and gas drilling, and grazing permitted under federal regulation. The Canadian Rockies produce a large portion of that nation's timber, supporting numerous sawmills and pulp and paper mills. In the United States, by contrast, timber production from the Rockies is small compared with other forested regions, and recreation is the principal source of revenue in the national forests.

Environmental concerns. Serious problems have arisen as a result of timber harvesting, grazing, oil exploration, mining, and reservoir operations in the Rockies. Logging and oil exploration have been responsible for accelerated slope erosion, both from the operations themselves and from the access roads built to reach them. Erosion has stripped away the often thin soil cover and caused serious silting of streams. Trace quantities of harmful metals have been released into streams and groundwater from mining operations, particularly from the leaching of mill tailings. Reservoir operations have disrupted fisheries by altering the temperature and flow patterns of streams and by disrupting riparian (streamside) vegetation communities. Wildlife habitat has been lost through the development of lands for agriculture and livestock grazing.

Study and exploration. The Rocky Mountains were one of the last regions in North America to be explored by Europeans, because of the inaccessibility and ruggedness of the terrain. Roman Catholic missionaries worked their way northward from Mexico into New Mexico in the 17th and

18th centuries. In 1776–77 Silvestre Vélez de Escalante and his party explored and documented their travels into what is now Utah, reaching almost to the Great Salt Lake. The Scottish explorer Alexander Mackenzie, searching for a river course to the Pacific Ocean from the Canadian prairie, crossed the Rockies (1792–93) at a latitude higher than any other expedition until the early 19th century. The Lewis and Clark Expedition in 1804–06 explored and charted a route up the Missouri River into Montana and thence across Idaho and Oregon to the Pacific. The English explorer and fur trader David Thompson explored the headwaters of the Saskatchewan and Columbia rivers in the Canadian Rockies in 1807–11, setting up the first trading posts in that region and producing the first survey of the entire length of the Columbia River.

Possibly the most remarkable of all western explorations were those of Jedediah Smith in 1822–31. Following the Missouri River into east-central Montana, Smith first worked his way southward into the Bighorn Basin and thence into southeastern Idaho, northern and southwestern Utah, and southern Nevada, around the Sierra Nevada, and back to the Great Salt Lake across the Great Basin. Also important were the expeditions of John C. Frémont in the 1840s. Frémont followed the North Platte River into Wyoming, went up the Sweetwater River to the south end of the Wind River Range (South Pass), and thence traveled southwestward into Utah. This was an important scientific survey because he charted distances, determined latitudes, longitudes, and elevations, and recorded objectively in some detail what he saw.

The four western surveys

Four great western surveys were organized by the U.S. government following the American Civil War: the survey of the 40th parallel led by Clarence King (1867–78), the geologic survey of Nebraska and Wyoming led by Ferdinand Hayden (1867–78), the 100th-meridian survey led by George Wheeler (1872–79), and the expeditions to the Green and Colorado rivers in Wyoming, Utah, Arizona, and southern Nevada led by John Wesley Powell (1871–79). The maps and preliminary observations of these important surveys laid the groundwork for the great mass of scientific research that followed. The Rocky Mountains, with their abundant deposits of fossil fuels, uranium, and other minerals, continue to attract the attention of geologists. (A.J.E./R.A.Ma.)

SIERRA MADRE

The Sierra Madre is the principal mountain system of Mexico and includes the three ranges of the Sierra Madre Occidental (to the west), the Sierra Madre Oriental (to the east), and the Sierra Madre del Sur (to the south). These ranges enclose the great central Mexican Plateau, which itself is a part of the system—although the northern portion of the plateau also is considered to be part of the Basin and Range Province of the United States—and is broken by blocks of mountain ranges and large populated ephemeral drainage basins (*bolsones*). The greater part of Mexico comprises this comprehensive Sierra Madre.

Physical features. *Geology.* The Mexican Plateau is composed largely of folded strata of the Mesozoic Era (*i.e.,* between 245 and 66.4 million years old). Formations predominate from the second half of the Mesozoic among exposed rocks, but older sediments are widespread. The region's elevation, folding, and faulting were contemporaneous with the uplift of the Rocky Mountains. Early in the Tertiary Period (which began 66.4 million years ago and ended 1.6 million years ago), great outpourings of lava terminated a long interval of weathering and erosion. Subsequently, the large plateau block was uplifted, the displacement being greater to the south than to the north. Its margins have been dissected into the deeply gouged angular landscape of the Sierra Madre Occidental and the more rounded but rugged terrain of the Sierra Madre Oriental.

Although the western fringe of the plateau, the Sierra Madre Occidental, was long assumed to be a structurally simple feature consisting of nearly horizontal lavas manteling Mesozoic sediments and old crystalline rocks, a complex structural history has become apparent. The underlying strata were deformed by folding and faulting during several periods, and there are many intrusions of varying size. Strata mostly from the latter part of the Paleozoic Era (540 to 245 million years ago) overlie materials from the early part of the era in the Sierra Madre Occidental and to the west. Large amounts of lava and ash were deposited on earlier surfaces in the Tertiary Period.

The Sierra Madre Oriental, composed largely of folded sedimentary rocks of Cretaceous age (66.4 to 144 million years old), owes its present relief to uplift, faulting, and erosion since the mid-Tertiary. Igneous intrusion forms are numerous.

Volcanism

Marking the southern edge of the Mexican Plateau and spanning Mexico from coast to coast is a zone where volcanism developed during two episodes. The first episode occurred during the early and middle parts of the Tertiary, when immense quantities of lava were poured over the land. The second volcanic episode, which began in the Pliocene Epoch (5.3 to 1.6 million years ago) and has continued to the present, is associated with the development of such spectacular peaks as Citlaltépetl, or Orizaba (18,406 feet [5,610 metres]), Popocatépetl (17,930 feet), Iztaccíhuatl (17,159 feet), Toluca, or Zinantecatl (15,354 feet), and the Nevado de Colima (13,911 feet). In 1759 and 1943, respectively, the smaller volcanoes of El Jorullo and Paricutín burst into existence. Additional peaks, cinder cones, and other evidence of volcanism occur throughout the region.

To the west of the Isthmus of Tehuantepec in southern Mexico the great scarp of the Southern Highlands rises several thousand feet. This deeply dissected mountain mass reveals east-to-west folds in its base rocks of metamorphosed Cretaceous sediments and intrusives. The narrower western section of the highlands is known as the Sierra Madre del Sur. It is breached by the Balsas River.

Physiography. The Sierra Madre Occidental extends approximately 700 miles (1,100 kilometres) from northwest to southeast and is about 100 to 300 miles in width. Summits mostly exceed altitudes of 6,000 feet, and some peaks rise above 10,000 feet. From the east the mountains present relatively slight but broken relief; from the west they appear as formidable escarpments whose benched flanks drop into deep canyons called *barrancas.* The great mountain ranges and canyons trend northwest to southeast, which is generally the trend of the folds in the Mesozoic and older basement strata. The local relief may exceed 5,000 feet, and the majestic dimensions of some of these *barrancas*—notably Barranca del Cobre ("Copper Canyon")—compare with the Grand Canyon of the United States.

Extending southeastward from the Big Bend of the Rio Grande (called Río Bravo del Norte in Mexico) is a series of low mountains that are composed of folded sedimentary strata. South of Monterrey these mountains become a striking range, the Sierra Madre Oriental. Summit elevations are about 7,000 feet, but some peaks rise above 10,000 feet (Cerro Peña Nevada). Steep-walled, narrow valleys, a number of which are north to south in alignment, lie in the sierra; and there are several gateways from the Gulf of Mexico lowlands to the plateau.

The core of Sierra Madre del Sur is outlined by a narrow and discontinuous coastal plain to the southwest and by the structural depression of the Balsas River on the north. To the east of this depression is the Sierra Mixteca, which forms a highland bridge between the volcanic axis and the Southern Highlands. A labyrinth of narrow ridges and steep-flanked valleys forms the Southern Highlands. Much of this broken country crests at elevations of about 6,500 feet, and only a few peaks exceed 10,000 feet. Whereas the Mexican Plateau's volcanic mantle is relatively free of dissection, the Southern Highlands have been stripped of much of their volcanic cover. The older basement rocks are exposed in what are probably the most highly dissected landscapes of Mexico. There is very little flatland in the region. Abruptly terminating the region on the east is a magnificent scarp that overlooks the downfaulted block of the Isthmus of Tehuantepec.

Elevation as a factor of climate

Climate. Elevation is more important in determining the thermal characteristics of Mexican climate than is latitude. The decrease in temperature that occurs with increasing elevation has made it possible to identify distinct



The Sierra Madre.

vertical temperature zones: *tierra caliente,* or "hot land", *tierra templada,* or "temperate land", and *tierra fria,* or "cold land". Unlike climatic areas farther from the Equator, there is little seasonal variation in temperature at any elevation in the tropics.

The *tierra templada,* which includes elevations from 3,000 to 6,000 feet, has mean temperatures of 65° to 75° F (18° to 24° C). Much of highland Mexico is in this thermal zone. It is the most pleasant of the zones for human habitation. During winter, frost may occur. In the cooler *tierra fria* the mean annual temperatures are between 55° and 65° F (13° and 18° C). Above 10,000 to 11,000 feet the mean annual temperature is less than 50° F (10° C), and above 14,000 to 15,000 feet it is less than 32° F (0° C).

Mountain masses, besides creating islands of cooler climate within the tropics, play a major role in the incidence of clouds and precipitation. The mountains form barriers over which air may be raised, cooled, and caused to condense. Within the mountains and in their lee there is a lower incidence of clouds and precipitation. Lee or descending air becomes warmer, and its capacity to retain moisture rises. Illustrating the effect of the mountains upon precipitation and cloudiness is the contrast between 80 inches (2,000 millimetres) of rain and 150 cloudy days per year for the eastern slopes of the Sierra Madre Oriental and the 40 inches of rain and 90 cloudy days per year that characterize much of the Pacific slope west of the Sierra Madre del Sur. The drier areas are in the rain shadow of the mountains.

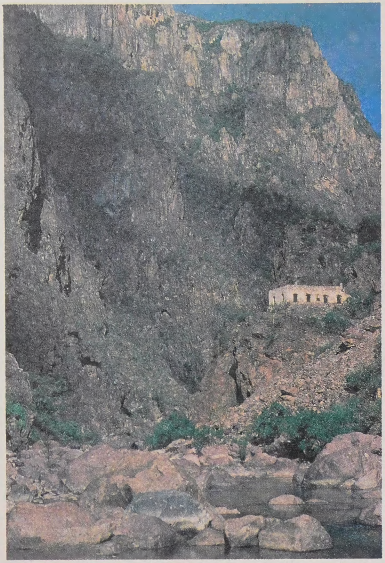
Plant and animal life. The extent of the once-ubiquitous mountain forests has been greatly curtailed by centuries of human activity, owing not only to clearing of land for farming but also to the widespread use of wood in earlier times to make charcoal for metal smelting. Simultaneously, the distribution of animal life has been restricted. In the *tierra fria,* forests of conifers are found, followed in the *tierra templada* by mixed forests of oak and pine. At still lower elevations, and especially in the rain shadows, the Sierra Madre Occidental is characterized by a diverse, scrubby assemblage of xerophytic (drought-tolerant) plants. In contrast, the lower levels of the Sierra Madre Oriental display, especially in the southern part, a broad-leaved tropical luxuriance correlated with the reliable and adequate rainfall that they receive.

Deer and coyotes are widespread in the Sierra Madre. Gray wolves are still found in remote parts of the northern Sierra Madre Occidental. The grizzly bear probably became extinct in the wild after 1960, but the population of black bears has remained fairly stable. Large cats (jaguar and puma) are becoming scarce; but cottontail rabbits abound, and collared peccaries are fairly plentiful, as are wild turkeys and smaller game birds.

The people and economy. The remoteness, relative inaccessibility, and many habitable valleys of the Sierra Madre made it a refuge for a number of Indian peoples who succeeded in retaining much of their aboriginal culture for two or three centuries after their first contact with the Spaniards. Well known are the Huichol and the Cora in the southern states of Nayarit and Jalisco and the Tarahumara in the north (Chihuahua), as well as a number of other groups, especially in the Sierra Madre del Sur. The gradual acculturation of these peoples to the Mexican mestizo way of life was unavoidable, however, and in many areas the use of traditional languages, clothing patterns, and house types has been replaced; many young adults have abandoned the ways of their ancestral societies. Technological progress has furthered this process in the second half of the 20th century. Trucks and buses and even small airplanes capable of operating with short landing strips increasingly have been used to transport goods and people, replacing the traditional horses, mules, and burros.

Acculturation of mountain peoples

The rugged topography of the Sierra Madre Occidental



Cobre Canyon in the Sierra Madre Occidental, in Chihuahua, with (centre right) an abandoned miner's house.
© Kerrick James

has been a serious barrier to east-west communications. Because of the mountains, Spanish exploration, regional commercial evolution, and the present road and railway systems developed independently on the Mexican Plateau and in the Pacific Coastal Lowlands of Sinaloa and Sonora states. No railroad crossed the mountain barrier until 1962, although construction was begun many years earlier on lines between Durango and Mazatlán and between Chihuahua and Topolobampo. The latter was finally completed. Only a few paved roads through the region link interior cities with Pacific coastal resorts and towns. The sparse settlement in this mountainous area is confined to mining centres or to farming and pastoral hamlets. Forest industries are most highly developed in the states of Chihuahua and Durango, but it may be that the long-term worth of the forest cover as watershed protection exceeds its value as timber. The Sierra Madre Occidental is the source of waters that support the oases of the plateau and of the lowlands adjoining the Gulf of California. Oases that have been formed by water from the mountains include those along the Carmen, Conchos, Nazas, and Aguanaval rivers in the plateau. The westward-flowing Yaqui, Mayo, Fuerte, Sinaloa, and Culiacán rivers water important farming districts in the coastal lowlands.

Among the substantial rivers that have watersheds that penetrate the Sierra Madre Oriental are the Moctezuma and Pánuco, the combined drainage system of which has captured a considerable area of the central plateau. The process of capture was aided by the opening of a drainage canal in 1607 (expanded in 1900) to tap the Basin of Mexico. Numerous harnessed and potential sources of hydroelectric development exist among the rivers that drain the eastern front of the mountains. Agricultural settlement is particularly dense in the state of Veracruz.

Study and exploration. The exploration and study of the Sierra Madre occurred in three main stages. The first, which lasted until the mid-16th century, consisted of Spanish reconnaissance and the subjugation of native peoples. The second, lasting until the late 19th century, was based on the mining of silver deposits—first in the south (Guanajuato, Zacatecas, and San Luis Potosí) and then progressively farther north and west (Fresnillo, Durango, Hidalgo del Parral, and Álamos). Along with the miners went Roman Catholic priests, and some Indian settlements received Jesuit missions. The more successful mining settlements later became cities and even state capitals. The third stage, that of scholarly inquiry, began with scattered Spanish studies in the 17th century. Modern scientific study of the mountains was initiated with the work of the Norwegian explorer and ethnologist Carl Lumholtz, who in 1890–98 did extensive fieldwork throughout the Sierra Madre Occidental. Lumholtz was followed by other scholars from Europe, Mexico, and the United States in such fields as archaeology, anthropology, art, history, geography, sociology, geology, botany, and zoology. The Sierra Madre and adjacent areas proved to be a source not only of mineral wealth but also of matters of scholarly and cultural import. (G.C.E./H.J.Bn.)

Work of Lumholtz

SIERRA NEVADA

The Sierra Nevada is a major mountain range of western North America, running along the eastern edge of the U.S. state of California. Its great mass lies between the large Central Valley depression to the west and the Basin and Range Province to the east. Extending more than 250 miles (400 kilometres) northward from the Mohave Desert to the Cascade Range of northern California and Oregon, the Sierra Nevada varies from about 80 miles wide at Lake Tahoe to about 50 miles wide in the south. Its magnificent skyline and spectacular landscapes make it one of the most beautiful physical features of the United States. As a recreation centre, its year-round facilities prove a magnet to the inhabitants of the huge urban areas of California, and it has considerable importance as a source of power and water. It was the focus of the celebrated California gold rush.

The Sierra Nevada range is an excellent example of how the human occupation and use of an area can modify its landscape. First mining and later logging and tourism have done more in 150 years to alter the flavour of the mountain scenery in many areas than the actions of ice and water over millennia.

For map coverage of the Sierra Nevada, see above *North American Desert*.

Physical features. *Physiography.* The Sierra Nevada is an asymmetrical range with its crest and high peaks decidedly toward the east. The peaks range from 11,000 to 14,000 feet (3,350 to 4,270 metres) above sea level, with Mount Whitney, at 14,494 feet (4,418 metres), the highest peak in the coterminous United States. Summits in the northern portion are much lower, those north of Lake Tahoe reaching altitudes of only 7,000 to 9,000 feet.

Much of the rock is granite or a near relative of granite. There are dividing bands of metamorphosed (heat- and pressure-altered) sedimentary rock—all that is left of a once extensive sedimentary basin—and some large areas of extrusive rock, especially from Lake Tahoe northward; at the northern limit of the Sierras, these rocks merge with the volcanic rocks of the Cascades.

Geology. It has long been recognized that the Sierra Nevada is a tilted block of the Earth's crust. A major fault zone bounds the block on the east, and it was along this that the great mass that became the Sierra Nevada was uplifted and tilted westward. This explains the asymmetry of the range. As the block was uplifted the abrupt, east-facing escarpment was cut into by the erosive action of wind, rain, temperature change, frost, and ice, and a series of steep-gradient canyons developed. Though the massive uplift began many millions of years ago, much of it occurred in the past two million years. The present-day relief of 10,000 to 11,000 feet along the eastern slopes in the southern Sierra Nevada attests to the tremendous uplift.

The basic tilted block

Drainage and glaciation. The more gentle west-facing slope has been dissected by a series of streams, much longer than those of the eastern slope. Such rivers as the



The Sierra Nevada from Owens Valley, Calif., with (centre) Mount Whitney, the highest point in the coterminous United States.
© Craig Aurness/West Light

Yuba, American, Mokelumne, Stanislaus, Merced, and Kern have carved deep valleys into the predominant granite and some volcanics. All but the Kern drain either into the Sacramento River in the Central Valley on the north or into the San Joaquin on the south, their waters ultimately reaching the Pacific Ocean through the combined delta of these two rivers in San Francisco Bay. The Kern River has internal drainage into the Buena Vista Lake basin, south of the San Joaquin River.

During the Pleistocene glaciations, which started about 1,600,000 years ago and ended about 10,000 years ago, the river-eroded valleys were covered several times by great expanses of ice. Glacial climates developed and dissipated at least four times, and each time excessive snows built snow and ice fields and deep glaciers. The ice carved what had been V-shaped valleys into U-shaped ones down to an elevation of about 5,000 feet on the western slopes. So much ice existed on the mountaintops that an ice cap was formed as the glaciers coalesced. This cap extended almost 200 miles from Lake Tahoe in the north to the southern high sierra near Mount Whitney.

Extending from the cap were fingerlike valley glaciers, long on the more gentle western slopes but shorter on the sharply uplifted eastern face. The erosion caused by these glaciers is spectacular. It includes huge cirques (amphitheatre-shaped basins with precipitous walls), moraines (accumulations of rock debris), and thousands of glacial lakes dotting the Alpine and subalpine landscape. Such striking and beautiful landforms are the focus of Yosemite National Park and the Lake Tahoe basin. Lake Tahoe is the largest and deepest Alpine lake in the world; it has a surface area of nearly 200 square miles and reaches a maximum depth of about 1,640 feet in its northwestern portion.

Climate. The mid-latitude location of the range and its proximity to the moderating influence of the Pacific Ocean give the Sierra Nevada an unusually mild mountain climate. Although winter temperatures below 0° F (−18° C) are common in valley locations, they are rare on mountain slopes. The northwest-southeast orientation of the range, athwart the winter-storm tracks of central North America, produces copious precipitation during the wet season (November to April) on the windward (western) slopes, but a sharp rain-shadow effect occurs on the leeward (eastern) face. Precipitation averages from 30 inches (760 millimetres) in the western foothill zone to 70–80 inches between elevations of 4,500 to 6,500 feet in the northern half of the range. The leeward slopes receive substantially less—from 20 to 40 inches. Snowfall increases with elevation and latitude, the northern peaks of the range averaging 33 to 38 feet per year. As much as 5.5 feet has fallen in a single day at Echo Summit, and about 67 feet has been measured at the 7,085-foot Donner Pass. Snowpacks of 10 to 15 feet are not uncommon above altitudes of 7,000 feet. Snowfall

The Pacific High anticyclone, which dominates the wind pattern over the Sierra Nevada, is at its strongest in summer, when it draws dry air seaward across the mountains. Droughts of several years' duration—such as those of the mid-1930s, mid-1970s, and mid-1980s to early '90s—result when this high-pressure zone fails to loosen its grip during successive winters; when this occurs, the mid-latitude jet-stream storm track is weakened, split, or pushed to the north.

Plant life. Generally speaking, there are five fairly distinct vegetation zones on the western slopes. The lower foothills support mostly deciduous trees and shrubs, as well as the evergreen interior live oak (*Quercus wislizenii*). Black oak, Ponderosa pine, and incense cedar occur in the upper foothills. The montane forest, which constitutes the primary commercial timber zone, contains Douglas fir, red fir, Jeffrey pine, and the celebrated big tree, or giant sequoia, for which Sequoia National Park was designated a public preserve. Lodgepole pine, mountain hemlock, Sierra juniper, and western white pine are among the trees of the subalpine forest. Mosses, lichens, and low-flowering Alpine plants prevail above the tree line. The arid eastern slopes support sagebrush, bitterbrush, juniper, piñon pine, and aspen. Chaparral, a shrublike assemblage of broad-leaved evergreen shrubs dominated by chamiso, scrub oak, manzanita, and ceonothus, grows in all but the Alpine zones on both sides of the range.

Animal life. The large mammals most readily identified with mountainous regions have become less plentiful in the Sierra Nevada in the 20th century, in part because of increased human presence. Black bear inhabit a larger area than the more reclusive grizzly. Mountain sheep are now found only in the southern part of the range. The mule deer and its predator the mountain lion live in the foothills. Smaller mammals of the lower- and middle-

elevation forests include the American badger, striped skunk, bobcat, golden beaver, and northern flying squirrel. The fisher and wolverine have become rare. At the upper limit of woody vegetation live the cony, rock rabbit, and marmot.

The rich birdlife of the Sierra Nevada includes the Brewer blackbird, California horned lark, and pheasant of the lower valleys; the California quail, canyon wren, and roadrunner of the chaparral and foothills; mountain chickadee, spotted owl, and band-tailed pigeon in the timber zone; and goshawk and Hammond flycatcher in the upper forests. The pine grosbeak and white-toed woodpecker are among the birds of the subalpine zone.

Some trout species are native to the streams of the Sierra Nevada, but others have been introduced; fish stocking is now common in all areas because of damming and other disturbances to the natural habitat. Salmon and steelhead reach the mountain rivers during spawning season.

The people and economy. The American Indian inhabitants of the Sierra Nevada were divided into five main groups: the Yokut, Sierra Miwok, and Maidu on the western slopes and the Mono and Washo on the eastern. The hunting-and-gathering economy of these peoples had little permanent effect on the landscape other than locally through fires set to catch game. The first Europeans in the region were Spanish explorers and missionaries, who visited Alta (Upper) California beginning in the 1700s; their impact on the Sierra Nevada also was negligible. In the early 1800s Jedediah Smith, Joseph Walker, and other, less-celebrated American hunters and fur trappers passed through the region. In the mid-19th century the pristine serenity of the Sierra Nevada was ended as prospectors came, stayed, and stamped their mark on the region.

The California gold rush

The gold nuggets found in January 1848 on the American River (near present-day Placerville, Calif.) ushered in an international gold rush that was to have tremendous significance in the historical evolution not only of California but of the entire United States as well. Within two years of the initial discovery there were perhaps 50,000 working miners in the range. Banks, retail businesses, transportation facilities, timber operations, agriculture, and industry all arose and prospered in response to the needs of a burgeoning population. This economic boom hastened California's admission to the Union and fostered the region's first urban centres, notably San Francisco and Sacramento. By 1880 the gold era had peaked, though some mining activity has continued there since that time.

The first crude mine roads were followed by the regional and transcontinental railroads built in the 1860s and '70s. The first paved highways crossed the Sierra Nevada in the 1920s. The central portion of the range, however, still lacks a year-round road or rail crossing. Rapid economic development has brought environmental compromise. The Lake Tahoe basin, for example, one of the most beautiful settings in any mountain region and thus a tourist magnet, now incurs periodic air and water pollution, traffic congestion, and sewage-disposal problems, as well as aesthetic degradation.

The need for water and power (and, since World War II, recreation) also has changed the face of the Sierra Nevada. Three-fourths of the streams that drain the long western slopes are controlled. The first large water project in the early 1900s impounded the Hetch Hetchy Reservoir in Yosemite National Park for water use in San Francisco, inundating natural features that rivaled those of nearby Yosemite Valley. A more recent and extensive scheme is the California State Water Project, which was begun in the 1960s with the construction of the Oroville Dam on the Feather River in the northern Sierra Nevada.

Study and exploration. For many readers, the naturalist John Muir's *My First Summer in the Sierra,* a diary of camping and exploration in 1869, is one of the classics of American geographic writing. Muir, the founder of the Sierra Club (1892), a conservationist group concerned with the preservation of the scenic resources of the Sierra Nevada and like areas of the United States, dedicated his book to members of the club in 1911.

Geologists have studied the Sierra Nevada systematically since the late 19th century. Especially significant studies concern the Mother Lode system, Jurassic stratigraphy and its relation to intrusive granites, glacial erosion, placer gold, multiple intrusions, isotope ages, and chronology and nature of emplacement. (A.J.E./J.W.Ja.)

Drainage systems and waterways

COLORADO RIVER

Fed by thick blankets of melting snow where it rises in the high Rocky Mountains of north-central Colorado in the western United States, the Colorado River cuts a winding, southwesterly path for 1,450 miles (2,330 kilometres) to the Gulf of California. Its drainage basin covers 246,000 square miles (637,000 square kilometres) and includes parts of seven states—Wyoming, Colorado, Utah, New Mexico, Nevada, Arizona, and California. For 17 miles the river forms the international boundary between the U.S. state of Arizona and Mexico. The river drains a vast arid and semiarid sector of the North American continent, and because of its intensive development it is often referred to as the "Lifeline of the Southwest."

For map coverage of the Colorado river, see above *North American Desert.*

Physical features. *Physiography.* For more than a thousand miles of its course, the Colorado has cut a deep gorge. Where the river system is joined by lateral streams—the Virgin, Kanab, Paria, Escalante, Dirty Devil, and Green rivers from the west, and the Little Colorado, San Juan, Dolores, and Gunnison from the east—a transverse system of narrow, winding deep canyons has been cut. Each entering river and each lateral creek has cut another canyon, and thus the upper and middle parts of the Colorado basin are traversed by a labyrinth of deep gorges. The longest of these unbroken trunk canyons through which the Colorado flows is the spectacular Grand Canyon, extending from the mouth of the Paria to the Grand Wash Stream. Canyonlands National Park encompasses another of these regions at the juncture of the Green and Colorado rivers in southeastern Utah.

The Grand Canyon

Farther downstream the lower Colorado is flanked by two great deserts, the Mojave and the Sonoran. In a subsection of the Sonoran Desert comprising the Colorado and Yuma deserts lies the Salton Trough (Salton Basin), a large structural depression extending to the northwest from the head of the Gulf of California for a distance of 150 miles. At one time the gulf extended farther to the northwest, above the point at which the Colorado now enters. As the river brought its load of silt from the mountains and hills above to the gulf, however, it gradually erected a vast natural dam, and the waters on the north were separated from those on the south. The Colorado then cut a channel into the lower gulf. The upper waters, cut off from the sea, gradually evaporated, forming a large area of desert land extending to about 235 feet below sea level.

In 1905 floodwaters caused, about three miles south of the California-Mexico border, a break in diversion controls of the Imperial Canal. As a result, all the waters of the Colorado rushed into the Salton Sink, creating the Salton Sea, about 70 feet deep, 50 miles long, and 10 to 15 miles wide, with a total water area of some 300 square miles. The break threatened to inundate the agriculturally rich Imperial Valley and to block permanently a major railroad route. Because of the imminent danger, the railroad repaired the break and in 1907 completed a line of protective levees.

Plant and animal life. The Colorado River drainage area encompasses a wide range of natural environments—from Alpine tundra and coniferous forests in its headwaters and upper elevations; through semiarid plateaus and canyons supporting piñon pine, juniper, and sagebrush; to the truly arid landscapes dotted with creosote bush and other desert plants in the lower basin and delta. The distribution of animals varies with these habitats. Large mammals such as the elk, mountain sheep, pronghorn, mule deer, mountain lion, bobcat, and coyote (and formerly the grizzly bear and gray wolf) occupy the middle and upper elevations. Beavers, muskrat, and birds, including the great bald eagle, favour stream banks lined with willow, cottonwood, and tamarisk.



The Colorado River in Marble Canyon at the northeastern end of Grand Canyon National Park, northwestern Arizona.
© Gary Ladd

Modern river development has radically disrupted native species and habitats in the Colorado basin. Accidentally introduced in the mid-19th century, the tamarisk shrub has spread rapidly along the river, consuming large amounts of water. Large predators were systematically eliminated to support the ranching economy. River otters once flourished in the lower reaches. Four native fishes (the humpback chub, bonytail chub, Colorado squawfish, and razorback sucker), purposefully eradicated in the mid-20th century, subsequently have been protected at great expense under the Endangered Species Act.

History and economy. *Early inhabitants.* Ute and Southern Paiute Indian tribes, now living in reduced numbers on reservations, hunted and gathered in the plateaus and canyonlands of the upper Colorado basin for centuries. In the lower basin, the largest prehistoric canal irrigation system in the American West was built by the Hohokam Indians on the Gila and Salt rivers. Yuman tribes practiced more extensive patterns of floodplain farming and hunting on the Colorado, which was too large and variable for canal irrigation. In the face of economic exploitation of the region by whites, and the resultant ecological changes, Indian groups have struggled to maintain vestiges of traditional lifeways with respect to the river.

Study and exploration. The modern period began with Spanish exploration and settlement from the mid-16th century, which yielded brief descriptions of the Colorado but no permanent settlements such as those along the upper Rio Grande. Prior to the Civil War, American surveyors focused on routes, passes, and territorial boundaries. With the help of Indian scouts, they acquired enough information to map the river and its main tributaries. Mormons settled the Great Basin of Utah in 1847, moved quickly into tributary valleys of the Colorado in Utah and Arizona, and acquired knowledge that contributed to later scientific surveys.

Inland-shipping entrepreneurs such as Joseph Christmas Ives assessed the navigability of the river as early as 1858. The federal government sponsored major scientific surveys in the 1870s. John Wesley Powell's exploration of Colorado River canyons (1869 and 1871–72) was the most celebrated and the first to concentrate directly on the river. Powell's account combines vivid descriptions of geologic formations, rapids, and Indian cultures. George Wheeler's survey report of 1889 estimated the velocity and discharge of the river. After 1900, investigations would focus on issues of river development: flood control, irrigation, hydropower, and water supply.

The Powell expedition

Economic development. In 1922 the Colorado River Compact was concluded by the seven states that constitute its drainage area to facilitate federal investment in dams and reclamation. The river was divided at Lees Ferry, Ariz., into the lower compact states—Arizona, Nevada, and California—and the upper compact states—Wyoming, Utah, Colorado, and New Mexico; the total annual flow of the Colorado River was estimated to be 17 million acre-feet (the volume of area that would cover one acre to a depth of one foot) at Lees Ferry, of which 15 million acre-feet were equally, yet somewhat ambiguously, divided between the lower and the upper compact states. A treaty in 1944 allocated 1.5 million acre-feet of water per year to Mexico. It was later discovered that the initial estimate of Colorado River supplies was based upon an abnormally wet period and that substantially less water was available than the amounts specified in the agreements.

The first major development of the Colorado began in 1928, when Congress passed the Boulder Canyon Project Act. The act authorized the construction of Boulder (now Hoover) Dam, a multipurpose water-storage project that was a major engineering feat of its time; since its completion in 1936, the dam and Lake Mead, which it created with its impounded waters, have become major tourist attractions. The Colorado River system thus was the first drainage basin in which the concept of the multipurpose dam was employed—*e.g.,* for power development, irrigation, recreation, flood control, and navigation.

Many additional projects have since been undertaken. In the mid-1960s Glen Canyon Dam was completed, impounding Lake Powell. The dam was a controversial project: opposition to its construction helped shift policy from building large dams toward concepts of water management, environmental protection, and policy analysis. Three other large multiple-storage projects upstream have been completed on major tributaries. These are Flaming Gorge on the Green River in Wyoming and Utah, Aspinall (Curecanti) on the Gunnison River in Colorado, and the Navajo on the San Juan River in New Mexico and Colorado.

Shortly after the completion of Hoover Dam, planning and construction began downstream on the Parker Dam. From Havasu Lake, the reservoir impounded by the dam, water is transported some 250 miles across California to supply a portion of the water needs for Los Angeles and most of the water supply for San Diego. Davis, Imperial, Laguna, and Morelos dams further regulate flow and diversion in the lower basin.

Water diversion beneath the Rockies

The facilities described above do not serve all the demands for water from the Colorado. In 1945 the Colorado–Big Thompson Project, the first federal interbasin water-diversion project in the United States, was completed. Water was diverted by tunnel beneath the Continental Divide in Rocky Mountain National Park to help irrigate cropland in northern Colorado. Another large project, the Fryingpan-Arkansas, diverts water from Fryingpan River, a Colorado tributary, under the Sawatch Range of the Colorado Rockies and into the Arkansas River to supply water for the rapidly growing municipal areas of Pueblo and Colorado Springs. On the Blue River, another tributary, the city of Denver has built Dillon Reservoir, the water of which is piped beneath the Continental Divide to the large and growing Denver conurbation. Tunnel diversions also deliver water from the Colorado to the Rio Grande, Great Basin, and North Platte drainages.

In 1963 a decision of the U.S. Supreme Court made explicit the amount of water apportioned among the lower-basin states, as well as the amounts that had been implicitly "reserved" for Indian tribes and federal public lands. This decision paved the way for funding of the Central Arizona Project (completed in the 1980s), which transferred water to the cities of Phoenix and Tucson. The project consists of a mountain tunnel through which water from the southern end of Lake Havasu is pumped up and into an aqueduct that flows southward to the two cities.

Laced with innumerable dams, both large and small, that impound the total flow of the Colorado and by increasingly severe competition for whatever small quantities of water might remain, the basin remains fraught with litigation and controversy. Water projects must now undergo thorough environmental-impact studies in accordance with federal environmental protection legislation. Controversy between the United States and Mexico over the salinity of water delivered to Mexico was addressed in an international agreement in 1972, which led to desalinization experiments in the lower basin and irrigation management and projects for the disposal of saline water in the upper basin. Tensions continue to arise among the basin states over water allocation, interstate water marketing, drought management, potential effects of global climatic change, Indian water rights, and reservoir management. These issues have been watched closely not only in the affected region but also in other areas of the world, for which the Colorado River serves as a laboratory of water-resource experimentation and innovation. (M.J.Lo./J.L.W.)

COLUMBIA RIVER

The largest river flowing into the Pacific Ocean from North America, the Columbia River is exceeded in discharge on the continent only by the Mississippi, St. Lawrence, and Mackenzie rivers. The Columbia is one of the world's greatest sources of hydroelectric power and, with its tributaries, represents a third of the potential hydropower of the United States. In addition, its mouth provides the first deepwater harbour north of San Francisco. Two-fifths of the river's course, some 500 miles (800 kilometres) of its 1,240-mile (2,000-kilometre) length, lies in Canada, between its headwaters in British Columbia and the United States border.

For map coverage of the Columbia River, see above *North American Desert*.

Physical features. *Physiography and hydrology.* The Columbia drains some 258,000 square miles (668,000 square kilometres) of which about 85 percent of this basin is in the northwestern United States. Major tributaries are the Kootenay, Snake, Pend Oreille, Spokane, Okanogan, Yakima, Cowlitz, and Willamette rivers. High flows occur in late spring and early summer, when snow melts in the mountainous watershed. Low flows occur in autumn and winter, causing water shortages at the river's hydroelectric plants.

Major tributaries

The Columbia flows from its source in Columbia Lake, at an elevation of 2,700 feet (820 metres), in British Columbia near the crest of the Rocky Mountains, to the Pacific Ocean at Astoria, Ore. For the first 190 miles, its course is northwesterly; it then flows to the south for 270 miles to the border of Canada and the United States (elevation 1,290 feet), where it enters northeastern Washington. It traverses east-central Washington in a sweeping curve known as the Big Bend, its prehistoric course having been disarranged first by lava flows and later by ice sheets. The ice sheets were instrumental in creating the Channelled Scablands, a series of coulees (steep-walled ravines) trending northeast-southwest in the northern part of the Columbia Plateau; Grand Coulee is the largest of these. Shortly below the confluence with the Snake River, its largest tributary, the Columbia turns west and continues 300 miles to the ocean as the boundary between Oregon and Washington; in this last stretch the river has carved the spectacular Columbia Gorge through the Cascades Range.

Tides flow upriver for 140 miles. Portland, Ore. (about 110 miles from the mouth), and Vancouver, Wash. (100 miles), are the upper limit of oceangoing navigation, aided by a dredged channel; through the use of a series of locks, barge traffic is made possible to Lewiston, Idaho, more than 460 miles inland from the river's mouth at the junction of the Clearwater and Snake rivers.

Climate. The basin's climate, strongly affected by orographic influences, is partly continental and partly marine. The Rocky Mountains to the east block out most of the severe winter storms of the interior of the continent, and the Cascade Range to the west shields the basin from moist Pacific Ocean air. Summers are typically hot and dry with only occasional thundershowers; winters are moderately cold and dry with occasional snow or even rain. Temperature and precipitation vary greatly with elevation, but in the central basin January average daily temperatures are between about 25° and 30° F (−4° and −1° C), and July averages are mostly between 70° and 75° F (21° and 24° C). Average annual precipitation ranges from less than 8 inches (200 millimetres) at the lowest elevations to about 15 inches near the mountain foothills and 40 inches or more in the mountains. West of the Cascades the climate is marine-influenced, with long, rainy winters and cool, dry summers.

Plant and animal life. Native vegetation at lower elevations of the interior basin is mostly of the shrub-steppe variety, dominated by sagebrush and bunchgrasses. With increasing elevation, shrub-steppe gives way to ponderosa pine and then to fir, larch, and other pines. More than half of the original shrub-steppe vegetation has been eliminated by grazing and farming. Cheatgrass has become a troublesome invader. Greasewood and alkali salt grass dominate on poorly drained saline soils, while willow and black cottonwood dominate along watercourses. West of the Cascades, forests of Douglas fir with hemlock and western red cedar prevail.

Animal life was abundant and varied prior to white settlement. Notable were the great runs of salmon and steelhead trout; populations of beaver, deer, elk, bear, and bighorn sheep; flocks of waterfowl and upland birds, including eagles, ospreys, hawks, and falcons; and numbers of western rattlesnakes. The ability of the region to sustain large populations of wildlife has been drastically reduced, especially for salmon and beaver. The bald eagle and peregrine falcon have been listed as endangered, and such a designation has been considered for several salmon runs.

Reduction of wildlife

The economy. Many controversies have marked the economic development of the Columbia River. Notable among these have been the division of responsibility between public and private agencies, the effect on the fish life (particularly salmon) and loss of traditional Indian fishing sites, proposals for a Columbia Valley Authority, the proper rate of interest to be charged on the federal government's investment in hydroelectric power development, and arrangements for sharing power-generating revenues and costs with Canada for upstream storage reservoirs in British Columbia. Nonetheless, exploiting the river's hydroelectric and irrigation potentials has been instrumental in developing the region's economy.

This multipurpose development of the Columbia's main stem began in the 1930s with construction of Grand Coulee and Bonneville dams by the federal government. Nearly all of the river's 1,290-foot fall within the United States has been converted into a series of "stair steps" by 11 dams on the main river, augmented by dams on



Wells Dam on the Columbia River in central Washington, in the irrigated fruit-growing region of the state.
© Harald Sund

tributaries and three upstream storage reservoirs in British Columbia constructed in accordance with a treaty between the United States and Canada. The four lower dams on the Columbia, plus four more on the lower Snake, provide large navigation locks; and all are equipped with fish-passage facilities, the original assumption being that these fish ladders would make possible the continued annual upstream run of the salmon.

Grand Coulee Dam, the largest and most complex of the Columbia's dams, augments the low winter flows when power demand is greatest. A powerhouse completed in the 1970s makes use of the Canadian storage capacity, and the dam has remained one of the world's largest hydroelectric power plants. Water is also pumped from Franklin D. Roosevelt Lake, the reservoir behind Grand Coulee Dam, for the Columbia Basin Irrigation Project, the largest single project of its kind in the Northwest and the first large-scale use of the Columbia River itself for irrigation. The first water delivery was made in 1952 to the designated lands, which previously had been covered by sagebrush and other desert vegetation. Some three-fifths of the project's planned area is now being irrigated. A major share of the cost of this expensive project is being paid by the sale of the power generated at Grand Coulee Dam.

All power plants along the system are connected by high-voltage federally owned transmission lines, the backbone of a power network in which all utilities of the Pacific Northwest participate. This system is linked with the power grid in the state of California and with the American Southwest; surplus Columbia River power is sold to the Southwest during the summer (and Southwestern steam-generated power to the Northwest during the winter).

The treaty with Canada (1961), supplemented by a further pact in 1964, called for the United States to pay British Columbia sums representing that province's share of power- and flood-control benefits, for British Columbia to build three large dams (two of them on the Columbia), and for the United States to build a fourth dam on the Kootenay in Montana.

History. Numerous American Indian peoples inhabited the Columbia River basin for several thousand years.

Early explorers

Spanish explorers sailing up the Pacific coast in about 1775 probably were the first Europeans to sight the river's mouth. The Boston trader Robert Gray sailed up the Columbia in 1792 and named it for his ship. The American Lewis and Clark Expedition wintered at its mouth in 1805–06, and an English geographer, David Thompson, explored most of the river for the North West Company, reaching the mouth in 1811—only to find that Fort Astoria was already being built by the Americans. The upper basin was explored for the North West Company in 1807–11. Other early posts included Fort Vancouver (1825), of the Hudson's Bay Company, and Fort Walla Walla (1818), of the North West Company (after 1821 it merged with the Hudson's Bay Company).

Irrigation apparently was practiced at Fort Walla Walla (near present-day Wallula, Wash.) by the early 1830s and at the mission established in 1836 by Dr. Marcus Whitman at nearby Waiilatpu, and it was later extended to many tributary valleys east of the Cascade Range. The main stem of the Columbia was too deeply entrenched for early irrigation, but, as the only sea-level route to the interior, it served as the major transportation artery until the coming of the railroad. The canoes and barges of the fur traders and early immigrants had given way to river steamers by the 1850s. The many rapids—21 to the mouth of the Snake River—made navigation difficult; the worst point was circumvented by the first railroad in Washington, a 1.5-mile, wooden-railed, mule-drawn tram that later was replaced by a 6-mile rail line with steam locomotives. The heavy agricultural and mining trade of the Columbia River basin was dominated by Portland through a monopolistic combination of river steamers and connecting stages. A railroad was completed from Portland to Walla Walla, Wash., in 1882 and from St. Paul, Minn., to Portland and thence to Tacoma, Wash., on Puget Sound, the following year. In 1887 the Northern Pacific Railway reached Tacoma directly over the Cascade Range, and the monopoly of the Columbia River route was ended.

The abundance of salmon was noted by the early explorers. The first cannery on the Columbia opened in 1866, and by 1881 some 30 Columbia River canneries were supplying world markets, especially Great Britain, with salmon caught in nets, traps, and wheels. From a record of 21,500 tons in 1883, the annual Columbia River salmon catch has declined to about 10 percent of that quantity. Although such organizations as the Northwest Regional Power Council and the Bonneville Power Administration have made considerable effort to increase the size of the river's annual salmon run, much doubt remains as to whether fish populations can ever be restored to earlier levels or even maintained at their current size. Serious impediments have included the barriers to upstream migration presented by the dams and power-generating equipment, the loss of spawning grounds through inundation, the displacement of naturally spawned fish by those raised in hatcheries, the supersaturation of the water by nitrogen trapped as floodwaters plunge over spillways, and the loss of the river's natural current to guide spawning fish. (M.E.Ms.)

GREAT LAKES

The Great Lakes—Superior, Michigan, Huron, Erie, and Ontario—of east-central North America are one of the great natural features of that continent and of the Earth.

Relative size of the lakes

Although Lake Baikal in Russia has a larger volume of water, the combined area of the Great Lakes—some 94,850 square miles (245,660 square kilometres)—represents the largest surface of fresh water in the world, covering an area exceeding that of the United Kingdom. Their drainage basin of about 295,800 square miles (which includes the areas of the lakes themselves and their connecting waterways) extends approximately 690 miles from north to south and about 860 miles from Lake Superior in the west to Lake Ontario in the east. Except for Lake Michigan, the lakes provide a natural border between Canada and the United States, a frontier that was stabilized by a boundary-waters treaty of 1909. It is a source of pride for both countries that there are no fortifications or warships along the boundary.

Areas and Volumes of the Great Lakes

	surface area		world rank	volume		world rank
	sq mi	sq km		cu mi	cu km	
Superior	31,700	82,100	2nd	2,900	12,100	4th
Michigan	22,300	57,800	5th	1,180	4,920	6th
Huron	23,000	59,600	4th	850	3,540	7th
Erie	9,910	25,670	11th	116	484	15th
Ontario	7,340	19,010	14th	393	1,640	11th

Individually, the lakes rank among the 14 largest in the world (see Table). They played a central role in the European colonization and development of North America and for decades have attracted people and industry; Lakes Erie and Ontario and the southern portion of Lake Michigan are now ringed with large population concentrations. The lakes have not benefited from this development, however, and have been seriously affected by pollution. Concern over the fate of the lakes reached a high pitch in the late 20th century, with both the U.S. and the Canadian governments and individuals investigating methods for reversing the consequences of years of misuse of the lakes' waters.

The Great Lakes form the western portion of the larger St. Lawrence hydrographic system. This system extends generally eastward from the St. Louis River in Minnesota (which flows into Lake Superior), through the lakes and the St. Lawrence River, and empties into the Atlantic Ocean at the Gulf of St. Lawrence. For a discussion of the system east of Lake Ontario, see below *St. Lawrence River and Seaway.*

Physical features. *Geology.* The age of the Great Lakes is still not definitely determined. Estimates range from 7,000 to 32,000 years of age. It is generally accepted that Lake Erie reached its present level about 10,000 years ago, Lake Ontario about 7,000 years ago, and Lakes Huron, Michigan, and Superior some 3,000 years ago.

The present configuration of the Great Lakes basin is the result of the movement of massive glaciers through the mid-continent, a process that began about one million years ago during the Pleistocene Epoch. Studies of Lake Superior indicate that a river system and valleys formed by water erosion existed before the Ice Age. The glaciers undoubtedly scoured these valleys, widening and deepening them and changing the drainage of the area.

The last glacial stage in North America is called the Wisconsin Glaciation because it advanced southward to what is now the southern border of the state of Wisconsin. As the ice sheet melted and receded about 18,000 years ago, the first segments of the Great Lakes were created. Lake Chicago, in what is now the southern Lake Michigan basin, and Lake Maumee, in present-day western Lake Erie and its adjacent lowlands, originally drained southward into the Mississippi River. As the ice retreat continued, Lake Maumee was drained into Lake Chicago through a valley that now contains the Grand River in Michigan. Eventually, drainage to the east and into the Atlantic Ocean was established, at one time down the valleys of the Mohawk and Hudson rivers and then along the course of the upper St. Lawrence River. At one high-water stage, the waters of the Huron and Michigan basin formed the large Lake Algonquin. At the same time, Lake Duluth, in the western Lake Superior basin, also drained to the Mississippi.

Retreat of the ice

The weight of the ice sheet exerted enormous pressures on the landmass. As the ice sheet retreated, low-lying areas, such as the region to the east of Georgian Bay, were exposed. About 10,000 years ago, the upper lakes evidently discharged through this area via the Ottawa River valley, and their levels were substantially reduced. After the weight of the ice was removed, the land began to rise, closing off some outlets and changing the water levels of the lakes. The largest postglacial lake, Nipissing, occupied the basins of Huron, Michigan, and Superior. Drainage through the Ottawa River valley ceased, and outflow from the upper lakes was established by way of the St. Clair and Detroit rivers into Lake Erie. Uplift has continued at a rate of about 1 foot (30 centimetres) every 100 years; this is evidenced by the drowned river mouths of western Lake Erie.

A wide range of rock types and deposits are found in the Great Lakes because of their broad area and glacial origin. The ancient rocks of the Canadian Shield cover part of the Superior and Huron basins, while younger sedimentary rocks make up the remainder of the basins. There are limestone outcrops and large deposits of sand and gravel, usually near shore. Glacial clays and organic sediments occur in the deep areas.

Physiography. The lakes drain roughly from west to east, emptying into the Atlantic Ocean. Except for Lakes Michigan and Huron, their altitudes drop with each lake, usually causing a progressively increasing rate of flow.

Lake Superior, bordered by Ontario, the Upper Peninsula of Michigan, Wisconsin, and Minnesota, is the northernmost and westernmost lake and can be considered the headwater of the system. It is the deepest lake (mean depth 487 feet [148 metres]), lies at an altitude of 600 feet above sea level, and discharges into Lake Huron through the St. Marys River at an average rate of 75,600 cubic feet (2,141 cubic metres) per second.

Lake Michigan lies south of Lake Superior and is bordered by the Upper and Lower peninsulas of Michigan, Indiana, Illinois, and Wisconsin. It has a mean depth of 276 feet. The average water level is 579 feet above sea level, and its waters flow northward into Lake Huron through the Straits of Mackinac at 47,800 cubic feet per second.

Lake Huron lies at the same altitude as Lake Michigan and is slightly larger. Its mean depth, however, is only 195 feet. It is bounded by Ontario and Michigan. The average outflow is 183,000 cubic feet per second through the St. Clair River, the shallow basin of Lake St. Clair, and the Detroit River to Lake Erie.

Lake Erie is bordered by Ontario, New York, Pennsylvania, Ohio, and lower Michigan. It is the shallowest of the Great Lakes, with a mean depth of 62 feet. The basin slopes from west to east with depths of 24 feet and 210 feet, respectively. It lies at an altitude of 570 feet, and its waters discharge at an average flow of 202,000 cubic feet per second. The course of the outflow is along the Niagara River and includes a rapid plunge over Niagara Falls before the waters reach Lake Ontario.

Niagara Falls

Lake Ontario has the smallest surface area of the system. It has, however, the second greatest mean depth—283 feet. It lies between Ontario and New York, at an altitude of 245 feet, and discharges into the St. Lawrence River at an average rate of 242,000 cubic feet per second.

Hydrology and climate. The lakes ultimately receive their water supply from precipitation, which increases from west to east. The average annual precipitation in the Lake Superior basin is 30 inches (760 millimetres), in Lakes Huron and Michigan it is 31 inches, and in Lakes Erie and Ontario it is 34 and 36 inches, respectively. Between 65 and 85 percent of the annual precipitation is lost by evaporation, with the largest proportion occurring on Lake Erie (Erie receives most of its water from Lake Huron). Some water enters Lake Superior from the Hudson Bay drainage system via the Long Lake–Ogoki River diversion, while water drains out of Lake Michigan through the Chicago Sanitary and Ship Canal.



The Great Lakes and their drainage basin.

The lakes greatly modify the climate of the surrounding region. They absorb a large quantity of heat in the warmer months, which is then lost to the atmosphere during the colder months. This causes cooler summers and warmer winters. Precipitation is substantially higher along the eastern shores of the lakes, creating a snowbelt that afflicts Erie, Penn., Buffalo, N.Y., and similarly situated cities. Severe storms can occur over the lakes, particularly in late fall and early winter. Winds can reach gale force and generate waves 10 feet or more in height. Large areas of the surface waters freeze during winter, although open patches usually remain in the centres of the lakes.

Lake levels generally vary about one to two feet throughout the year, the highest levels occurring in summer and the lowest in late winter and early spring. There are small tides of about two inches, but they are relatively unimportant. Seiches—harmonic oscillations of the lakes—are caused by such atmospheric disturbances as winds or differences in barometric pressure. They have resulted in water piling up temporarily on one side, or end, of the lakes and have caused differences in the water level between Buffalo, N.Y., and Toledo, Ohio, on Lake Erie, as high as 13 feet or more. Currents are highly variable, they respond quickly to wind changes, and their direction is determined by the rotation of the Earth and the shape of the lake basins.

The Great Lakes have bicarbonate waters, the alkalinity of which ranges from 46 parts per million of carbonates in Lake Superior to 113 parts per million in Lake Michigan. Because Lake Huron is fed by both Superior and Michigan, its chemical content lies in the middle of the range. Alkalinity then increases slightly as the waters flow into and through Lakes Erie and Ontario.

The overall chemical composition of the lakes does not differ greatly from that of other large bodies of fresh water. Limestone in the Lake Michigan basin supplies large amounts of calcium and magnesium to the system, while sodium concentrations are greater than those of magnesium in Erie and Ontario. Although chemical distribution is relatively uniform in any one lake, concentrations of phosphorus and nitrogen are greatest along the shores, in bays and harbours, and especially near urban centres.

Chemical composition

During the 20th century, concentrations of most chemicals have increased significantly in all the lakes except Superior. Chloride, sodium, and sulfate have increased considerably in Lakes Erie, Michigan, and Ontario. Chloride concentrations have increased almost four times over levels reported in 1900, and limited data for Lake Erie indicate that nitrogen concentrations increased fivefold and phosphorus threefold in 30 years. Special importance is attached to these nutrients because they stimulate growth of algae, and their increased concentrations reflect the process of nutrient enrichment called eutrophication.

Plant and animal life. Diatoms—microscopic algae with glasslike shells of silica—are the major forms of algae, although green and blue-green algae are abundant during the summer in Lakes Erie, Ontario, and Michigan. Copepods and cladocerans, microscopic crustaceans, are important in the animal forms of plankton. Most abundant during the spring months in the upper lakes, plankton reaches two peaks of abundance—spring and fall—in the lower lakes and in the more productive waters of the upper lakes.

The organisms living on the bottom in shallow waters are the same kinds of snails, clams, worms, mayflies, and caddisflies found in most small lakes. The deep waters, however, are the realm of some organisms that are found only in the deep, cold lakes of the northern latitudes. These include the delicate opossum shrimp, the deepwater scud

(a crustacean), two types of copepods, and the deepwater sculpin (a spiny, large-headed fish). During the 1980s two nonindigenous creatures—the spiny water flea (a crustacean) and the zebra mussel (a mollusk)—gained access to the lakes and established large populations. Both have threatened the food web of native species, and the zebra mussel has become a nuisance by clogging water-intake pipes, covering spawning reefs, and fouling boat hulls.

The fish community of the lakes and tributaries includes representatives of most families of North American fishes. Lake trout, whitefish, and lake herring have always been important in the lakes, while perch, walleye, bass, and catfish are abundant in the shallow, warmer waters. The fish population has changed drastically over the past century. By 1880 the damming and pollution of tributaries had caused the elimination of Atlantic salmon and the restriction of whitefish. At the same time, lake sturgeon were purposely overfished, and carp were introduced. Smelt entered Lake Michigan in 1927 and in a short time had spread throughout the lakes. The predatory sea lamprey migrated into the upper lakes and established spawning populations in the 1930s, causing the collapse of the lake trout populations in Lakes Huron and Michigan by the early 1950s. Other large predators also were drastically reduced in numbers by the sea lamprey. Consequently, when the alewife migrated into the upper lakes between 1931 and 1954, it met little competition and predation and soon became the most abundant species. Alewives are of little commercial value, however, and have caused costly sanitary operations when, periodically, millions of them die and are washed up to rot on the beaches. A major international program to control the sea lamprey reduced its population substantially; and during the 1960s lake trout were reintroduced when it appeared that the sea lamprey was under control. Coho and chinook salmon were introduced both to provide a sports fishery and to control the alewife. Among the accidently introduced species, the small, perchlike ruffe preys on the eggs of native fishes, while the bottom-dwelling round goby competes for food and habitat with indigenous species.

The changing fish population

Herring and ring-billed gulls and terns are the most common birds; small islands are important nesting grounds for them. The lakes are important as wintering areas for ducks such as the scaup and the old-squaw duck, and a diversity of shorebirds and songbirds migrate through the region during the spring and fall. Various places along the shoreline, such as Point Pelée (Ontario) in Lake Erie, are favoured locations for bird-watching.

The economy. Early interest in the lakes was stimulated by the easy transportation route that they offered into the heartland of the continent. The value of the extensive forests and fertile land in the region was soon realized, and lumbering and agriculture became important. Large coalfields and deposits of iron, copper, limestone, and other minerals were found along or near the extensive shorelines. The combination of these vast resources with a plentiful water supply naturally favoured the development of huge industries and large metropolitan areas around the Great Lakes. Major urbanized areas include a band that extends from Milwaukee, Wis., through Chicago and around southern Lake Michigan; a band that stretches southward from Detroit, Mich., and then continues along the southern shore of Lake Erie; and the Toronto-Hamilton area on the northern shore of Lake Ontario.

Resources. Although most of the virgin pine forests were felled by 1910, the growing of timber is important and is supported by both federal and state governments. About half of the land in the counties bordering the lakes in the United States is devoted to farming, while nearly one-third of that in the bordering Canadian counties is under agriculture. The major crops raised are corn, soybeans, animal fodder, and fruits and vegetables; pork and dairy products are produced as well.

The ranges around Lake Superior—such as the Mesabi in Minnesota—were once a major source of iron ore for the United States. Peak production occurred in 1953, when almost 100 million net tons were produced. The large deposits of rich ores have since been depleted, but low-grade taconite ores can now be efficiently processed. Lake Superior's Keweenaw Peninsula is a major source of copper, although sources outside of the lakes are relatively more important.

Iron ore

Of major importance is the water supply that the lakes provide for bordering industries and municipalities. Hydroelectric generating stations exist on the St. Marys, Niagara, and St. Lawrence rivers. Numerous thermal- and nuclear-powered generating plants around the lakes utilize lake water for cooling.

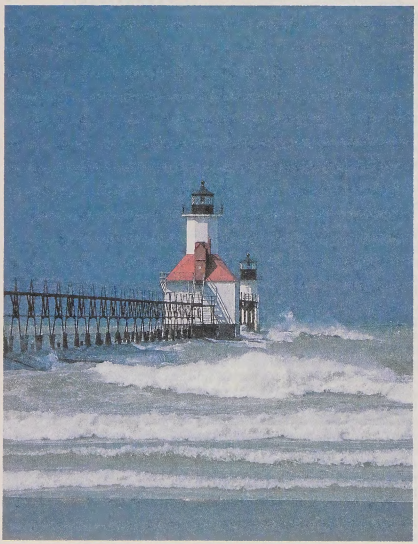
Industry and transportation. The industry of the lakes region is highly diversified. The large steel mills in Illinois, Indiana, Ohio, and Ontario and the automobile industry centred in the Detroit area produce a large proportion of the continent's steel and motor vehicles. Nonetheless, many more workers are employed in the service industry.

Most of the total shipping tonnage includes iron ore, coal, and grain for lake ports, but some tonnage is shipped overseas through the St. Lawrence Seaway. The Welland Canal allows passage around Niagara Falls from Lake Ontario into Lake Erie, and the channels and locks in the St. Marys River have made Lake Superior accessible to ships up to 800 feet in length.

Fishing and recreation. Commercial fishing was once a primary industry on the lakes, but the decline of the more desirable species led to its collapse. A limited amount of commercial fishing is still carried on, however, for species such as whitefish. Emphasis has switched to sport fishing based on coho and chinook salmon, lake trout, walleye, and rainbow trout; this has grown into a major industry.

The value of the lakes for a broad spectrum of recreational activities is inestimable. Powerboating and sailing have become popular activities, and numerous marinas have been built. Many miles of sandy beaches stretch along the lake shores. State, provincial, federal, and county lands offer hundreds of camping, picnicking, and park areas for a thriving tourist industry.

Human impact on the lakes. The multiple uses of the



North Pier lighthouse on Lake Michigan at St. Joseph, Mich., as a storm approaches.

© John & Ann Mahan

lakes are often conflicting. The shipping and hydroelectric-power industries favour higher water levels, for example, but property owners along the shoreline find that high levels increase erosion of the shoreline. Conservationists believe that the diversion of treated sewage away from the lakes, such as is being done at Chicago and various other cities, is the best solution for maintaining the quality of the lake waters. Regardless of the approach that is taken, it is clear that changes have occurred in the plant and animal life of the lakes and that these changes have been related to increases in the content of introduced chemicals, depletion of dissolved oxygen in some places, and the accumulation of sewage sludge on lake bottoms near urban areas.

Pollution of the lakes

Significant changes first became noticeable in about 1900 and paralleled the buildup of human population around the lakes. Misuse of the lakes became all too apparent and was perhaps most clearly dramatized by the growing number of beaches that were closed after 1950 because of pollution; but the less obvious accumulation of toxic substances in wildlife, especially fish and fish-eating birds, had much more serious implications. It came to be realized that pollution could affect either directly or indirectly all uses—raising the cost of water treatment, killing valuable fish species or rendering other species unfit to eat, and adversely affecting the tourist industry and the value of shoreline property. Since the 1970s a major cooperative effort at pollution control has been undertaken by authorities in Canada and the United States, and this has resulted in improved water quality and the resurgence of some fish populations.

Study and exploration. The Great Lakes region was inhabited for centuries by numerous American Indian peoples. With the colonization and expansion of European peoples in North America, the lakes became an integral part of the exploration and development of the continent. It was once speculated that Vikings explored the region in the 14th century—based on the discovery of a broken sword, an ax, and a shield boss near Nipigon Lake, Ont., and a rune stone at Kensington, Minn.—but it is much more likely that the first Europeans entered the region in 1535, when the French explorer Jacques Cartier traveled up the St. Lawrence River to the site of modern Montreal in his search for a route to the Orient. The Huron Indians told him of the great seas lying beyond, but the upper St. Lawrence and Lake Ontario were controlled by the Iroquois, who were unfriendly to the Europeans. Consequently, further exploration by another leading French explorer of North America, Samuel de Champlain, followed the course of the Ottawa River, Lake Nipissing, and the French River to Georgian Bay. He reached Lake Huron in 1615 and is credited with being the first European to see the Great Lakes. In 1634 Jean Nicolet—dispatched by Champlain to seek a route to China—led an expedition into Lake Michigan and down the length of Green Bay to the Fox River, where he encountered the Winnebago Indians. Other French explorers, including René-Robert Cavelier, Lord de La Salle, explored the lakes, made peace with the Indians, and established early settlements.

Three major conflicts affected the history and development of the Great Lakes. The French and Indian War (1754–63)—a struggle between the French and British to gain control of rich fur-producing lands—concluded with the cession of Canada to England. The main consequences of the American Revolution (1775–83) for the Great Lakes region were the migration of thousands of loyalists to New Brunswick, Nova Scotia, Quebec, and Ontario and the establishment of the international boundary between the United States and Canada. During the War of 1812, Lake Erie was the site of a major naval battle.

Modern research

Although several of the early explorers recorded observations of short-term fluctuations in water levels in early geographic writings, the first purely scientific expedition on the Great Lakes was not carried out until 1848. It was led by the Swiss naturalist Louis Agassiz and concentrated on studies of the north shore of Lake Superior. Water-level gauges were established in all the lakes by 1860, and all waters were charted by 1882. Studies of plant and animal life began in the 1870s, and the first study of lake currents was conducted in the early 1890s. Research on the lakes since 1900 largely has been in response to a sequence of crises. The collapse of the lake-herring fishing industry in the 1920s resulted in two major studies of Lake Erie. The invasion of the sea lamprey in the 1930s and concern over lake pollution and eutrophication since World War II has led to international research and cooperation for mitigative measures. Since 1980 additional research has been stimulated by concerns over shoreline erosion and the possible effects of global climatic change. (A.M.B.)

MACKENZIE RIVER

The Mackenzie River is one of the major river systems in the drainage pattern of North America: its basin is the largest in Canada, and it is exceeded on the continent only by the Mississippi-Missouri system. The Mackenzie system drains an area of some 697,000 square miles (1,805,200 square kilometres), which is almost as large as Mexico. From the headwaters of the Finlay River, which flows into Williston Lake (the impounded waters of the Peace River) west of the Rocky Mountains, the entire river system runs for 2,635 miles (4,241 kilometres) through the lake-strewn Canadian north to empty into the cold waters of the Beaufort Sea in the Arctic Ocean. The Mackenzie itself is 1,025 miles long, according to the conventional measurement from Great Slave Lake. The river is generally wide, mostly from 1 to 2 miles across, and in island-dotted sections, 3 to 4 miles wide. It has a strong flow. Its lake-covered triangular delta measures more than 120 miles from north to south and is about 50 miles wide along the Arctic shore.

The headwaters of the system include several large rivers, which themselves drain vast forested plains of northeastern British Columbia and northern Alberta. These drainage basins include the Liard River (about 107,000 square miles), the Peace River (116,800 square miles), and the Athabasca River (36,800 square miles). Much shorter rivers flow into the system from the east, draining the low rocky hills of the ancient structural mass known as the Canadian Shield. The system also includes the huge Great Slave Lake (11,030 square miles), Great Bear Lake (12,100 square miles), and the smaller Lake Athabasca (3,060 square miles).

The whole region is subject to a harsh winter climate, and its resources are few and less accessible than those of southern Canada. Yet it is one of the few great unspoiled areas of the world, offering a varied wildlife and spectacular scenery.

For map coverage of the Mackenzie River, see above *Alaskan mountains.*

Physical features. The Mackenzie River itself begins at the western end of Great Slave Lake, at 512 feet (156 metres) above sea level. Deep (more than 2,000 feet in some places), clear water fills the lake's eastern arm, and shallow, murky water is found in the western part. Because of its large size and the extent of its winter ice cover, Great Slave Lake is the last part of the Mackenzie waterway to be free of ice in the spring, with some ice remaining until mid-June in the lake's centre.

Great Slave Lake

The ice on the Mackenzie River begins to break up in early to mid-May in its southern section, being preceded by breakup on the Liard River. Tributary rivers are free of ice before the Mackenzie itself, and high water and flooding are common during the breakup period, particularly when ice dams form. The ice across the lower Mackenzie River breaks up in late May; the channels in the Mackenzie River delta are usually free of floating river ice by the end of May or early June, with the western channels being influenced by the earlier breakup of the Peel River. Sea ice usually remains offshore from the delta in the Beaufort Sea during June, particularly if prevailing winds are onshore.

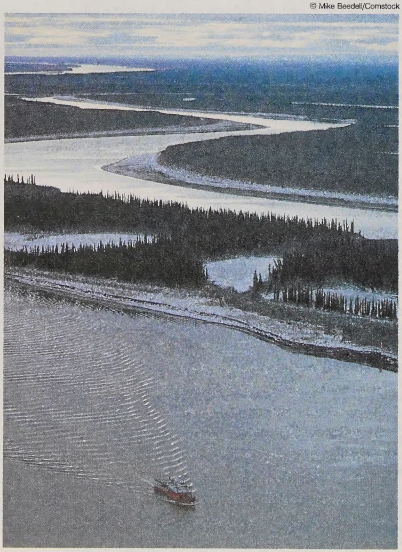
The upper course. The head of the Mackenzie River is about six miles wide where the western end of the Great Slave Lake narrows and is filled by one large island and several small ones. The river narrows to less than a half mile in width near Fort Providence, and it is there that ice bridges are built across the river in early winter to carry truck traffic along the branch of the Mackenzie

Highway that reaches Yellowknife on the northern arm of the Great Slave Lake. Ferries are used for this crossing in summer, but all road traffic ceases during the breakup period in May. Branch roads extend to Fort Simpson and Fort Liard; and, except for a winter trail that is used only occasionally, there are no through roads farther north along the Mackenzie River valley. Mills Lake is a shallow broadening of the Mackenzie River west of the village of Fort Providence. To the west the river again narrows to about a mile in width, and the current is fast at Green Island Rapids, about 12 miles east of Fort Simpson. There is, however, a channel among the boulders in these rapids that is deep enough for the flat-bottomed barges pushed by shallow-draft tugs that operate out of the southern Great Slave Lake terminal of the town of Hay River and along the Mackenzie.

At Fort Simpson the Liard River (693 miles long) joins the Mackenzie from the west from its source in the southeastern Yukon Territory. The contrast between the muddy, silt-laden water of the Liard and the clear water of the Mackenzie is sharply apparent in the river after the junction, as these "two rivers in one" remain separate in terms of certain physical properties for about 300 miles downstream. At Fort Simpson, as for much of its course, the Mackenzie flows between steep, gray gravel banks, 100 to 200 feet high, which obscure the view of the adjacent lowlands from the river.

Along most of its course, the Mackenzie flows through the Mackenzie Lowlands region, which is about 250 miles wide near Fort Simpson. Although it is classed as forested—mainly with a few species of coniferous trees, such as black and white spruce, and some balsam poplar—much of the region away from the tributary rivers is covered by swamps, muskegs (bogs), and lakes, as well as many open areas of grassy vegetation and low bushes. The Mackenzie Mountains rise steeply on the western side of the Mackenzie valley to altitudes of 5,000 to 6,000 feet; since the tree line is at about 3,000 feet, the upper slopes are barren. The eastern edge of the Mackenzie Lowlands is formed by ancient hills of the Canadian Shield, which slope up to altitudes of about 1,000 feet.

The Mackenzie Mountains


© Mike Beedell/Comstock

Tugboat on the Mackenzie River in the delta region near Inuvik, N.W.Terr.

The Mackenzie Lowlands are underlain by flat-lying sedimentary rock of the Cretaceous (*i.e.,* about 100 million years old) and Devonian (about 400 million years old) periods. Little of this rock is exposed at the surface, however, because it is mantled with glacial and alluvial deposition of clays, sands, and gravels.

North of Fort Simpson the Mackenzie River is a little less than 400 feet above sea level, is a mile wide, and flows between steep banks. The mean annual discharge is measured at 239,000 cubic feet (6,760 cubic metres) per second at Fort Simpson; the average monthly flow at high water during the summer (May to October) is more than 365,000 cubic feet per second, and this seems to derive equally from the Liard and upper Mackenzie. The latter supplies a larger share of the river's volume during winter.

The lower course. North of the trading post at Wrigley, the Redstone and Keele rivers enter from the west; they have deep canyons where they break out of the Mackenzie Mountains but flow across the lowland as shallow, braided streams. These rivers and the others that drain from the Mackenzie Mountains have their peak flows in June after the snow melts in the mountains and become shallow rivers in late summer. The Mackenzie River picks up relatively little volume within its valley lowland, as the average summer precipitation recorded at dispersed settlements is only about 7 or 8 inches (175 to 200 millimetres); total annual precipitation throughout the Mackenzie valley is 10 to 14 inches.

At the village of Fort Norman the cold, clear water of the Great Bear River enters from the east. This short river empties out of Great Bear Lake and is navigable for shallow-draft vessels, except for a short portage around rapids about 30 miles east of its mouth. Once more, there is a distinct summer demarcation for 50 miles northward in the Mackenzie River between its silt-laden water and the clear water from the Great Bear River on the eastern bank. At Norman Wells the Mackenzie River broadens to about 4 miles in width and is less than 175 feet above sea level. The mean annual discharge of the river there is 302,000 cubic feet per second, but flows during the summer months usually will average 460,000 cubic feet per second.

The Mackenzie Lowland is only about 30 miles wide in this section, being broken by the treeless summits of the Franklin Mountains, which rise to altitudes of little more than 3,000 feet on the east side of the river. Small lakes are not so common across the Mackenzie valley in this area as they are on the lowland west of Great Slave Lake. Forest vegetation is scanty except in the river valleys and in areas of better drainage; most of the trees are stunted spruce.

Where the Mountain River joins the Mackenzie from the west there is a fast-water section known as Sans Sault Rapids; the river drops about 20 feet within a few miles. There is ample depth of water for the shallow-draft barges during July, but, despite deepening of the channel by rock blasting, shallow water is sometimes a navigation problem in late summer. South of the Indian village of Fort Good Hope, the Mackenzie narrows as it flows between 100- to 150-foot perpendicular limestone cliffs known as The Ramparts. North of Fort Good Hope, the Mackenzie crosses the Arctic Circle. It is slightly entrenched and meanders across its flat valley floor, its banks being two to three miles apart; low islands are numerous, and shifting sandbars are a problem for the riverboats. Where the Arctic Red River enters from the south, the Mackenzie again flows between steep rock walls, which rise about 100 to 200 feet directly from the water.

The delta region. The Mackenzie River delta begins at Point Separation. The mean annual discharge of Mackenzie water into the delta, measured at the confluence of the Arctic Red River, is 340,000 cubic feet per second, increasing to an average of 540,000 cubic feet per second in summer. From the south the 425-mile Peel River is the last major tributary of the Mackenzie, although it actually flows into the Mackenzie delta to the west of Point Separation. The delta covers about 4,700 square miles and is a maze of branching, intertwining channels, numerous cut-

off lakes, and circular ponds. These lakes are an excellent habitat for muskrat, and the trapping of these animals became the main source of income for the Indian and Eskimo inhabitants of the delta in the period 1920–60.

The permafrost region

The perpetually frozen subsurface soil layer known as permafrost lies a few feet beneath the surface of the islands in the delta and exists in a discontinuous layer beneath the entire Mackenzie Lowlands north of Great Slave Lake. Depending on the type of vegetation cover, the top few inches to several feet of ground above the permafrost melts during the summer months. Northern construction of airfields, roads, and pipelines has to be adapted to these permafrost conditions; houses and other buildings are usually placed on wooden piles that are sunk and frozen into the permafrost to give stability. One of the distinctive features of the town of Inuvik is a utilidor, a linear boxlike metal container raised slightly above the surface of the ground, in which the separate sewer, water, and heating pipes are placed. Mackenzie River water-transport routes terminate at Tuktoyaktuk on the Arctic coast northeast of the delta; there cargo is transferred to other vessels of greater draft, which serve the small settlements, radar stations, and oil-exploration sites along the western Arctic coast.

The people and economy. The Mackenzie River basin is sparsely populated. Its natural resources are few, and they are less accessible than comparable resources in southern Canada. Fur-bearing animals were the resource attraction of the 19th century; although they are still trapped throughout the forests of the river basin, particularly by the Indian population, furs now constitute a minor element in the regional economy. Muskrat, marten, beaver, lynx, and fox are the main pelts sought. The forests in the southern part of the basin have been utilized locally for lumber and pulpwood in the Peace River area. The small conifer trees have future value as a source of pulpwood.

Agricultural land is developed only in the south, particularly in the Peace River area. Settlers moved into the Athabasca River, Lesser Slave Lake, and Peace River areas in large numbers after 1920, when the farmlands of the Canadian prairies were almost all occupied. When railroad connections were established southward to Edmonton, these farms were able to produce grain, livestock, and legume seed for external markets. A few farms and many gardens produced well along the Mackenzie River before 1940, but the improved transport since World War II has permitted most food to be imported. With July mean temperatures averaging about 60° F (16° C), and daily temperatures that reach into the 70s and sometimes 80s (*i.e.,* between about 21° and 29° C), climate does not prevent the growth of certain crops.

Minerals—particularly oil and natural gas—are the economic basis of some of the larger settlements in the basin. The first oil field was discovered at Norman Wells in 1921, but production did not begin until the 1930s. A small refinery at Norman Wells produces petroleum products for the industries, transport, and homes of the northern parts of the Mackenzie River valley, and the oil field there was enlarged in the 1980s and connected by a pipeline to Alberta. Other oil and natural gas fields have been discovered near the Mackenzie delta and offshore in the Beaufort Sea. The largest fields are in the southern parts of the river basin, in northwestern Alberta and northeastern British Columbia. The oil and gas from them also is carried southward by pipelines to be distributed from Edmonton, Alta., to refineries in southern Canada and the northern United States. An enormous reserve of petroleum lies in the Athabasca Tar Sands along the Athabasca River north of Fort McMurray; production there was initially limited by high development costs, but it increased in the 1980s as oil fields in Alberta were depleted.

The role of oil and minerals

Metallic minerals have been found along the eastern and southern edges of the basin. Valuable uranium ores were produced on the eastern shores of Great Bear Lake (1933–61) and on the northern side of Lake Athabasca (1950–80) in northwestern Saskatchewan; and the richest uranium mines yet discovered in Canada began operation in the 1980s on the southeastern side of Lake Athabasca. High-quality gold mines are the resource base of the city of Yellowknife, the capital of the Northwest Territories. Lead and zinc mines on the southern side of Great Slave Lake were depleted by 1990; the size of these deposits had been large enough, however, to bring the first railroad into the Northwest Territories, which was built in the 1960s from the Peace River area to the town of Hay River.

The water of the upper Mackenzie River system was too far from large industrial and urban markets to be used for hydroelectric power until the late 1960s. At that time the Peace River was dammed as it broke out of the Rocky Mountains and a large storage lake formed westward in the Rocky Mountain Trench. This electric power is transmitted south 600 miles to Vancouver, B.C. Otherwise, the only developed waterpower sites are on the Snare and Taltson rivers, which drop westward out of the Canadian Shield to the Mackenzie Lowlands and supply power to the mines and residents at Yellowknife. There is no utilization of the water of the Mackenzie River itself, except for river transportation.

Two of the large lakes of the Mackenzie basin are sources of lake trout and whitefish. Lake Athabasca was first exploited during the 1930s, and Great Slave Lake was opened to commercial fishing after 1945. In the latter lake, fish are caught in both summer and winter and transported south by truck or rail to urban markets in both Canada and the United States. The catch is controlled by seasonal quotas that prevent depletion of the species. The cold water of Great Bear Lake has some fish, but they grow too slowly to sustain anything but sport fishing. Fish of the Mackenzie River are netted by some local residents to supplement their imported food.

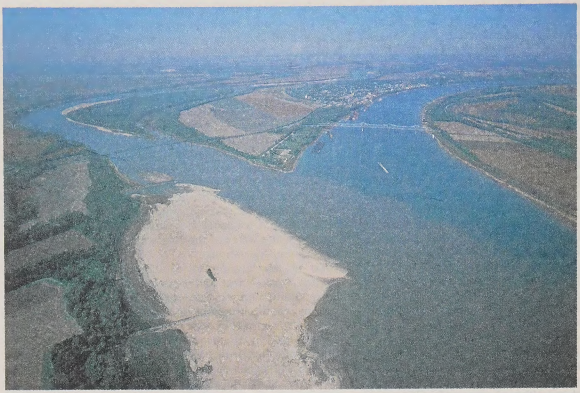
European exploration

History. Explorers and fur traders pushed westward across Canada in the late 18th century to the headwaters of rivers that flowed into Hudson Bay, seeking to tap the fur resources in the lands beyond. In 1778 one of them, Peter Pond, found Portage La Loche (Methy Portage) connecting the headwaters of Churchill River with the Clearwater River, itself one of the east-bank tributaries of the Athabasca River. In 1789 Alexander Mackenzie made his historic journey northward from the trading post of Fort Chipewyan on Lake Athabasca, exploring, with a crew of 12 in three canoes, the full length of the river that now bears his name.

Other fur traders of the North West Company followed early in the 19th century, establishing posts at several sites along the river and on its headwater tributaries. From the mid-1820s, supplies were carried in by the distinctive York boats, shallow-draft vessels with a sharply angled stern and bow. In 1884 the first steamer began to operate northward from Fort McMurray, at the junction of the Clearwater and Athabasca rivers, to Fitzgerald on the Slave River. At this point there are 16 miles of rapids in Slave River, the only break in 1,700 miles of shallow-draft river navigation from Fort McMurray to the Arctic Ocean. In 1886 the first steamer began operating north of Fort Smith—on the present border between the Northwest Territories and Alberta—taking supplies to the Mackenzie River trading posts and bringing out bales of fur. During the period 1920–1940, flat-bottomed stern-wheelers operated on the Mackenzie, but they were replaced after 1945 by small diesel tugs that could push several barges. (J.L.Ro.)

MISSISSIPPI RIVER

Paramount among North American rivers, the Mississippi combines with its major tributaries to form the world's third largest drainage system in area (approximately 1.2 million square miles, or 3.1 million square kilometres). As the central river artery of a highly industrialized nation, the Mississippi has become one of the busiest commercial waterways in the world; and, as the unruly neighbour of some of the continent's richest farmland, it has been subjected to a remarkable degree of human control. Furthermore, the river's unique contribution to the history and literature of the United States has woven it like a bright thread through the folklore and national consciousness of North America, linking the names of two U.S. presidents—Abraham Lincoln and Ulysses S. Grant—with that of the celebrated author Mark Twain. Draining all or part of 31 U.S. states and two Canadian provinces, the outline of the Mississippi system resembles a sturdy tree with two



Confluence of the (left) Mississippi and Ohio rivers at Cairo, Ill.
© Alex S. MacLean/Landslides

main lateral branches, the Ohio River to the east and the Missouri River to the west. Only a thin line carries the name of the parent trunk northward to the river's source at Lake Itasca, Minn.

Although the Mississippi can be ranked as the fourth longest river in the world by adding the length of the Missouri-Jefferson (Red Rock) system to the Mississippi downstream of the Missouri-Mississippi confluence—for a combined length of 3,710 miles (5,971 kilometres)—the 2,350-mile length of the Mississippi proper is comfortably exceeded by 19 other rivers. In volume of discharge, however, the Mississippi's rate of roughly 600,000 cubic feet (17,000 cubic metres) per second is the eighth greatest in the world.

Regional divisions

On the basis of physical characteristics, the Mississippi River can be divided into four distinct reaches. The headwaters reach, from the source to the head of navigation at St. Paul, Minn., is a clear, fresh stream winding its unassuming way through low countryside dotted with lakes and marshes. The upper Mississippi extends from St. Paul to the mouth of the Missouri River near St. Louis, Mo. Flowing past steep limestone bluffs and gathering in the streams and rivers of Minnesota, Wisconsin, Illinois, and Iowa, the river in this segment assumes the character that led Algonkian-speaking Indians to name it the "Father of Waters" (literally *Misi,* "Big"; *Sipi,* "Water"). Below the Missouri River junction, the middle Mississippi follows a 200-mile course to the mouth of the Ohio River. The turbulent, flotsam-laden Missouri, especially when in flood, adds impetus as well as enormous quantities of silt to the clearer Mississippi. Beyond the confluence with the Ohio at Cairo, Ill., the lower Mississippi swells to its full grandeur. Often a mile and a half from bank to bank, it becomes a brown flood, descending with deceptive quiet toward the Gulf of Mexico.

To geographers, the lower Mississippi has long been a classic example of a meandering alluvial river; that is, the channel loops and curls extravagantly along its floodplain, leaving behind meander scars, cutoffs, oxbow lakes, and swampy backwaters. More poetically, Mark Twain compared its shape to "a long, pliant apple-paring." Today the sunlight glittering on the twisted ribbon of water remains one of the most distinctive landmarks of a transcontinental flight. Now curbed largely by an elaborate system of embankments (levees) and spillways, this lower section of the Mississippi was the golden, sometimes treacherous, highway for the renowned Mississippi steamboats, those "palaces on paddle wheels" that so fired public imagination. From the explosive master pilot Horace Bixby, portrayed by Mark Twain, down to the nostalgic lyrics of Oscar Hammerstein's song "Ol' Man River," the creations of that era on the Mississippi have added colour to America's heritage.

Physical features. *Physiography.* The geology and physical geography of the Mississippi drainage area are essentially those of the Interior Lowlands and Great Plains of North America. Fringes also touch upon the Rocky and Appalachian mountains and upon the rim of the Canadian (Laurentian) Shield to the north. The focus of the system, the floodplain of the lower Mississippi, is of particular interest in that the geology and physical geography of the region are of the river's own making. Like a huge funnel, the river has taken sediment and debris from contributory areas near the lip of the funnel and deposited much of the product in the alluvial plain of the funnel's spout, illustrating the interdependence of the entire Mississippi system.

The most significant contributory area in recent times has been to the west of the river. Rising in western uplands, notably in the foothills of the Rockies, rivers such as the Red, Arkansas, Kansas, Platte, and Missouri remove considerable silt loads from the rolling expanses of the Great Plains. A wide, gently sloping mantle of unconsolidated materials, laid down over rock beds of the Cretaceous Period (*i.e.,* about 100 million years old), allows for each river to pick up an independent course toward the "Father of Waters." Precipitation in these western areas is light to moderate, usually less than 25 inches (635 millimetres) per year; but, because at least 70 percent of this precipitation falls as rain between April and September, the erosive capability of the rivers is enhanced (the runoff from winter snowmelt is more gradual than from rainstorms). The prairie soils, moreover, offer little resistance to erosion, so that the rivers are not only incised and braided in their courses but their silt load is high in relation to their volume.

Contributory areas

The Mississippi's eastern contributory rivers drain the well-watered Appalachian Mountain system. Most of this group, including the Kentucky, Green, Cumberland, and Tennessee rivers, flows via well-defined valleys into the Ohio and thence into the Mississippi. The erosive capacity of these rivers varies in relation to the geologic structure of their basins. These consist of harder rocks in the higher elevations and a softer sill of limestone of the Late Carboniferous Period (*i.e.,* about 300 million years of age), lying below the 1,000-foot elevation line between the Ohio and Tennessee rivers and in the glaciated area of the Ohio's right-bank tributaries.

The third contributory area of the Mississippi differs,



The Mississippi River basin and its drainage network.

once again, from the other two. The upper Mississippi gathers its strength in a region marked and scarred by glacial action. After the great ice sheets of the Wisconsin Glaciation had put down layers of debris across much of Minnesota, Wisconsin, northern Illinois, and northern Iowa, huge quantities of meltwater flowed south, washing channels through this debris. Today the upper Mississippi and its tributaries, the Wisconsin, St. Croix, Rock, and Illinois rivers, all trace the lines of these former sluiceways.

Pouring southward, the glacial meltwaters were joined by the proto-Missouri and Ohio rivers. The combined flood then gouged out the great north-south trough along which the lower Mississippi now flows. A thousand miles long, this trough is from 25 to 200 miles wide and bounded by escarpments rising up to 200 feet above the valley floor. Geologic studies have revealed that the floor of the glacial trough was later buried by a deep layer of material washed out from the ice sheet and dumped to a thickness of 100 to 300 feet in the central section.

The Mississippi's delta is an even more striking monument to the river's constructive work. There, at the tip of the drainage funnel, millions of years of sedimentation have spilled out across the floor of the Gulf of Mexico, forming a great cone of sediment 300 miles in radius and 30,000 square miles in area. The surface expression of this cone (just to the east of its apex) is the Mississippi's present delta, with an area exceeding 11,000 square miles. Stretching its distributaries into the gulf, the Mississippi delivers some 220 million tons of sediment there each year.

The delta

Climate. During winter, mean monthly temperatures in the Mississippi basin range from 55° F (13° C) in subtropical southern Louisiana to 10° F (−12° C) in subarctic northern Minnesota. Mean monthly temperatures in summer range from 82° F (28° C) in Louisiana to 70° F (21° C) in Minnesota.

Precipitation sources are low-level moisture from the Gulf of Mexico and some low-level and high-level moisture from the Pacific Ocean. Winter and spring precipitation occurs in the vicinity of fronts during passage of cyclonic storms that generally move from west to east. Average monthly precipitation in winter ranges from five inches or more in the south to more than three inches over much of the Ohio River basin to less than one inch over the western and northern Great Plains. Summer and early autumn rainfall occurs mostly as showers and thunderstorms and weaker frontal storms. Average monthly rainfall ranges from six inches in southern Louisiana and over the mountains of Tennessee and North Carolina to only two or three inches over the Great Plains.

Climates are humid over the eastern half of the basin,

with large quantities of winter and spring runoff generated over the Tennessee, Ohio, and southern Mississippi river basins. A north-south band of subhumid climates, neither fully humid nor semiarid, extends from central Texas northward to eastern North Dakota. To the west are the semiarid climates of the Great Plains, and along the Rocky Mountain crests an alpine climate prevails, in which winter snowfalls are released as spring and early summer meltwater runoff.

Hydrology. It is not surprising that the hydrology of so powerful a river as the Mississippi has been the subject of intense study. In the 19th century, Mark Twain described with considerable wit how the pilots of the Mississippi paddle wheelers banded together to run a common information service about changing conditions along the channel. Today the Mississippi River Commission is responsible for river work and considers it worthwhile to maintain a working scale model of the river so that its engineers can test new plans in miniature before embarking on expensive, full-scale projects. Indeed, by the 1920s it was generally believed that enough was known about the river's hydrology and enough control structures had been built to have tamed the river. Then in 1927 came the most disastrous flood in the recorded history of the lower Mississippi valley. More than 23,000 square miles of land were flooded. Communications, including roads and rail and telephone services, were cut in many places. Farms, factories, and whole towns went temporarily underwater. An immense amount of property was damaged, and at least 250 people lost their lives. The river engineers took another look at the hydrology of the Mississippi.

Mean water discharge data

Since the freak conditions of 1927, the mean discharge of water into the lower Mississippi by its major tributaries has been carefully monitored. The mean discharge of the main river past Vicksburg, Miss., is calculated at 570,000 cubic feet per second. About 135 miles downriver from Vicksburg, approximately 25 percent of the sediment and water discharge of the river is diverted into the Atchafalaya River through the Old River Complex (Old River Control Structures). These statistics, however, conceal all-important variations in river flow linked with the fluctuating state of the Mississippi's larger tributaries.

Broadly speaking, the western tributaries are the most irregular. They reach a spring or early summer peak that is up to three or four times as great as their winter contribution. The upper Mississippi and its tributaries reach their maximum flow about the same time (March–June), when melting snows are followed by early summer rains. The winter runoff from this area, however, is substantial. The crest of the Ohio's flow occurs slightly earlier. At Metropolis, Ill., just above the confluence with the Mississippi, the greatest monthly discharge is usually recorded in March, at which time the Ohio may be providing more than three-fifths of the water being monitored past Vicksburg in the lower river.

Thus, the Ohio is chiefly responsible for the lower Mississippi flood situations, which may be aggravated by such factors as early rains in the Great Plains, a sudden hot spell in early spring that melts the northern snows, and heavy downpours throughout the lower valley. Under such conditions the lower river will rise over its banks and put pressure against the levees. Tributaries will back up and form lakes on the far side of these same levees. The current, which normally runs no more than 2 to 3½ knots (2½ to 4 miles per hour), may then double at constricted points along the main channel. Thus, the monitoring station at Vicksburg, which at low water in 1936 recorded as little as 93,800 cubic feet per second, measured 2,060,000 cubic feet per second at high-water stage the following year.

Water quality

A variety of pollutants, derived from municipal, industrial, and agricultural sources, have been identified in the waters and sediments of the Mississippi River. Organic compounds and trace metals occur in relatively low concentrations; in addition to those naturally present in the water, they derive from industrial and municipal wastes and runoff from agricultural and urban areas. High concentrations of bacteria associated with human waste, however, have been found downstream from some cities and have been attributed to inadequately treated sewage flowing into the river; concentrations downstream from New Orleans, for example, have been found to be many times greater than concentrations above the city. Pollutants have had little widespread effect on the composition of benthic invertebrate populations, which are indicative of changes in water quality. Water samples taken at New Orleans have shown a relatively high dissolved-oxygen content and low biochemical oxygen demand. Thus, by this index, river pollution may be said to be low.

Plant and animal life. Although the natural vegetation of the Mississippi's immediate valley is the product of climate and soil rather than of the river, the Mississippi's swamps and backwaters are ecologically noteworthy. Threaded along the river, from the wild-rice marshes of Minnesota to the coastal wetlands of the delta, are pockets of thriving plant-animal associations. There, the abundance of natural cover, the comparative isolation, and the food provided by such plants as sedges, pondweeds, and millets encourages regular colonization by waterfowl. The path of these birds, as they move up and down the river with the seasons, has been called the Mississippi Flyway, an appropriate name for the vast aerial highway that reaches from the delta to the distant summer nesting grounds in northern Canada. An estimated eight million ducks, geese, and swans winter in the lower part of the flyway, and many more birds use it en route to Latin America. Typical flyway migrants are Canada geese and lesser snow geese, large numbers of mallard and teal, black ducks, widgeon, pintail and ring-necked ducks, and coots.

The most important varieties of fish found in the river include several types of catfish (some of which grow to considerable size and are fished commercially by local concerns along the middle and lower river); walleyes and suckers, which thrive in the upper river and provide the basis for a sport-fishing industry in Minnesota and Wisconsin; carp; and garfish. Alligators are now rare, being found only in the most isolated backwaters, while the shrimp and crab fisheries of the brackish waters are in decline.

History and economy. *Early settlement and exploration.* As its respectful Indian name indicates, the Mississippi played an important role in the lives of the aboriginal peoples settled on its banks. To the Indians of the river, the Mississippi was both highway and larder. On it they paddled their cottonwood dugouts and their bark canoes, and from it they took the fish that was a mainstay of their diet. Constant shifts of migration, local or large-scale, interwove tribal languages and cultures. By the time Europeans arrived, the Sioux, who originally had lived on the upper river, had withdrawn westward to give place to Ojibwa, Winnebago, Fox, and Sauk. Downriver the Illinois tribe had established prosperous agricultural communities. And in the lower valley itself lived clans of Choctaw, Koroa, Taensa, Chickasaw, Tunica, Yazoo, Pascagoula, Natchez, Biloxi, and Alibamu.

Early exploration

The Spanish explorer Hernando de Soto, commander of the first European expedition to penetrate to the river, had high hopes of plundering the southern tribes. In May 1541 his raiding force reached the river at a point south of what is now Memphis, Tenn. But the "Rio Grande," as the Spaniards called it, provided the newcomers with small profit and much grief. The river Indians launched repeated attacks; the Mississippi floods caught the Spanish unawares; and, ironically, de Soto, the European discoverer of the river, was buried in its waters, after which the rest of his disappointed expedition retreated to the sea, their homemade boats under a running fire from the Indians.

The next European explorers of the river appeared in 1673 out of French Canada—two canoeloads of voyageurs commanded by Louis Jolliet, a French government agent, and Jacques Marquette, a Jesuit priest. Portaging from the Fox River to the Wisconsin, they paddled down the Mississippi as far as the mouth of the Arkansas River. Nine years later the French explorer Renê-Robert Cavelier, Lord de La Salle, reached the delta itself, having opened the even easier portage from the Great Lakes via the Illinois River. He grasped at once the strategic significance

of the huge drainage system and promptly claimed the entire Mississippi basin for France. Within a generation, the Mississippi was a vital link between France's Gulf of Mexico settlements and Canada, and La Salle's claim was vaguely designated as "Louisiana."

But France's grasp on the Mississippi was never firm. French traders settled the upper river, establishing towns like St. Louis and Prairie du Chien (now in Wisconsin), whose names survive to this day. But the lower river passed into Spanish hands in 1769; the Treaty of Paris (1783) optimistically declared the river as the western boundary of the United States; and republican France reacquired the much-bartered stream only long enough to sell it to the United States as part of the Louisiana Purchase (1803). This last move recognized what had been obvious for a quarter of a century—the growing domination of the river by the Americans. They came by raft, flatboat, and ark (a "raft with a rim"), built and loaded on the left-bank tributaries that were in the forefront of the westward expansion of the United States. Unwieldy and expendable, these craft floated downstream to leave their cargoes and occupants as advance guards of American political and economic expansion. Only the long, slim keelboats made the return trip. They were worked upstream under pole, paddle, or sail or by the backbreaking "cordelle," a system under which the crew went ashore with a long bow hawser and pulled the vessel upstream by brute strength.

The torch of exploration also passed to the Americans after the Louisiana Purchase. In 1805–06 the pioneer expedition of the U.S. Army officer Zebulon M. Pike struggled to within 80 miles of the river's source, and in 1832 Henry Rowe Schoolcraft, an Indian agent for the U.S. government, identified and named Lake Itasca (from the Latin *veritas caput,* "true head") as the Mississippi's starting point.

The coming of the steamboats

Development of the river's commerce. Built in Pittsburgh, Pa., in 1811, the *New Orleans* was the first steamboat to appear on the river. Like some fearful omen, its maiden voyage coincided with the series of powerful earth tremors centred in Missouri just south of St. Louis (called the New Madrid earthquake) that caused much flooding and sudden relocation of sections of the main channel. But the *New Orleans* won through, and within a decade its successors had wrought a revolution on the Mississippi. In 1814 only 21 steamboats called at New Orleans, whereas 191 arrived during 1819, and 14 years later more than 1,200 cargoes were unloaded during the year. As the freight rates by steamer on the Ohio and Mississippi rivers plummeted, it became cheaper to send freight from Cincinnati, Ohio, to the U.S. east coast via the Mississippi and the long sea passage from New Orleans than to transport it over the Appalachians, a route that was 10 times shorter.

With the introduction of larger, high-pressure engines and more streamlined hulls, the steamboats extended their range, and the Mississippi became economic overlord to half the country. In 1820 the *Western Engineer* probed up the Missouri. In 1823 the *Virginia* churned its way up to Fort Snelling at the junction of the Mississippi with the Minnesota River. The steamboats brought an era of unprecedented prosperity to the river. Town after town sprang up, dependent on the regular arrival of packet boats bringing mail and passengers or freight boats that took on local produce and left off manufactured goods. Riverbank plantations maintained their own landings so they could ship crops direct, and riverside towns vied with each other to provide services such as fueling and warehousing. The waterfront at New Orleans, with its double line of twin-stacked steamers mingled with oceangoing ships, was among the busiest in the nation.

In 1861, however, came the Civil War; a sharp struggle for control of this vital waterway ensued immediately, which culminated in Ulysses S. Grant's siege of Vicksburg helped by the fortified gunboats and armoured steamers of the Union. When Vicksburg and the river fell into Union hands, the Confederacy was dealt a heavy commercial and strategic blow. President Abraham Lincoln, who himself had been a Mississippi flatboatman, could report that "the Father of Waters flows unvexed to the sea."

During the years immediately after the Civil War there was a brief but glorious revival in river traffic. New and faster steamboats were built and operated, often in rivalry to one another, a rivalry made famous by the three-day race, commencing June 30, 1870, between the *Natchez* and the *Robert E. Lee.* The latter won by dint of stripping out all unnecessary superstructure and taking on extra fuel supplies from tenders while steaming upriver at full speed. Yet even as the river was at its most flamboyant, the same westward expansion that had brought its development now passed it over. With the construction of east-west railroads and canals, the Mississippi's north-south alignment came to be regarded as a nuisance. Towns that had once sought to become staging posts up and down the river now competed to become crossing points. Commercial traffic dwindled, and the grand luxury paddle wheelers gave way to sombre, more prosaic towboats with blocks of barges.

Modern commercial activity. World War I produced a major resurgence in river trade. As other lines of transport became congested, the river was recognized as an increasingly valuable asset. With federal initiative, new barge lines were organized, and by 1931 the annual barge traffic moving along the river was twice the volume moved in any single year during the previous century. In 1907, for instance, the steamer *Sprague* established a new world record for size of tow. Its raft of 60 coal barges weighed 67,307 tons and covered an area of 6.5 acres (2.6 hectares).

Barge traffic

Sprague's record is unlikely to be matched by any other paddle wheeler, for the remaining steamboats are mostly showpieces, and the modern Mississippi towboat is of design radically different from its forebears. Screw-driven and diesel-engined, the modern towboat is made fast to the stern of its tow. Ahead stretches a rigid platform of barges as much as 1,500 feet long and with a designed draft of 9 feet. Most barges are built for specific cargoes. For dry cargo, they average 1,500 tons capacity and measure 195 feet long by 35 feet wide; for liquid cargo, the proportions are about 2,500 tons capacity and 295 feet by 50 feet. To aid navigation, towboat captains have at their disposal electronic depth finders, radar, contraguide rudders, a sophisticated system of riverbank lights and markers, and a radio telephone to warn other river users of their approach in narrow passages. Among the cargoes to be carried along the river in this fashion since about 1960 are the booster rockets for space research, which are so bulky as to be unsuitable for any other mode of transport.

Commercial use of the Mississippi waterway has shown sturdy growth. Leading cargoes, by bulk, were petroleum and derivative products, coal and coke, iron and steel, chemicals, sand and gravel, and sulfur. An increasing emphasis on bulk handling inevitably has meant the rapid growth of a few key port cities at the expense of their rivals.

Responsibility for overseeing the maintenance and improvement of the Mississippi as a commercial waterway, as well as the related tasks of flood control and bank protection (see below), falls upon the Mississippi River Commission. Created by act of Congress in 1879, the commission has supervised a massive program of river work that has profoundly reshaped the character of the Mississippi. The main stages of the navigation improvement program include a channel 9 feet deep and 250 feet wide at low water between Cairo, Ill., and Baton Rouge, La., authorized in 1896; a widening of this channel to 300 feet, approved in 1928; and its deepening to 12 feet, begun in 1944 and still under way. In addition, a ship channel 45 feet deep from Baton Rouge to the Gulf of Mexico has been under construction since its authorization by Congress in 1945. Farther upriver, the outstanding achievement has been the construction of 29 locks and dams on the upper river to take the 9-foot channel upstream to Minneapolis–St. Paul. Connecting into the Mississippi is a vast complex of related waterways—from the Intracoastal Waterway in the south, stretching between Florida and the Mexican border, to the channels that lead up the Ohio to its tributaries and through the Illinois waterway to the Great Lakes and St. Lawrence Seaway.

Flood control. Flood control along the river dates to the foundation of New Orleans in 1717 by the French, who built a small levee to shelter their infant city. Over

Levees

the next two centuries a complex array of riverbank structures was erected along the river to contain or divert floods. But it was not until after the catastrophic flood of 1927 that the federal government became committed to a definite program of flood control. The target has become an integrated flood-control system able to master a "project flood," the largest theoretical flood expected along the river. This program has altered the face of the river even more than the navigation program—with which it is linked—has altered its bed.

In principle, the Mississippi's floods are either constricted by levees, hastened out of danger zones by floodways and improved channels, dissipated down spillways and into reservoirs, or starved by the impounding of tributary floods. From Cape Girardeau, Mo., to the sea, the river is virtually "walled in" by a vast line of main-stem levees. This concrete barrier has, incidentally, isolated the river from much of the surrounding countryside, and many former riverbank towns are severed from their natural setting. In the event that the main levees are threatened, the excess floodwater drains away down spillways (*e.g.,* from north of New Orleans it is diverted past the city by spillways leading through Lake Pontchartrain to the Gulf of Mexico) or bursts "fuse plugs," the specially weakened sections of levee leading to harmless floodways or reservoirs. A major example of this type of floodway occurs at New Madrid, Mo., just south of the Ohio confluence.

Elsewhere, a massive program of bank strengthening using mattresses of concrete slabs has reduced lateral erosion and increased channel stability. The careful positioning of underwater dikes to deflect the current, the cutting through of oxbow bends at their necks, and a continuous dredging schedule have all helped to reduce flood levels. Although the system operated successfully against the high-water levels of 1945 and 1950, it could not contain the flood of 1973 nor the record inundation of 1993 of the upper and middle Mississippi and lower Missouri.

Thus, the Mississippi flood-control program is not without its problems. It has been increasingly necessary, now that the river is caught behind the main-stem levees, to attend to the isolated tributaries. In some cases, costly pumping stations have been installed to lift the impounded water over the levees and into the main river. More dramatic has been the penalty for using the Atchafalaya River as a convenient spillway for floods on the lower river. The Mississippi threatened to divert permanently into this secondary channel, inundating the lower Atchafalaya, bypassing New Orleans, and rendering useless millions of dollars of flood-control works. Only at the cost of a vast and complex system of locks and barrages has the danger been averted. It has become increasingly clear that the river's delicate hydrology has been disturbed and that the program of river work must continue for many years.

(G.T.Se./R.A.Mu./R.H.K.)

PANAMA CANAL

The Panama Canal is a canal of the lake-and-lock type connecting the Atlantic and Pacific oceans through the narrow Isthmus of Panama, where the Continental Divide dips to one of its lowest points. The length of the Panama Canal from shoreline to shoreline is about 40 miles (65 kilometres) and from deep water in the Atlantic to deep water in the Pacific about 51 miles. The canal is one of the two most strategic artificial waterways in the world, the other being the Suez Canal. From its opening in 1914 until 1979, it was controlled solely by the United States, which built it. In 1979, however, control passed to a joint agency of the United States and the Republic of Panama, and Panama's participation gradually increased. By treaty, complete control of the canal passed to Panama at noon on Dec. 31, 1999, and administration of the canal became the responsibility of the Panama Canal Authority.

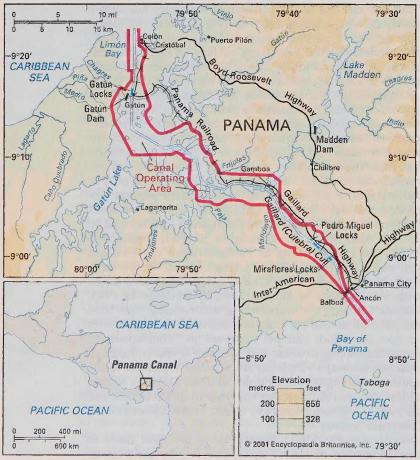
Length of the canal

Ships sailing between the east and west coasts of the United States, which otherwise would be obliged to round Cape Horn in South America, shorten their voyage by about 8,000 nautical miles by using the canal. Savings of up to 3,500 miles also are made on voyages between one coast of North America and ports on the other side of South America. Ships sailing between Europe and East Asia or Australia can save as much as 2,000 miles by using the canal.

Physical features. *The canal.* The Panama Canal lies at a latitude of 9° N. The canal does not, as is generally supposed, cross the isthmus from east to west. It runs due south from its entrance at Colón on the Atlantic side through the Gatún (Gatun) Locks to a point in the widest portion of Gatún Lake; it then turns sharply toward the east and follows a course generally to the southeast until it reaches the Bay of Panama, on the Pacific side. Its terminus near Balboa is some 25 miles east of its terminus near Colón. Parallel to the canal are the Panama Railroad and the Boyd-Roosevelt Highway.

In passing from the Atlantic to the Pacific, vessels enter the approach channel in Limón Bay, which extends a distance of about seven miles to the Gatún Locks. At Gatún a series of three locks lift vessels 85 feet (26 metres) to Gatún Lake. The lake—formed by Gatún Dam on the Chagres River and supplemented by waters from Lake Madden (called Lago Alajuela in Panama) formed by the Madden Dam—covers an area of 164 square miles (425 square kilometres). The channel through the lake varies in depth from 45 to 87 feet and extends for about 23 miles to Gamboa. At Gamboa the Gaillard (Culebra) Cut through the Continental Divide begins. The channel through the cut has an average depth of about 42 feet and extends some eight miles to the Pedro Miguel Locks. The locks lower vessels 31 feet to Lake Miraflores, at an elevation of 54 feet above sea level. Vessels then pass through a channel one mile long to the two-stepped locks at Miraflores, where they are lowered to sea level. The final segment of the canal is a dredged approach passage seven miles long through which ships pass into the Pacific. Throughout its length the canal has a minimum bottom width of 500 feet; in Gatún Lake the width of the channel varies between 500 and 1,000 feet, and in Lake Miraflores the width is 750 feet.

Locks. The canal locks operate by gravity flow of water from Gatún, Madden, and Miraflores lakes, which are fed by the Chagres and other rivers. The locks themselves are of uniform length, width, and depth. Each set of locks is built in tandem, to permit the simultaneous transit of vessels in either direction. Each lock gate has two leaves, 65 feet wide and 7 feet thick, set on hinges. The gates range in height from 47 to 82 feet; their movement is powered by motors recessed in the lock walls. They are operated from



The Panama Canal.



Ships traveling in opposite directions through the Miraflores Locks, Panama Canal. At centre on cog tracks on the lock wall are the electric locomotives used to tow the ships.
© Mario Alguze/The Image Works

a control tower, located on the wall that separates each pair of locks, and from which the flooding or emptying of the lock chambers is also controlled. The lock chambers are 1,000 feet long, 110 feet wide, and 41 feet deep.

Towing locomotives

Because of the delicate nature of the lock mechanisms, only small craft are allowed to pass through the locks under their own power. Larger craft are taken through by electric towing locomotives, which operate on cog tracks on the lock walls. Before a lock can be entered, a fender chain, stretched between the walls of the approach, must be passed. If all is proceeding properly, this chain is dropped into its groove at the bottom of the channel. If by any chance the ship is moving too rapidly for safety, the chain remains stretched and the vessel runs against it. The chain, which is operated by hydraulic machinery in the walls, then pays out slowly by automatic release until the vessel is brought to a stop. If the vessel should get away from the towing locomotive and, breaking through the chain, ram the first gate, there is a second gate 50 feet away that protects the lock and arrests further advance.

Breakwaters. Long breakwaters have been constructed near the approach channels in both oceans. Breakwaters extend from the west and east sides of Limón Bay; the west breakwater protects the harbour against severe gales, while the east one reduces silting in the canal channel. On the Pacific side a causeway extends from Balboa to three small islands (Naos, Perico, and Flamenco) and diverts crosscurrents that carry soft material from the shallow harbour of Panama City into the canal channel.

The economy. *Navigation.* Ships are taken through the canal by one or more pilots, who board each ship before it leaves the terminus. With waiting time, ships require about 15 to 20 hours to negotiate the canal. The average transit time, once a vessel has been authorized to proceed, is about 9 hours from deep water to deep water. When Gaillard Cut is not being dredged, canal traffic generally proceeds in both directions. The heavy rainfall of Panama makes operation feasible despite the irrevocable loss of large quantities of water with each transit. To conserve water, two or more vessels moving in the same direction are passed through together when their size permits.

Each ship is also boarded by measurers to verify its carrying capacity and to collect tolls. Manifests, ships' papers, and other documents are inspected and recorded. Transits are scheduled and monitored at points along the route by an automated marine-traffic control system.

Maintenance. Continual maintenance work on the canal and its associated facilities is needed to keep it in operation in a tropical climate. This includes dredging channels, scheduling overhauls of locks, and repairing and replacing machinery. Because of heavy rainfall and unstable soils, landslides in the hills adjoining Gaillard Cut have been an intermittent problem since the canal was built. Preventive and remedial measures frequently have been taken to keep the channel open, and a program to stabilize its banks was designed to draw away rainfall that might otherwise undercut its slopes. Two major slides have occurred since 1970, the first in 1974 and the second in 1986; in both cases one-way traffic had to be imposed for a time in the affected area.

Another serious problem threatening the canal has been the increased silting and sedimentation rate of the rivers and streams of the watershed and, ultimately, of the canal itself. This degradation has been caused by the slash-and-burn agricultural techniques practiced by local migratory farmers. The canal watershed was still completely forested in the early 1950s, but by the late 1970s it had been almost completely deforested, except for the area of the former Canal Zone. Measures to control soil erosion have been undertaken jointly by the governments of the United States and Panama.

Canal traffic. Traffic through the Panama Canal is a barometer of world trade, rising in times of world economic prosperity and declining in times of recession. From a low of 807 transits in 1916, traffic rose to a high point of 15,523 transits of all types in 1970. The cargo carried through the canal that year amounted to more than 132.5 million long tons. Although the total number of transits decreased thereafter, the canal carried more freight than ever because the average size of vessels had increased.

Principal trade routes

The principal trade routes served by the Panama Canal run between the following points: the east coast of the U.S. mainland and Hawaii and East Asia; the U.S. east coast and the west coast of South America; Europe and the west coast of North America; Europe and the west coast of South America; the east coast of North America and Oceania; the U.S. east and west coasts; and Europe and Australia.

Trade between the east coast of the United States and East Asia dominates international canal traffic. Among the principal commodity groups carried through the canal are crude oil and petroleum products, grains, and coal and coke. (N.J.P./W.D.B./B.L.G./W.W.)

Panama Canal Authority. The Panama Canal Authority was created by amendment of the Panamanian constitution. It is charged not only with administration, operation, conservation, maintenance, and modernization of the canal itself but also with maintenance and preservation of water resources in the entire Panama Canal watershed. The watershed is essential to the operation of the canal, and it also supplies water to cities at either end of the canal route.

The Authority is governed by a board of directors. The board consists of 11 members. The chairman, who has the rank of minister of state for canal affairs, is selected by the president of the republic. The legislative branch of the government designates one director, and the remaining nine members are appointed by the president with the concurrence of the Cabinet council. They must be ratified by an absolute majority of the legislative assembly.

Tolls. While under U.S. administration, tolls for use of the canal were set at rates calculated to cover costs of maintenance and operation, thereby making the canal self-financing. The charge for each transit was based upon the interior cargo or passenger-carrying capacity of a vessel. The rates established in 1914 remained virtually unchanged for 60 years. In 1973 the canal operated at a loss for the first time, and in 1974 the first of several rate increases went into effect.

In 1994 the Panama Canal Universal Measurement System (PC/UMS) went into effect. Traditionally, cargoes were carried below deck, and tolls were assessed on goods carried there. However, because of changes in marine de-

sign and the widespread use of containerized cargoes, a large portion of the burden is now carried on deck. These changes led to modifications in rules of admeasurement and to the assessment of tolls for on-deck container capacity. The Panama Canal Authority retained the toll rates in effect when the canal was transferred from U.S. control.

From the tolls collected, the Authority pays an annual fee to the Panamanian national treasury. Any surplus remaining after that and after the payment of canal operational and maintenance expenses also goes to the treasury.

History. *Construction.* As early as the 16th century, the Spanish recognized the advantages of a canal across the Central American isthmus. Eventually, two routes came to be considered, one through Panama and the other through Nicaragua. Impetus for selecting the route through Panama increased with the construction (by the United States) of the Panama Railroad in the mid-19th century, which closely followed the eventual route of the canal.

The first attempt to actually build a canal across Panama was undertaken in 1881 by the privately owned Compagnie Universelle du Canal Interocéanique (Universal Interocean Canal Company), which was financed by French capital and was under the leadership of Ferdinand de Lesseps, builder of the Suez Canal. The company collapsed in 1889, the victim of poor planning, terrible losses from disease among the workers, and bankruptcy. It was reorganized unsuccessfully in 1894 and had virtually ceased operation by 1898, after which its sole hope lay in holding together an enterprise that could be offered for sale.

The Spooner Act of 1902

Hope became reality with the passage of the Spooner Act of 1902 by the U.S. Congress, which authorized purchasing the assets of the French company and building a canal provided that a satisfactory treaty could be negotiated with Colombia (of which Panama was then an integral part). When treaty negotiations with Colombia broke down, Panama, with the implicit backing of the United States, declared its independence and was recognized by the United States in November 1903. The Hay–Bunau-Varilla Treaty was then negotiated between Panama and the United States. The treaty satisfied the Spooner Act and created the Panama Canal Zone; it was proclaimed in February 1904.

From the first Senate resolution in 1835 favouring Nicaragua until the dramatic change of location for the canal in the Spooner Act, the American public and government had consistently and overwhelmingly supported a canal through Nicaragua. That the canal was built in Panama is primarily attributable not to the intrinsic merits of the Panama route but to the ingenuity and zeal of two remarkable men who worked separately toward a common goal—the French engineer Phillipe-Jean Bunau-Varilla and the American lawyer William Nelson Cromwell. The political power that turned the U.S. government in favour of Panama was supplied by two people: President Theodore Roosevelt and Senator Mark Hanna. Roosevelt, once committed, supported the project enthusiastically and so is almost universally thought of as the "father" of the canal. Most of the actual work on the canal was done during the administration of William Howard Taft (1909–13), who had also been involved earlier in Roosevelt's administration.

When work on the canal began in the summer of 1904, the builders faced one crucial question, unsolved during the French era, of whether to build at sea level or at a high level with locks; and they had to deal with the great construction problem of how to control the Chagres River. The other major problem faced by the French—how to control tropical diseases like yellow fever and malaria—was largely solved during the canal's construction. In 1906 it was decided to build the locks according to a plan similar in all essential respects to one proposed in 1879 by Adolphe Godin de Lépinay de Brusly but rejected by Lesseps. The plan included the solution to the construction problem: the erection of an enormous earthen dam across the Chagres River, thereby creating what was then the largest artificial lake (Gatun Lake) in the world.

Work then began in earnest on what became the greatest engineering feat yet attempted. At times more than 40,000 people were employed on the project, which featured the use of massive steam shovels to dig Gaillard Cut (originally called Culebra Cut). The canal was opened to traffic on Aug. 15, 1914.

Opening of the canal

Capital improvements. The first major capital improvement on the canal was the construction of the Madden Dam and Power Project, which was completed in 1935. This not only stemmed and controlled the flow of water moving into Gatun Lake—to a rate of some 200 billion cubic feet (6 billion cubic metres) per year—but also created a large reservoir (Lake Madden) and increased the production of electric power in the region. The Boyd-Roosevelt Highway was then built across the isthmus, thereby adding a third means of transportation to the waterway and the railroad. In 1955 the Thatcher Ferry Bridge was built, which connected Panama City and Balboa to the west side of the canal. In 1970 Gaillard Cut was widened to 500 feet from its original 300 feet; and in 1974 the channel was deepened, permitting a constant allowable draft of 39.5 feet.

Many of the ships built since the 1970s—notably supertankers and large naval vessels—are too large to pass through the canal. Thus, there has been much study on the feasibility of either widening the existing canal and locks or building a larger sea-level canal at another location. Proponents of the sea-level canal contend that it would be less expensive to operate and—since it would have no locks—less vulnerable to military attack than the Panama Canal. Opponents to such a project cite its enormous expense and the possibility that it could create serious environmental problems by permitting the exchange between the two oceans of long-separated plant and animal species.

International status. The Hay–Bunau-Varilla Treaty was an irritant to Panamanian sensibilities from the moment it was signed. It had been written—and negotiated for the infant republic—by Bunau-Varilla, a French citizen who had not been in Panama for 18 years and who later openly admitted that he was willing for Panama to pay any price to ensure acceptance of the treaty by the U.S. Senate. The most onerous part of the treaty, in the Panamanian view, was the right granted to the United States to act in the entire 10-mile-wide, ocean-to-ocean Canal Zone as "if it were the sovereign." Thus, the Canal Zone became in effect a foreign colony that bisected Panama, despite Theodore Roosevelt's declaration in 1906 that no such result was intended. Some of the harsher effects of the treaty were ameliorated by subsequent treaties, principally those of 1936 and 1955, but the Panamanians continued to press for more drastic changes. After years of negotiation, agreement was reached between the two governments in 1977.

The Panama Canal Treaty

The Panama Canal Treaty of 1977 terminated all prior treaties between the United States and Panama concerning the canal; it also abolished the Canal Zone. The treaty recognized Panama as territorial sovereign in the former Canal Zone, but it gave the United States the right to continue managing, operating, and maintaining the canal and to use lands and waters necessary for those purposes during a transition period of 20 years. The treaty also provided for joint study of the feasibility of a sea-level canal and gave the United States the right to add a third lane of locks to the existing canal. The treaty went into effect on Oct. 1, 1979, and expired on Dec. 31, 1999.

The 1977 treaty was supplemented by a separate, but interrelated, Neutrality Treaty that also went into effect in 1979 but has no termination date. Under the Neutrality Treaty, the United States and Panama guarantee the permanent neutrality of the canal, with nondiscriminatory tolls and access for all nations; U.S. and Panamanian warships, however, are entitled to expeditious passage. After the termination of the Panama Canal Treaty in 1999, no nation other than Panama may operate the canal or maintain military installations within Panamanian territory. The United States, however, reserved the right to use military force, if necessary, to keep the canal open; this was, in part, the rationale behind the U.S. military intervention in Panama in 1989–90.

The U.S. Senate ratified the two treaties in 1978, after one of the lengthiest treaty debates in American history. The treaties were then implemented into U.S. domestic law by the Panama Canal Act of 1979. This act, among other things, established the Panama Canal Commission, which

replaced both the Panama Canal Company and the Canal Zone government. With the turnover of the canal in December 1999, the Panama Canal Authority assumed complete responsibility for the canal.

The international status of the canal also is affected by two older treaties. In the Hay-Pauncefote Treaty of 1901, the United Kingdom gave up its interest in an isthmian canal, and the United States agreed that there would be "entire equality" in the treatment of ships of all nations with respect to "conditions and charges of traffic." In the Thompson-Urrutia Treaty of 1914, the government-owned vessels of Colombia were exempted from paying tolls. (W.D.B./B.L.G./W.W.)

RIO GRANDE

The Rio Grande, the fifth longest river of North America and the 20th longest in the world, forms the entire border between the U.S. state of Texas and Mexico (in which country it is known as the Río Bravo or Río Bravo del Norte). The area within the entire Rio Grande watershed is some 336,000 square miles (870,000 square kilometres). Because a large proportion of the river's basin is arid or semiarid, however, only about half of the total area, or about 176,000 square miles, actually contributes to the river's flow. Rising as a clear, snow-fed mountain stream more than 12,000 feet (3,700 metres) above sea level in the Rocky Mountains of Colorado, the Rio Grande descends across steppes and deserts, watering rich agricultural regions as it flows on its way to the Gulf of Mexico; the total length of the river is about 1,900 miles (3,060 kilometres).

Physical features. From its sources in the San Juan Mountains of southwestern Colorado, the Rio Grande flows to the southeast and south for 175 miles in Colorado, southerly for about 470 miles across New Mexico, and southeasterly for about 1,240 miles between Texas and the Mexican states of Chihuahua, Coahuila, Nuevo León, and Tamaulipas to the Gulf of Mexico.

Diversity of landscapes and environments

Its early course follows a canyon through forests of spruce, fir, and aspen into the broad San Luis Valley in Colorado, after which it cuts the Rio Grande Gorge and White Rock Canyon of northern New Mexico and enters the open terrain of the Basin and Range and the Mexican Plateau physiographic provinces. There, declining elevation, decreasing latitude, and increasing aridity and temperature produce a transition from a cold steppe climate with a vegetation of piñon pine, juniper, and sagebrush to a hot steppe and desert climate characterized by mesquite, creosote bush, cactus, yucca, and other desert plants. Shortly before entering the Gulf Coastal Plain, the Rio Grande cuts three canyons between 1,500 and 1,700 feet in depth across the faulted area occupied by the "big bend," where the Texas side of the river comprises the Big Bend National Park. Along the remainder of its course the river wanders sluggishly across the Gulf Coastal Plain to end in a fertile delta where it joins the Gulf of Mexico.

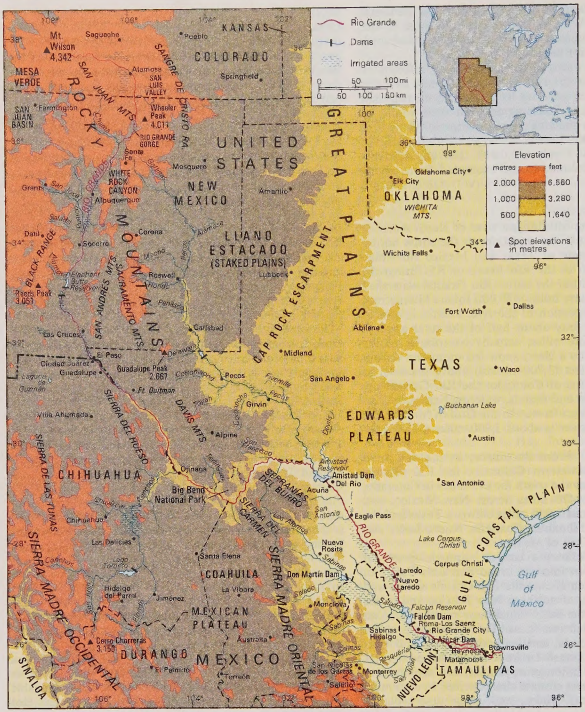
The principal tributaries of the Rio Grande are the Pecos, Devils, Chama, and Puerco rivers in the United States and the Conchos, Salado, and San Juan in Mexico. The peak of flow may occur in any month from April to October. In the upper reaches of the Rio Grande it usually is in May or June because of melting snow and occasional thunderstorms, whereas the lower portion commonly experiences its highest water levels in June or September because of the occurrence of summer rainstorms. It has been estimated that the Rio Grande has an average annual yield of some 2.6 million acre-feet (3.2 billion cubic metres), of which about a third reached the gulf before the building of the Falcon Dam, upstream from Rio Grande City, in 1953; the river's average discharge rate is now about 3,000 cubic feet (85 cubic metres) per second.

The economy. Irrigation has been practiced in the Rio Grande basin since prehistoric times, notably among the ancestors of the Pueblo Indians of New Mexico. Increases in population and in the use of water made necessary the water treaties (1905–07 and 1944–45) between the United States and Mexico, as well as the Rio Grande Compact (1939) among Colorado, New Mexico, and Texas, concerning shared use of the waters of the upper Rio Grande subbasin (above the site of former Fort Quitman, Texas), and the Pecos River Compact (1948) between New Mexico and Texas, concerning the Pecos above Girvin, Texas. Essentially all of the average annual production of more than three million acre-feet in the upper Rio Grande (including the 60,000 acre-feet allotted to Mexico by treaty) is consumed within this subbasin. Not only below Fort Quitman but also in many stretches of the river from the New Mexico–Colorado border to below Brownsville, Texas, there has been no surface flow at various times. In some places the depth of the river has varied from nearly 60 feet to a bare trickle or nothing. Below Fort Quitman the Rio Grande is renewed by the Conchos and other Mexican rivers. The Conchos, which rises high in the Sierra Madre Occidental of Chihuahua, is the Rio Grande's most important tributary: it supplies more than one-sixth of the Rio Grande's total and, with the other Mexican rivers, produces about two-thirds of the available water. A number of large springs in the area between Hot

© Tom Algire



The Rio Grande flowing through the desert at the foot of the Chisos Mountains in Big Bend National Park, Texas.


Rio Grande
Dams
Irrigated areas
0 50 100 mi
0 50 100 150 km
Elevation
metres feet
2,000 6,560
1,000 3,280
500 1,640
Spot elevations in metres
KANSAS
COLORADO
UNITED STATES
NEW MEXICO
OKLAHOMA
TEXAS
ROCKY MOUNTAINS
GREAT PLAINS
CAP ROCK ESCARPMENT
LLANO ESTACADO (STAKED PLAINS)
EDWARDS PLATEAU
COASTAL PLAIN
CHIHUAHUA
COAHUILA
MEXICAN PLATEAU
DURANGO
MEXICO
SIERRA MADRE OCCIDENTAL
SIERRA MADRE ORIENTAL
TAMAULIPAS
NUEVO LEON
SINALOA
Gulf of Mexico
Mt. Wilson 4,342
Sangre de Cristo Mts.
Sacramento Mts.
Davis Mts.
Sierra del Nogal
Sierra de los Tumas
Big Bend National Park
Falcon Reservoir
Amistad Dam
Del Rio
Eagle Pass
Laredo
Nuevo Laredo
Corpus Christi
Lake Corpus Christi
Falcon Dam
Rio Grande City
Brownsville
Matamoros
Monterrey
Saltillo
Albuquerque
Santa Fe
Amarillo
Oklahoma City
Wichita Falls
Lubbock
Abilene
Fort Worth
Dallas
Midland
San Angelo
Waco
Austin
San Antonio
Pecos
Carlsbad
El Paso
Ciudad Juárez
Chihuahua
Ojinaga
Presidio
Alpine
Del Rio
Nuevo Progreso
Reynosa
Camargo
Mier
Guerrero
Nuevo Laredo
Sabinas Hidalgo
Monclova
Piedras Negras
Acuña
Ciudad Acuña
Nueva Rosita
Sabinas
Hidalgo del Parral
Jiménez
La Víbora
Cerro Churreras
Durango
El Palmito
Torreón
Saltillo
Monterrey
Ciudad Victoria
Matamoros
Brownsville
Rio Grande City
Roma-Los Saenz
Falcon Dam
Falcon Reservoir
Amistad Dam
Del Rio
Eagle Pass
Laredo
Nuevo Laredo
Corpus Christi
Lake Corpus Christi
Buchanan Lake
Lake Amistad
Rio Grande
Pecos
Devils
Nueces
Frio
Salado
Conchos
Sabinas
San Juan
Alamosa
Saguache
Pueblo
Springfield
Farmington
Gallup
Grants
Socorro
Roswell
Clovis
Tucumcari
Las Cruces
Guadalupe Pass 2,067
Guadalupe
Fort Quitman
Presidio
Ojinaga
Chihuahua
Villa Ahumada
Los Barriles
Santa Elena
Nuevo Progreso
Reynosa
Camargo
Mier
Guerrero

began in 1749 along the lower Rio Grande. With the Mexican explorations of Juan Bautista de Anza in the San Luis Valley of Colorado in 1779, the exploration of the entire Rio Grande basin was completed. Because most of the entire narratives of exploration and the resultant maps remained unpublished in the various archives of the Spanish government, American and European historians have tended to stress later non-Spanish explorations such as those by the Americans Zebulon M. Pike in 1807 and John C. Frémont in 1848–49 in the upper Rio Grande area. The careful scientific survey of the river, accompanied by good cartography, did not commence until the first of the international boundary commissions began its fieldwork in 1853, directed by a Mexican commissioner and surveyor and their equivalents representing the United States. From the 1850s to 1874—when the river was swept clean of all man-made structures by a great hurricane—small steamboats navigated the lower Rio Grande upstream to Rio Grande City and even to Roma when the river was high. Since then, accelerated erosion, silting, and sandbar formation have precluded navigation and have forced the United States and Mexico to spend much money and time in adjusting the international boundary to the numerous changes in the river channel. In October 1967 the United States formally returned to Mexico the El Chamizal area, between El Paso and Ciudad Juárez, which a shift of the river in 1864 had transferred to the left (north) bank.

Erosion, silting, and changes in course

(D.D.Br./R.H.Sc.)

ST. LAWRENCE RIVER AND SEAWAY

The St. Lawrence is the great hydrographic system of east-central North America. It connects the North River (source of the St. Louis River, in the U.S. state of Minnesota, which flows into Lake Superior) with Cabot Strait, leading into the Atlantic Ocean in the extreme east of Canada, crossing the interior of the North American continent for some 2,500 miles (4,000 kilometres). The St. Lawrence system is of vital geographic and economic importance to the United States and Canada. It can be divided into three broad sectors. Upstream lies the Great Lakes region, with narrow riverlike sections linking the broad expanses of the lakes themselves. In the centre, from the eastern outflow of Lake Ontario, near the Canadian town of Kingston, to the Île d'Orléans, just downstream from the city of Quebec, the system passes through a more normal watercourse. From the Île d'Orléans to the Cabot Strait, between Newfoundland and Nova Scotia, the system broadens out again, first as the St. Lawrence estuary, and then, passing Anticosti Island, as the oval-shaped marine region known as the Gulf of St. Lawrence. The discussion here is confined primarily to the latter two sectors; for a treatment of the first, see above *Great Lakes.*

The St. Lawrence is a mighty and unique hydrographic system. Bedded in an ancient geologic depression, it drains the heart of a continent. It is at once an international, an intra-Quebec, and a multiprovincial system. An axis of regional population, it is also a waterway linking Canada and the United States to western Europe and a large part of the rest of the world. The frontages of the several regions of the St. Lawrence River are not equally developed and do not maintain the same types of relationship with their hinterlands and with the outside world. Throughout its length, nevertheless, the St. Lawrence retains a great natural beauty, with landscapes beloved by all who live on its banks or make the long passage along its course.

The St. Lawrence Seaway, a massive navigational project undertaken jointly by Canada and the United States and completed in 1959, opened North America's industrial and agricultural heartlands to deep-draft ocean vessels. It forged the final link in a waterway some 2,340 miles long from Duluth, Minn. (at the westernmost point of Lake Superior), to the Atlantic by clearing a throughway in a 186-mile stretch of the St. Lawrence River between Montreal and Lake Ontario. Although the official seaway consists of only this stretch and the Welland Canal (connecting Lakes Ontario and Erie), the entire Great Lakes–St. Lawrence system, with 9,500 miles of navigable waterways, has come to be known as the St. Lawrence Seaway.

Physical features. *Geology.* The St. Lawrence River occupies a geologically old depression that involves three great geologic regions of North America: the Canadian Shield, the Appalachian Mountains, and the intervening sedimentary rock platform. This ancient setting has been broken up by movements of the Earth's crust along several zones of structural weakness and also has been worn down by a number of separate cycles of erosion. Toward the end of the Quaternary Period, the glaciers that had occupied the depression since the Pleistocene Ice Age were replaced by the Champlain Sea, which flooded the depression from about 13,000 to 9,500 years ago. A subsequent slight uplifting of the continent was enough to expel this arm of the ocean, and about 6,000 years ago a residual riverlike watercourse—the St. Lawrence—was established.

Physiography. The regional division of the St. Lawrence raises difficult problems, and, despite considerable scholarly work on the subject, the debate remains open. The following division has been based on such overall criteria as longitudinal gradient of the riverbed, tidal characteristics, salinity, the width of the river bottom, human geography, and animal life. Threshold zones, a dozen miles or so in length, mark the transition from one region to the next.

Regional divisions

The St. Lawrence of the International Rapids section forms a clearly defined region extending from Kingston to above Montreal, where the presence of sudden breaks of gradient in the riverbed, the necessity of a navigable route between Montreal and southern Ontario, and the regional needs for power have led to the creation of hydroelectric stations, canals, and a major part of the St. Lawrence Seaway. The flow volume of this section of the St. Lawrence, as measured at Cornwall, Ont., is about 218,000 cubic feet per second (6,100 cubic metres per second).

The region of the Quebec lowlands is made up of a short section with a calm and nonreversible flow. This portion of the river course is characterized by the inflow of the system's principal tributary, the Ottawa (Outaouais) River, by the presence of numerous islands, by the development of the greater Montreal conurbation, and also by a certain amount of water pollution. The development of the port of Montreal has depended on, among other factors, the deepening of the river channel—downstream through dredging and upstream through canalization—by means of engineering projects that were begun in the 18th century. During the winter months, a thick crust of ice connects the two banks of the river, and icebreakers maintain an open channel for shipping. In the past, the possibility of ice jams was great, with notable ice catastrophes occurring in 1642, 1838, and 1896. However, the port of Montreal has been kept open year-round since the mid-1960s.

The upper estuary extends from Lake Saint-Pierre to below the Île d'Orléans at Quebec. There, the current of a freshwater tide begins to be reversible. During the winter months, the ice covering recalls the conditions at Montreal, but it also anticipates those of the middle estuary (see below), where a distinction is necessary between banked (or reef) ice, which is solid and fissured, and conglomerate ice, which moves past offshore. High bluffs rising from the river littoral, which had great strategic value, led to the foundation of the city of Quebec in this region, in 1608. The immediately adjacent area became the historical cradle of the distinctive French-speaking population of Canada.

In the middle estuary, from the eastern end of the Île d'Orléans to the upstream side of the confluence with another major tributary, the Saguenay River, the St. Lawrence broadens but remains relatively shallow. Progressively, the water ceases to be fresh and becomes brackish, and with an east wind it may be possible, for the first time, to catch a whiff of seaweed. Tides, thrust into a narrowing channel, attain maximum height in this section. Breakaway reef ice from this area constitutes one of the major sources of ice in the downstream parts of the estuary.

The lower estuary, one of the greatest topographic alterations in the entire course of the St. Lawrence, is found near the Saguenay confluence, at right angles to a submarine furrow. In this region, the river bottom exhibits a significant break of gradient: within 10 miles of the confluence, the depth of the water increases from about 80 feet (25 metres) to 1,145 feet. It is by way of this drowned

The Saguenay confluence



The St. Lawrence hydrographic system, with (top) the five main sectors of the St. Lawrence Seaway project and (bottom right) cross sections of the lock and canal system.
By courtesy of the St. Lawrence Seaway Development Corp.

valley that the cold, marine waters from downstream enter the region. In spite of the width of the watercourse, a number of ferries connect the two banks. In contrast to the thinly settled northern bank, behind which lie the inhospitable, rugged landscapes of the Canadian Shield, the southern frontage of the lower estuary is open largely toward its hinterland; and major roads, including the Trans-Canada Highway, lead away from the river toward New Brunswick and other Canadian maritime provinces.

The limits of the maritime estuary are, upstream, the promontory of the Pointe-des-Monts and, leading to the Gulf of St. Lawrence, Anticosti Island. (The latter, by reason of its size and its own circular currents, is an entity in its own right and cannot be considered as an element of the estuary.) Below the Pointe-des-Monts, the submarine valley mentioned above doubles in width, to more than 50 miles. A major arm of the counterclockwise current stemming from the Gulf of St. Lawrence, after entering the northern portion of this region, turns back to the east. The salinity found there discourages ice formation, and, on the northern shore, the port of Sept-Îles—although situated much farther north than Montreal—is in fact easier to keep open to navigation in winter. The north frontage, with a hinterland rich in iron ore and hydroelectric-generating potential and running at right angles to this portion of the estuary, offers great economic possibilities.

Climate and hydrology. In terms of both climate and hydrology, the St. Lawrence system as a whole covers several zones. First, in the movement downstream from the upper part of the system, some of the associated boreal character is lost; in its path from the northern streams tributary to Lake Superior down to Lake Erie, the system passes from a subarctic to a more temperate southern zone. This pattern is reversed in the eastern half of the system; thus, from the western end of Lake Erie to the northern coast of the St. Lawrence estuary, the climate again reverts progressively to a subarctic level. This basic division brings out the regional contrasts in the hydrology of the central section of the river. Lake Erie, for example, loses much water through summer evaporation, whereas the affluents feeding the estuary of the St. Lawrence are heavily influenced by snowfall characteristics. At Montreal a good portion of the river flow comes from the Great Lakes—hence its remarkable regularity. At the mouth of the estuary, on the other hand, the volume of ocean water coming in at high tide is considerably greater than the volume of river water flowing down at low tide; and there the St. Lawrence is profoundly marine, rather than lacustrine, in character. These basic regional hydrographic traits are also accentuated by a large seasonal variation in water temperature.

Plant and animal life. The biological world of the St. Lawrence region is relatively unchanged, although it has been influenced by humans for centuries. Some clear regional distinctions have been made between the upper and lower sections of the system and also between the depths and the surface of the water and between the banks and the centre of the river course.

Animal life comprises fish (including sturgeon, smelt, and herring), mammals (including the beluga [white whale] in the gulf), and mollusks (including the soft-shell clam [*Mya arenaria*]). A noted phenomenon, which is characteristic of all regions of the river, is the massive migration of ducks, bustards, and geese, which make use of the sandy shores or river reefs as seasonal food sources. The vegetation associated with the river undoubtedly reflects

Migration of waterfowl

the great shrubby zones that extend from Lake Erie to the northeast of the Gulf of St. Lawrence, made up of deciduous forest, mixed forest, coniferous forest, and open taiga. In addition, however, it exhibits such specifically river-linked characteristics as the sandbank grasses of the freshwater section and the halophytic (salt-tolerant) plants found from the middle estuary onward. (L.-E.H./P.C.)

The economy. The seaway has had a major economic impact on the United States and Canada. A principal reason for its construction was the discovery, in Quebec and Labrador, of vast deposits of iron ore needed by steel mills in the United States. Canada, an importer of American iron ore before the seaway opened, exported ore, the second largest commodity, to the United States thereafter. The largest commodity moved is grain, from farms on Canada's prairies and in the American Midwest, shipped through the seaway at considerable savings. Major users of the seaway are vessels known as lakers, which are designed to the maximum limits of the seaway locks in order to facilitate two-way trade. A laker can pick up grain in the western Great Lakes, destined for world markets, and return with Canadian iron ore, loaded in the lower St. Lawrence. The third-largest seaway commodity is coal, moved chiefly from U.S. mines via the Welland Canal to Canadian steel mills and power plants. Another commodity that is significant—because of its value rather than the amount moved—is imported iron and steel.

Bulk commodities make up about 90 percent of annual cargo tonnage, but vessels of many nations also use the seaway to deliver or pick up general cargoes.

The Great Lakes–St. Lawrence River system has become one of the world's most heavily used international trade routes. Some 35 to 40 million tons of cargo move annually through the Montreal–Lake Ontario section. Although the system often is characterized as a vast inland sea comparable to the Mediterranean, its use is restricted by limited access and by a severe winter climate that shortens the shipping season to about eight and a half months. In 1959 the seaway allowed passage of about 80 percent of the world's ships, a figure that has since decreased. The size of a vessel that uses it is limited to a draft of 26 feet, a length of 730 feet, and a beam of 76 feet. These dimensions have become relatively small by the standards of world cargo-ship construction.

History. *Early navigation.* Efforts to sail into the heart of the continent date from 1535, when the French explorer Jacques Cartier, seeking a northwest passage to the Orient, found his path blocked by the Lachine Rapids, southwest of what is now Montreal. The digging of shallow St. Lawrence canals for bateaux and Durham boats (long, tapering boats with flat bottoms and auxiliary sails) in the early 1780s; the construction of the Erie Canal from Buffalo, N.Y., to the Hudson River from 1817 to 1825; the opening of the first canal around Niagara Falls in 1829; and the completion of the first lock, at Sault Sainte Marie, Mich., in 1855, all fostered the dream of a navigable waterway into the continental interior. The United States, however, proved a reluctant partner in a venture, pursued by Canada from the beginning of the 20th century onward, to open the Great Lakes to sea traffic. The U.S. Senate rejected the Seaway Treaty of 1932 and allowed a second treaty, signed in 1941, to remain unratified for eight years. Faced with the likelihood that Canada would proceed alone, the U.S. Congress finally approved participation in the project in May 1954.

Interest in a navigable waterway

Construction of the seaway. The seaway project was one of the largest civil engineering feats ever undertaken. Construction began in the summer of 1954 and took nearly five years to complete. Over its course the project employed some 22,000 workers and utilized enough cement to build a highway 1,000 miles long and enough steel to girdle the Earth. About 6,500 people living in riverside communities had to be relocated, bridges were raised, and tunnels, dikes, and roads were constructed. Locks had to be constructed in the seaway and modernized in the Welland Canal to raise and lower large ships a total of 557 feet, making it the world's greatest waterway lifting operation. It takes about seven minutes for water to pour in or out of a seaway lock; the average locking takes about half an hour. To overcome the navigational hazard of the swift-flowing, 226-foot fall of the St. Lawrence River between Lake Ontario and Montreal and to develop its hydroelectric power potential required an investment of more than $1 billion.

For the navigation portion of the project, the Canadian government built two canals and five locks around the Cedar, Cascades, and Lachine rapids and three seaway dams; and the U.S. government built two locks, a 10-mile canal around the International Rapids, and two seaway dams and cleared shoals from the Thousand Islands section of the river. This series of operations created a waterway 27 feet deep, replacing six canals and 22 locks that had been limited to a depth of 14 feet.

In order to make the seaway operational, a number of other projects had to be undertaken as well. The U.S. Army Corps of Engineers deepened the Straits of Mackinac, between Lakes Michigan and Huron; the St. Marys River, between Lakes Superior and Huron; the Detroit River, Lake St. Clair, and the St. Clair River, between Lakes Erie and Huron; and many Great Lakes harbours. In addition, between 1913 and 1932 Canada had built seven lift locks of seaway dimensions in the Welland

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Commodity-carrying laker in the St. Lawrence Seaway at Montreal.

Canal, which overcame the 326-foot plunge of the Niagara River and Falls, between Lakes Erie and Ontario. The seaway became operational in April 1959.

To tap the considerable energy of the river's tumbling waters, the seaway project included the construction in the International Rapids section of the Iroquois Control Dam near Iroquois, Ont., and the Moses-Saunders Power Dam near Cornwall. The project created the 30-mile-long Lake St. Lawrence. Generation of hydroelectric power began in July 1958. The generating capacity is shared equally by Ontario and New York state.

Financing the seaway. As the price of approving seaway legislation, the U.S. Congress required that the seaway project be self-liquidating; the Canadian government also adopted this as a national policy. Tolls were to be assessed at a rate sufficient to pay back the cost of the project in 50 years, to pay annual interest on the funds borrowed to build it, and to pay all operating costs. The two nations jointly established a system of tolls, with each nation collecting tolls in its own currency. This resulted in a split of about three-fourths of the revenue to Canada and one-fourth to the United States.

Tolls

Revenues from tolls in the early years of the seaway's operation consistently fell far short of annual operating costs and interest payments, putting the seaway deeper in debt. Neither the Saint Lawrence Seaway Authority, operating Canada's installations, nor the Saint Lawrence Seaway Development Corporation, running U.S. operations, was able to increase tolls to keep pace with higher operational costs until the late 1970s, when a new Joint Seaway Tariff of Tolls agreement was accepted by both countries. Tolls were again increased in the early 1980s. Annual shipping tonnage had reached its peak in 1977, however, after which a gradual decline ensued. Thus, despite the increase in tolls, revenues generally continued to fall short of expenses.

In the mid-1980s the U.S. government assumed the financial obligations of the American seaway corporation. The tolls that were collected (the American share by this time had been reduced to 15 percent of the total) were returned as rebates to the seaway's users, and the federal government provided direct subsidies to the American corporation. The Canadian authority, meanwhile, continued to operate as before and to charge tolls. The incentives to shippers offered by the rebates, however, helped stabilize seaway traffic by the end of the decade. (R.W.B./P.C.)

YUKON RIVER

One of the major North American rivers, the Yukon flows through the central Yukon Territory of Canada and central Alaska. It discharges into the Bering Sea after flowing northwestward and then generally southwestward through a low plateau that slopes down across Alaska. Its numerous headwater tributaries drain an area of about 328,000 square miles (850,000 square kilometres) out of a surrounding semicircle of high mountains. This huge area—larger than Turkey—was occupied solely by North American Indians until the mid-19th century, when peoples of European descent (including explorers from the eastward-expanding Russian Empire) began to move into the region, first as fur traders and then in search of mineral wealth. The discovery of gold on the Klondike River, a Yukon tributary, in 1896 precipitated an influx of settlement that created an international mythology of romantic frontier existence associated with the name Yukon.

The Yukon River measures 1,980 miles (3,190 kilometres) from the headwaters of the McNeil River (a tributary of the Nisutlin River). The main east- and north-bank tributaries are the Teslin, Big Salmon, Pelly, Stewart, Klondike, Porcupine, and Koyukuk; the west- and south-bank tributaries are the Takhini, White, and Tanana.

For map coverage of the Yukon River, see above *Alaskan mountains.*

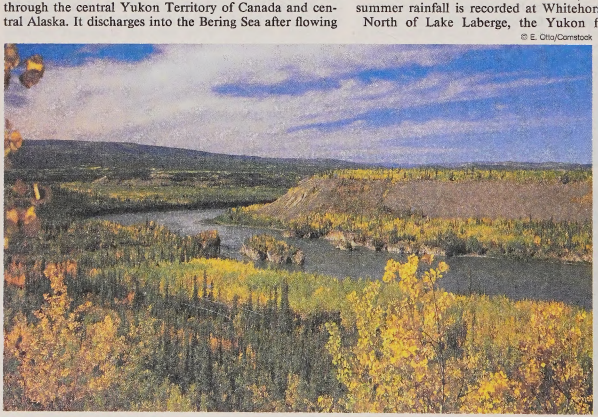
Physical features. *Physiography and hydrology.* The McNeil headwaters rise in the Pelly Mountains of south-central Yukon Territory and flow south into Teslin Lake and thence into the Teslin River. The main headwaters of the Yukon River, however, flow from Atlin Lake and Tagish Lake in the vicinity of the border between British Columbia and Yukon Territory. About 50 miles downstream the Yukon once rushed through the rocky walls of narrow Miles Canyon and tumbled over rock ledges at Whitehorse Rapids. These obstacles to river travel during the gold rush era necessitated the construction of the short railroad from Skagway, Alaska, to Whitehorse in Yukon Territory, the latter becoming the southern terminal of water transport northward. The river has since been dammed south of Whitehorse for hydroelectric power; the rapids are buried under the reservoir lake, and deep water fills the former canyon.

The upper course

River ice begins to break up at Whitehorse, the territorial capital, in early May and loosens northward on Lake Laberge a few days later. The snow-fed tributaries from the Mackenzie Mountains to the east reach their flood peak in June, but glacier-fed streams such as the White, draining the north slopes of the St. Elias Mountains, do not have their greatest runoff until July. Once these peak runoff flows have passed, the Yukon River becomes a shallow, braided stream, as summer precipitation in the Yukon basin is low—about 6 inches (150 millimetres) of summer rainfall is recorded at Whitehorse and Dawson.

North of Lake Laberge, the Yukon flows through a

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Five Finger Rapids on the upper Yukon River, Yukon Territory.

broad, generally flat-bottomed valley; riverbanks are not high, and the river meanders lazily across the valley floor, with numerous sandbars and small islands dotting the channel. About 25 miles north of the village of Carmacks, four small, rocky islands split the river into the Five Finger Rapids area, and the current flows swiftly past these islands. At the village of Selkirk, the junction of the Pelly River swells the Yukon's volume considerably, for the Pelly drains about 19,700 square miles of the generally uninhabited western slopes of the Mackenzie Mountains. North of Selkirk, the Yukon is a clear and gentle river, with numerous low islands breaking the channel. The White River, with a drainage area of about 19,500 square miles, adds silt from the glaciers and mountains to the southwest. The Stewart River, having about the same drainage area as the White River, flows out of the mining area of Mayo-Keno City to the east. At Dawson the Yukon has an average flow of 74,000 cubic feet (2,095 cubic metres) per second, but there is a wide difference between the high-water flows of June and the low water beneath the ice in March. There are no hydroelectric power developments on the Yukon, except for a small plant at Whitehorse. The river is thought to have considerable generating potential; but, because there has been no demand for power, no accurate evaluations have been made.

The Klondike is a small, east-bank tributary that joins the Yukon at the historic territorial town of Dawson. The Klondike valley floor is covered with sinuous, wormlike ridges of gravel deposited behind the gold dredges that have worked their way through the valley gravels over a period of nearly a century.

Downstream from Dawson the river valley narrows, and the low plateau is broken by mountains that rise to elevations of more than 4,000 feet, about 15 miles north of the Yukon River. The river itself is about 1,000 feet above sea level before it crosses the border into Alaska. The next large tributary, the Porcupine River, joins the Yukon at Fort Yukon, Alaska; the Porcupine drains the northern Yukon Territory and the southeastern slope of the high and rugged Brooks Range in Alaska, a land occupied by a small population of Indians. The Yukon then flows generally westward for about 150 miles across a broad, flat valley; the many channels of the braided river thread their way through numerous islands and sandbars. At the western end of the "flats" is a narrow gorge, where the river rushes through a low mountain barrier known as the ramparts.

The lower course

At the junction of the Tanana River, the main southern tributary in Alaska, the Yukon is less than 300 feet above sea level. Upstream on the Tanana lies Fairbanks, the largest city in the Yukon River basin. The snow- and glacier-fed waters of the Tanana drain the north slopes of the high Alaska Range, but, after the peak runoff in July, the Tanana becomes a shallow stream by late summer. West of the Yukon's confluence with the Tanana, the Yukon valley broadens south of the river; but within 5 miles of its northern banks rise the low Kokrines Hills, with peaks over 3,000 feet in altitude. About 175 miles downstream from the Tanana confluence, the last major tributary, the Koyukuk, drains southward from the south-central slopes of the Brooks Range. The Yukon there is only 117 feet above sea level and only about 100 miles due east of Norton Sound, but the river is forced to detour several hundred miles to the south and west around mountainous terrain.

As the Yukon nears the Bering Sea, it bends sharply northward to empty into Norton Sound. The river delta is about 40 miles across, swampy, and lake-covered. Many of the distributary channels are shallow, but the northeastern one, Apoon Pass, was once used by riverboats.

Climate. The valleys of the Yukon River basin, where nearly all of the population lives, have a subarctic climate with relatively warm, short summers; but the treeless upper mountain slopes, where there are no weather stations, are classified as having an Arctic climate. Bitterly cold air masses from Siberia or the Arctic Ocean cross Alaska and Yukon Territory throughout the long winter, but occasional warm air masses from the Pacific Ocean can penetrate over the high barrier of the St. Elias Mountains and bring warmer winter temperatures to the Whitehorse area. January mean temperatures are about −24° F (−31° C) at Dawson and about −6° F (−21° C) at Whitehorse. In 1947 the lowest temperature officially recorded in North America, −81° F (−63° C), was reported at Snag along the Alaska Highway in southwestern Yukon.

Average summer temperatures in the valleys of this high-latitude region, with its long hours of summer daylight, are moderately warm, with July mean temperatures of about 60° F (16° C) at Dawson and slightly lower at Whitehorse. Annual precipitation is low, as it is in most of northwestern Canada and central Alaska, with an average of about 10 inches (260 millimetres) recorded at Whitehorse and 12 inches at Dawson. Almost 50 percent of the precipitation falls as rain during the four summer months.

Plant and animal life. Coniferous forests grow to low height and low densities across the valley floors and lower mountain slopes of the Yukon River basin. The upper tree line is at an elevation of about 3,500 to 4,500 feet, depending on local exposure and drainage; thus, about two-thirds of mountainous Yukon Territory is treeless. The largest stands of potentially commercial forest are along the Alaska Highway in the Liard River valley in the southeastern Yukon, but this area is far from markets. White spruce is dominant on the valley floors, and black spruce grows in the poorly drained areas. In addition, Alpine fir and lodgepole pine are found in the lower areas along the Alaska Highway across the southern Yukon.

Mammals

A varied animal life inhabits the forested valleys. The larger mammals include black, brown, and grizzly bears; caribou, deer, and moose; and mountain goats and sheep at higher elevations. Timber wolves are common. Game birds such as grouse and ptarmigan are found, and waterfowl include many species of geese, swans, and ducks. The usual furbearers trapped by the Indian population include muskrat, mink, marten, lynx, weasel, fox, fisher, and squirrel. In the river itself are found species of such fish as Arctic grayling, burbot, pike, salmon, and whitefish.

The people and economy. The Yukon River basin has remained sparsely populated in the century and a half since it was first settled by Europeans. The lure of mineral wealth has been the main attraction of the region, and mining has maintained several of the settlements. Gold brought people to Fairbanks and Dawson; when the gold was depleted, Fairbanks continued to grow as it took on administrative and transportation functions for east-central Alaska, but the population of Dawson declined to only a tiny fraction of its size in the heyday of the gold rush. In the 1950s the Yukon territorial capital was moved from Dawson to the more accessible city of Whitehorse, on the Alaska Highway. Whitehorse then developed transportation and service functions for the other small settlements in the southern Yukon region and became the largest city in the territory.

Mines are marginal economic operations in the Yukon River basin because the area is far from world markets and has only a few land-transport routes. Lead, zinc, and silver have been produced at Keno City, near Mayo, since the 1920s, but the high-grade ore has to be transported southward to Trail, B.C., near the U.S.-Canadian border, for smelting. Since the early 1970s, copper and base metals have been mined at Faro, on the Pelly River west of the Mackenzie Mountains, and ore concentrates have been transported by truck to Whitehorse. Some gold is still extracted intermittently from alluvial deposits in several Yukon tributaries, and deposits of tungsten, iron, and coal are known.

Other economic activities are of minor importance in the Yukon basin. Fur trapping has been the traditional livelihood for the region's Indians, but low monetary returns plus the attraction of better pay from wage labour in the towns have taken many Indians away from their former migratory lives. Agriculture is a minor activity. Although vegetables, pasturage, and coarse grains can be grown during the long days of the short summer, only a small number of farms are operated; most of the food consumed in Whitehorse, for example, is shipped in from southern Canadian farms. Perhaps the main resource of the Yukon basin is its scenery, isolation, and sparse population, all of

which are attractive to tourists seeking to escape the more crowded and less scenically endowed areas of the continent. The many vistas of the winding river, its forested slopes supporting game and wildlife, and the game fish in the tributary lakes are all part of an attractive natural environment that has become more difficult to find in southern regions.

Era of the fur traders and the initial discoveries

History. The delta mouth of the Yukon River was known to the Russians when they occupied nearby St. Michael Island in 1831, but the headwaters in British North America remained unknown for another decade. By 1838 Russian fur traders had explored the river as far inland as Nulato (Alaska), where they established a post near the junction of Koyukuk River. By 1846 the Russians had mapped almost 600 miles of the lower river. The trader Robert Campbell, of the Hudson's Bay Company, explored Pelly River, one of the Yukon headwaters, in 1840. In 1848 he established a trading post at Fort Selkirk, at the junction of the Pelly and Yukon rivers, in order to trade with the local Indians. In 1851 Campbell explored the Yukon downstream to the junction of the Porcupine River, where Fort Yukon had been built in 1847. When the trading post at Fort Selkirk was burned by hostile Indians in 1852, however, Europeans withdrew from the upper Yukon basin for two decades.

Water transportation gradually extended upstream from the mouth of the Bering Sea. Shallow-draft steamers had been operating on the river in Alaska after 1866, and the first riverboat reached Yukon Territory a few years later. The Yukon River became known to the world following the rich gold strikes in 1896 on the Klondike River in Canada. In the summer of 1898 at least 20 vessels rounded the extremity of southwestern Alaska and navigated the lower Yukon River to reach the booming community of Dawson City (the name later was shortened to Dawson). Other gold seekers took a shorter route by penetrating north through the Coast Mountains from Skagway, Alaska; they made crude boats or rafts on Bennett Lake and floated downstream to the rapids near Whitehorse. From there riverboats took passengers and freight downstream to Dawson. When gold-mining activity declined during the years following World War I, the use of water transport on the Yukon River also decreased. The riverboats ceased to operate on the Canadian part of the river in the 1950s, being replaced by road and air transport to Dawson and other small towns. (J.L.Ro.)

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The economy. BRIAN J.L. BERRY, EDGAR C. CONKLING, and D. MICHAEL RAY, *The Geography of Economic Systems* (1976), is a general theoretical text, with detailed case studies including a survey of North America's industrial heartland. Another broad study is ANN MARKUSEN, *Regions: The Economics and Politics of Territory* (1987), an enterprising economist's effort to come to grips with the stubborn reality of regional differences and their economic and political implications. The relationship between the main sectors of economy and their locations is explored in HOWARD F. GREGOR, *Geography of Agriculture* (1970), an informative introduction, with most examples focusing on North America; E. WILLARD MILLER, *Manufacturing: A Study of Industrial Location* (1977), a standard text with special emphasis on the U.S. scene; ANN MARKUSEN, PETER HALL, and AMY GLASMEIER, *High Tech America: The What, How, Where, and Why of the Sunrise Industries* (1986), an excellent economic geography; SUSAN HANSON (ed.), *The Geography of Urban Transportation* (1986), a collection of original essays focusing on the U.S. situation; and JAMES E. VANCE, JR., *Capturing the Horizon: The Historical Geography of Transportation Since the Transportation Revolution of the Sixteenth Century* (1986), a comprehensive study of the topic, with ample attention to North America, and *The Merchant's World: The Geography of Wholesaling* (1970), a provocative theoretical and historical treatment with special reference to the United States.

Discussions of resources and their exploitation are found in LEONARD L. FISCHMAN (ed.), *World Mineral Trends and U.S. Supply Problems* (1980), a consideration of long-term potential supply and price problems for seven major nonfuel minerals; *Minerals Yearbook,* offering detailed annual surveys of the mineral industries of the United States and the world; MICHAEL WILLIAMS, *Americans and Their Forests: A Historical Geography* (1989), a definitive monograph on all aspects of U.S. forests and their exploitation, past and present; GORDON G. WHITNEY, *From Coastal Wilderness to Fruited Plain: A History of Environmental Change in Temperate North America, 1500 to the Present* (1994), also focusing on the forests; REXFORD DAUBENMIRE, *Plant Geography: With Special Reference to North America* (1978), a standard text on the subject; JOHN W. BARRETT (ed.), *Regional Silviculture of the United States,* 2nd ed. (1980), an assessment of the biological, physical, and economic qualities of the forested regions of the country; JAMES J. GERAGHTY *et al., Water Atlas of the United States,* new ed. (1973), a compendium of atmospheric, hydrologic, and water-use data; and WATER RESOURCES COUNCIL (U.S.), *The Nation's Water Resources, 1975–2000: Second National Water Assessment,* 4 vol. in 29 (1978), a comprehensive appraisal.

EARL COOK, *Man, Energy, Society* (1976), presents a broad review of the role of energy in modern society, with an emphasis on the fossil fuels and energy policy questions that face the United States. DAVID J. CUFF and WILLIAM J. YOUNG, *The United States Energy Atlas,* 2nd ed. (1986), offers comprehensive coverage of energy resources, production, transport, consumption, and other relevant topics using maps, graphs, and text. PHILIP R. PRYDE, *Nonconventional Energy Resources* (1983), is a broad survey of solar, wind, geothermal, hydroelectric, biomass, nuclear, electrochemical, and oceanic energy resources. (W.Ze.)

North American geographic features of special interest. *Landforms:* Information on the geology and physiography of the Alaskan mountains is found in HOWEL WILLIAMS (ed.), *Landscapes of Alaska: Their Geologic Evolution* (1958), a well-written description of all parts of the peninsula; CLYDE WAHRHAFTIG, *Physiographic Divisions of Alaska* (1966), a detailed summary survey with good maps and illustrations; and GEORGE PLAFKER and HENRY C. BERG, *The Geology of Alaska* (1994), a comprehensive work. MAYNARD M. MILLER, "Alaska's Mighty Rivers of Ice," *National Geographic Magazine,* 131(2):194–217 (February 1967), surveys the glacial character of Alaska's mountainous coast. Plant and animal life is outlined in LESLIE A. VIERECK and ELBERT L. LITTLE, JR., *Alaska Trees and Shrubs* (1972, reprinted 1986), a good field guide for identification; JACOB PETER ANDERSON, *Anderson's Flora of Alaska and Adjacent Parts of Canada,* new ed. edited by STANLEY L. WELSH (1974); and CLARENCE J. RHODE and WILL BARKER, *Alaska's Fish and Wildlife* (1953), a brief nontechnical summary. ROBERT MARSHALL, *Alaska Wilderness: Exploring the Central Brooks Range,* 2nd ed. (1970), describes the physiography, flora, and fauna of this region. NATIONAL GEOGRAPHIC SOCIETY (U.S.), SPECIAL PUBLICATIONS DIVISION, *Alaska's Magnificent Parklands* (1984), provides general descriptions of the state's main parks. (M.M.M.)

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A concise physical description of the Panama Canal is found in SANDRA W. MEDITZ and DENNIS M. HANRATTY (eds.), *Panama: A Country Study,* 4th ed. (1989). PAUL J. SCHEIPS (ed.), *The Panama Canal: Readings on Its History* (1979); and DAVID MCCULLOUGH, *The Path Between the Seas: The Creation of the Panama Canal, 1870–1914* (1977), detail the history of the canal's construction. The decision to build the canal in Panama as opposed to other locations is discussed in such historical works as MILES P. DUVAL, JR., *Cadiz to Cathay: The Story of the Long Diplomatic Struggle for the Panama Canal,* 2nd ed. (1947, reissued 1968); and GERSTLE MACK, *The Land Divided: A History of the Panama Canal and Other Isthmian Canal Projects* (1944, reprinted 1974). NORMAN J. PADELFORD, *The Panama Canal in Peace and War* (1942), focuses on the strategic significance of the waterway. Later works treat the canal mostly from the point of view of international law and foreign relations, including G.A. MELLANDER, *The United States in Panamanian Politics* (1971); PAUL B. RYAN, *The Panama Canal Controversy: U.S. Diplomacy and Defense Interests* (1977); J. MICHAEL HOGAN, *The Panama Canal in American Politics* (1986); and WALTER LAFEBER, *The Panama Canal: The Crisis in Historical Perspective,* updated ed. (1989). (B.L.G.)

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The geography, hydrology, and physical features of the St. Lawrence River and Seaway are detailed in CANADIAN HYDROGRAPHIC SERVICE, *Sailing Directions, Gulf and River St. Lawrence,* 6th ed. (1985). RONALD I. HEILMANN, HAROLD M. MAYER, and ERIC SCHENKER, *Great Lakes Transportation in the Eighties* (1986), reports shipping and economic conditions in the area. Relevant information is found in *Seaway Review* (quarterly). A short study, *The Great Lakes St. Lawrence System: The World's Richest Economic Region, Served by the World's Most Efficient Trade Route* (1984), offers a pertinent overview. Historical surveys are provided in GENNIFER SUSSMAN, *The St. Lawrence Seaway* (1978); and JEAN-CLAUDE LASSERRE, *Le Saint-Laurent* (1980). (P.C.)

RICHARD K. MATHEWS, *The Yukon* (1968), is an informative geography from the series *Rivers of America.* A brief study of hydrology is found in UNITED STATES, ARMY, CORP OF ENGINEERS, ALASKA DISTRICT, *Yukon and Kuskokwim River Basins, Alaska* (1987). *Yukon Data Book* (biennial) is a reference periodical published by the Yukon Territory government. Informative illustrated descriptions of travel along the river include KEITH TRYCK, *Yukon Passage: Rafting 2000 Miles to the Bering Sea* (1980); and STAN COHEN, *Yukon River Steamboats* (1982). ALLEN A. WRIGHT, *Prelude to Bonanza* (1976), describes the discovery and exploration of the territory. Other histories of the territory and the people include R.C. COUTTS, *Yukon: Places & Names* (1980); MELODY WEBB, *The Last Frontier* (1985, reissued as *Yukon: The Last Frontier,* 1993); and CATHARINE MCCLELLAN, *Part of the Land, Part of the Water: A History of the Yukon Indians* (1987). Surveys of present-day conditions can be found in D.K. REDPATH, *Land Use Programs in Canada, Yukon Territory* (1979). (J.L.Ro.)

Norway

Norway, the "northern way," occupies the western half of the Scandinavian peninsula of northern Europe. The country, called Norge in traditional Norwegian and Noreg in New Norwegian, has an area of 125,050 square miles (323,878 square kilometres), excluding the dependencies of Svalbard and Jan Mayen, Bouvet Island, and Peter I Island. With the Barents Sea to the north, the Norwegian Sea and the North Sea to the west, and Skagerrak (Skager Strait) to the south, Norway has land borders only to the east—with Sweden, Finland, and Russia. Nearly half of the inhabitants of the country live in the far south, in the region around Oslo, the capital. About two-thirds of Norway is mountainous, and off its much-indented coastline lie some 50,000 islands.

Norway has always depended heavily on its economic relations with foreign countries; this has been the case during both its periods of independence and those times when it has been politically united with its fellow Scandinavian nations, Sweden and Denmark. These foreign links are illustrated by the heritage of the Vikings, who plundered the coasts from the British Isles into the Mediterranean Sea and sailed the Atlantic Ocean to North America. Later the Norwegians turned to trading in fish and lumber, and the modern nation emerged as a major maritime transporter of the world's goods as well as a world leader in specialized shipbuilding. In the 1970s the exploitation of offshore oil and natural gas became the major maritime industry; shipbuilding declined substantially during the 1980s.

Lying on the northern outskirts of the European continent and thus avoiding the characteristics of a geographic crossroads, Norway has maintained a great homogeneity among its peoples and their way of life. Its projections for life expectancy are among the highest of any in the world. The main political division reflects differing views on the importance of free market forces. But the Socialists long ago stopped insisting on nationalization of the nation's industry, and the non-Socialists have accepted extensive governmental control of the country's economy. Such evidence of national consensus, along with abundant waterpower, offshore oil, and peaceful labour relations, have been a major factor in the rapid growth of Norway as an industrial nation in the 20th century and in the creation of one of the highest standards of living in the world.

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Physical and human geography

THE LAND

Norway occupies part of northern Europe's Fennoscandian Shield. The extremely hard bedrock, which consists mostly of granite and other heat- and pressure-formed materials, ranges from 1,000,000,000 to 2,000,000,000 years in age.

Glaciation

Relief. Glaciation and other forces wore down the surface and created thick sandstone, conglomerate, and limestone deposits known as sparagmite, as well as numerous extensive areas, called peneplains, whose relief has been largely eroded away. Remains of the latter include the Hardanger Plateau, 3,000 feet (900 metres) above sea level, Europe's largest mountain plateau, covering about 4,600 square miles (11,900 square kilometres) in southern Norway; and the Finnmark Plateau, 1,000 feet (300 metres) above sea level, occupying most of the northernmost and largest county of Norway.

From the Cambrian through the Silurian geologic periods, from about 570,000,000 to 395,000,000 years ago, most of the area was below sea level and acquired a layer of limestone, shale, slate, and conglomerate from 330 to 525 feet thick. Folding processes in the Earth then gave rise to a mountain system that is a continuation of the Caledonian System of the British Isles. Norway has an average elevation of 1,600 feet, compared to 1,000 feet for Europe as a whole.

Rivers running westward acquired tremendous erosive power. Following fracture lines marking weaknesses in the Earth's crust, they dug out gorges and canyons that knifed deep into the jagged coast. To the east the land sloped more gently, and broader valleys were formed. During repeated periods of glaciation in the Great Ice Age of the Quaternary Period, less than 2,500,000 years ago, the scouring action of glaciers tonguing down the V-shaped valleys that were then part of the landscape created the magnificent U-shaped drowned fjords that now grace the western coast of Norway. Enormous masses of earth, gravel, and stone were also carried down by glacial action as far south as present-day Denmark and northern Germany. The bedrock, exposed in about 40 percent of the area, was scoured and polished by the movements of these materials.

Soils. In the melting periods between ice ages, large areas were flooded by the sea because the enormous weight



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of the ice had depressed the land. Thick layers of clay, silt, and sand were deposited along the present coast and in large areas in the Oslo and Trondheim regions, which rise as high as 650 feet above sea level today. Some very rich soils are found below these old marine coastal regions. In the large areas covered by forests, the main soil has been stripped of much of its mineral content, creating poor agricultural land.

Drainage. The Glåma (Glomma) River, running south almost the entire length of eastern Norway, is 372 miles long—close to twice the length of the two other large drainage systems in southern Norway, which meet the sea at the cities of Drammen and Skien. The only other long river is the 224-mile-long Tana-Anarjåkka, which runs northeast along part of the border with Finland. Among Norway's more than 160,000 lakes, by far the largest is Mjøsa, which is 50 miles north of Oslo on the Lågen River, a tributary of the Glåma.

Climate. Although it occupies almost the same degrees of northern latitudes as Alaska, Norway owes its warmer climate to the Gulf Stream, which carries 4,000,000 to 5,000,000 tons of tropical water per second into the surrounding seas. The Gulf Stream usually keeps the fjords from freezing, even in the Arctic Finnmark region. Even more important are the southerly air currents brought in above these warm waters, especially during the winter.

Effect of the Gulf Stream

The annual mean temperature on the west coast is 45° F (7° C), or 54° F (30° C) above average for the latitude. In the Lofoten Islands, north of the Arctic Circle, the January mean is 43° F (24° C) above the world average for this latitude, one of the greatest thermal anomalies known. Norway lies directly in the path of the North Atlantic cyclones, which bring frequent gales and changes in weather. Western Norway has a marine climate, with comparatively cool summers, mild winters, and up to 80 inches (2,030 millimetres) of mean annual precipitation. Eastern Norway, sheltered by the mountains, has an inland climate with warm summers, cold winters, and less than 30 inches mean annual precipitation.

Plant and animal life. Norway has about 2,000 species of plants, but only a few, mainly mountain plants, are endemic to Norway. Thick forests of spruce and pine predominate in the broad glacial valleys up to 2,800 feet above sea level in eastern Norway and 2,300 feet in the Trondheim region. Even in the thickest spruce woods, the ground is carpeted with leafy mosses and heather, and a rich variety of deciduous trees—notably birch, ash, rowan, and aspen—grow even on the steepest hillsides. The birch zone extends from 3,000 to 3,900 feet above sea level, after which there is a willow belt that includes dwarf birch.

In western Norway conifers and broad-leaved trees abound in approximately equal numbers. North of the Arctic Circle there is little spruce, and pine grows mainly in the inland valleys amid their surprisingly rich vegetation. Wild berries grow abundantly in all regions: they include blueberries and cranberries of small size and yellow cloudberries, a fruit-bearing plant of the rose family that is little known outside Scandinavia and Great Britain.

Reindeer, wolverines, lemmings, and other Arctic animals are found throughout Norway, although in the south only in the mountain areas. Elk are common in the large coniferous forests and red deer on the west coast. Only 100 years ago large animals of prey were common in Norway, but now the bear, wolf, and lynx are found only in a few areas, mainly in the north. Foxes, otters, and many species of marten, however, are common, and in many areas badgers and beavers thrive.

Mammals

Most of the rivers and lakes have a variety of fish, notably



The Seven Sisters Falls, Geiranger Fjord, with sod roof houses on the hillside, western Norway.
Kirkendall—Spring Photographers

trout and salmon. The latter are found in at least 160 rivers, often in an abundance that attracts anglers from all over the world.

Of the large variety of birds, many migrate as far south as southern Africa for the winter. In the north people collect eggs and down from millions of seabirds, and, as far south as Ålesund, small cliff islands often are nearly covered by several hundred thousands of nesting birds. Partridges and several kinds of grouse are common in the mountains and in the forests and are popular game birds.

Traditional regions. There are four traditional regions of Norway, three in the south and one in the Arctic north. The three main regions of the south are defined by wide mountain barriers. From the southernmost point a swelling complex of ranges, jointly called Langfjellet (Long Mountains), runs northward to divide eastern Norway, or Østlandet, from western Norway, or Vestlandet. An eastward sweep of the mountains separates Østlandet in the north from the Trondheim region, or Trøndelag. Almost exactly at the midpoint of the country, northern Norway, or Nord-Norge, begins.

Eastern Norway. Østlandet has more than half of Norway's population, most of whom live in the metropolitan area of the national capital, Oslo, and in the many industrial cities and urban agglomerations on both sides of Oslofjorden.

The agricultural core of the Østlandet lies in the lowlands extending eastward and southward to the Swedish border. With suitable precipitation during the growing season, the highest July temperatures in Norway, a soil consisting of relatively rich marine deposits, and large nearby markets, the land is intensively cultivated. There are even a number of large, heavily mechanized farms producing cereal grains, which generally do not grow well in such latitudes. Most of the farms, however, are small. To supplement their income from domestic animals, vegetables, and fruits, a great number of farmers pursue forestry as a secondary occupation, since most of the forests are a part of farm acreages.

Norway has never had the agricultural villages that are common elsewhere in Europe. The more densely populated areas of the country have grown up around crossroads of transportation, from which people have moved to the cities and suburbs. Thus, there is actually little borderline between the rural and urban populations. For many years Oslo has attracted settlers from all over the country, becoming a national melting pot surrounded by the most important agricultural and industrial districts of Norway.

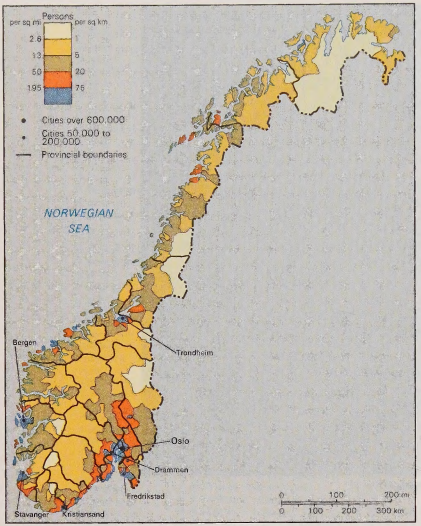
Urban and rural populations

In the interior of Østlandet, farms are located along the sides of the broad valleys, the bottoms of which contain only washed-out deposits of soil. Frost is more frequent in spring and fall than it is in the coastal areas. The largest forests in Norway are to be found between the Swedish border and the Glåma River, east of Oslo. The coastline facing Denmark across the Skagerrak passage, stretching from Oslofjorden to the southern tip of Norway, is densely populated and contains many small towns, coastal villages, and small farms. Centred on the city of Kristiansand, this southern area is sometimes set apart as a fifth region, Sørlandet. The coastline has developed into Norway's foremost summer vacation area. The land is hilly, but the growing season is slightly longer than around Oslo. The interior of this area, with narrow valleys running up into the beginnings of Langfjellet, is very sparsely populated, and the people of the scattered settlements depend more on dairy farming, sheep raising, and forestry. Economically and in view of other practical aspects, however, Sørlandet is usually included as part of Østlandet.

In all, about half of Østlandet is forested. The region has slightly more than half of Norway's total forest resources and an equivalent share of Norway's total area of fully cultivated land. In mining and manufacturing Østlandet also has more than half of the nation's total production value and of its total trade. These lions' shares of the national wealth, combined with the concentration of economic activity around Oslofjorden, secure for Østlandet the highest average income per household of the four regions.

Western Norway. The narrow coastal zone of Vestlandet has many islands and steep-walled, narrow fjords cutting deep into the interior mountain region. The major exception is the wide Jæren Plain, south of Stavanger. With rich glacier-formed soils, exceptionally mild winters, long growing seasons, and plentiful precipitation, Jæren boasts the highest yields of any agricultural area in Nor-

Agriculture in Jæren



Population density of Norway.

way, and those who farm this rich land are not distracted by the necessity of forestry or fishing.

Stavanger is an expanding industrial centre, particularly in canning and engineering. It is also the main base for the petroleum and natural gas activities in the North Sea. To the north, Haugesund thrives on fishing and other industries. The island of Karm comprises a rich agricultural area. The fjord areas of Hardanger are more sheltered, with rich fruit districts specializing in apples and cherries.

Bergen is the natural centre of Vestlandet. Since the late Middle Ages, when it was an active trading centre for northern Europe, the city has had a more international character than any other in Norway. The Sunnmøre district, farther north on the coast, has the important fishing port of Ålesund as its local centre; it contains many engineering firms, and the bulk of Norway's furniture industry is gathered on its rocky coast. Fishing, which predominates farther to the north, around the cities of Molde and Kristiansund, is a main second occupation, as forestry is in Østlandet. Deep in the Vestlandet fjords lie many of Norway's largest smelting plants.

Central Norway. Trøndelag is Norway's most typical agricultural region, with flat, fertile land around the wide Trondheim Fjord and the city of Trondheim. Nearly one-third of its area is forested, and fishing is important. It once had a large proportion of Norway's mining industry. Trondheim, the third largest city in Norway and for long periods the national capital, dominates the economic life of Trøndelag and is a centre for education and research.

Northern Norway. Nord-Norge, most of which is above the Arctic Circle, is truly the "land of the midnight sun" in the summer, whereas during December and most of January the sun does not rise. Most of the region is filled with mountains with jagged peaks and ridges, even on the islands. A long string of large islands jutting into the North Atlantic west of Vest Fjord forms the Lofoten Wall. Numerous fjords scissor into this narrow strip of Norway's northern tail. As many roads are closed during winter, sea and air transportation are vital.

Isolation of the north

Some of the inland valleys have dense forests. The short summers and poor soil limit agriculture to a largely subsidiary activity, though the production of milk, meat, and potatoes is surprisingly high in many districts. Fishing, mining, and manufacturing dominate the economy.

THE PEOPLE

In most parts of Norway the nucleus of the population is Nordic in heritage and appearance. Between 60 and 70 percent have blue eyes. An influx of people from southern Europe has been strong in southwestern Norway. Nord-Norge has about nine-tenths of the 20,000 to 30,000 Sami (Lapps, or Laplanders) living in Norway. Only about 2,800 of them still live on the Finnmark Plateau and move their reindeer herds down to the coast for summer grazing. The Sami were Norway's first inhabitants; they arrived at least 10,000 years ago, probably from Central Asia.

The Norwegian language belongs to the North Germanic branch of the Germanic language group. The alphabet has three more letters than the Latin alphabet—æ, ø, and å. Modern Norwegian has many dialects, but all of them, as well as the Swedish and Danish languages, are understood throughout Scandinavia. Until about 1850 there was only one written language, called Riksmål, or "Official Language," which was strongly influenced by Danish during the 434-year union of the two nations. Landsmål, or "Country Language," was then created out of the rural dialects. After a long feud, the forms received equal status under the terms Dano-Norwegian (Bokmål, or "Book Language") and New Norwegian (Nynorsk), respectively. Dano-Norwegian is the main language in local schools.

Dialect status

About nine-tenths of all Norwegians belong to the Evangelical Lutheran national church, the Church of Norway. In addition to other Christian denominations, there are small groups of Muslims and Buddhists.

With a significant increase in the proportion of the population over age 80, the population of Norway grew slowly but steadily at the end of the 20th century. The birth rate fell slightly during the 1990s—but so did the death rate, as life expectancy (about 75 years for men and about 81 years for women) was among the highest in Europe.

THE ECONOMY

The economy is dependent largely on the fortunes of Norway's important petroleum industry. Thus, it experienced a decline in the late 1980s as oil prices fell but by the late 1990s had rebounded strongly, benefiting from increased production and higher prices. Norway reversed its negative balance of payments, and the growth of its gross national product (GNP)—which had slowed during the 1980s—accelerated. By the late 1990s Norway's per capita GNP was the highest in Scandinavia and among the highest in the world. To reduce economic downturns caused by drops in oil prices, the government in 1990 established the Government Petroleum Fund, into which budget surpluses were deposited for investment overseas.

Fewer than 5 percent of the industrial companies in Norway have more than 100 employees. Nonetheless, they account for half of the industrial labour force and for more than half of production. The smaller companies are usually family-owned, whereas most of the larger ones are joint-stock companies. Foreign interests control companies accounting for about 10 percent of total production. Only a few larger concerns are state-owned, and even these are usually run with almost complete independence.

Industrial ownership

Agriculture and fishing are highly organized, and they are subsidized by the state. In remote districts private industry may receive special incentives in the form of loans and grants or tax relief. Taxes are high, with sharply progressive income taxes and a value-added (or consumption) tax of 23 percent on all economic activity. Total tax revenues are equivalent to about half of the GNP, but much of this represents transfers of income; *i.e.*, it is returned to the private sector in the form of price subsidies, social insurance benefits, and the like. All this has added to economic problems of inflation, but increases in productivity have made possible a high rate of growth in real income.

Resources and industry. By the mid-1990s Norway had become the world's second largest oil exporter (behind Saudi Arabia). About half of export earnings and nearly one-tenth of government revenues came from offshore oil and

gas. It was estimated that high oil production levels could last at least into the second decade of the 21st century.

More than one-fourth of the huge investment made in Norwegian offshore operations by the mid-1990s went toward the development of the Troll field just west of Bergen, one of the largest offshore gas fields ever found. Its development ranked as one of the world's largest energy projects. With a water displacement of one million tons and a height of nearly 1,550 feet (470 metres), the Troll A production platform was the tallest concrete structure ever moved when it was towed into place in 1995. Gas deliveries from the Troll field made Norway a leading supplier of natural gas to continental Europe.

About half of Norway's 65,000 largest lakes are situated at elevations of at least 1,650 feet (500 metres), about one-fifth of the country lies 2,950 feet (900 metres) or more above sea level, and predominantly westerly winds create abundant precipitation. As a result, Norway has tremendous hydroelectric potential. It is estimated that almost one-third of that potential is economically exploitable, of which more than three-fifths had been developed by the mid-1990s. Some 850 hydropower stations meet virtually all Norway's electrical consumption needs. Norway's per capita production of electricity is the world's highest, twice that of the United States.

Hydroelectric power

About one-third of the country's electricity production is utilized by the electrometallurgical industry. In addition to being among the world's leading exporters of metals, Norway is a significant producer of iron-based alloys. Europe's largest deposit of ilmenite (titanium ore) is located in southwestern Norway. The country also is the world's principal producer of olivine and an important supplier of nepheline syenite and dimension stone (particularly larvikite). Pyrites and small amounts of copper and zinc also are mined, and coal is mined on Svalbard. In all, mining and manufacturing (excluding petroleum activities) account for more than one-third of Norway's export earnings.

Agriculture, forestry, and fishing. By the 1990s the number of farms of at least 1.25 acres (0.5 hectare) had decreased by more than half of its 1950 total of more than 200,000. Much of the abandoned acreage was absorbed into the remaining farms. Nevertheless, many farms remain small; about half have more than 25 acres (10 hectares) of farmland, while about 1 percent have more than 125 acres (50 hectares). Labour for hire is scarce, and most of the work must be done by farmer-owners themselves. Extensive mechanization and fertilization, however, have kept total farm output on the increase. Livestock is the major agricultural product, and, though the country is more than self-sufficient in animal products, it remains dependent on imports for cereal crops.

Although less than one-twentieth of Norway's total area is agricultural land, productive forests comprise more than one-third of the total area. Along the coast fishing plays an important role. It forms the basis of a large and growing fish-processing industry and offers seasonal employment for many farmers. Most fishing vessels are owned by the fishermen themselves, the necessary crew members being paid by shares of gross income in a continuation of a centuries-old tradition of the sea. A critical problem is how to avoid depleting the fish resources while maintaining the volume. About half the catch, most of it near the coast, goes into fish meal and oil, but some is processed for human consumption in freezing plants.

Employment in fisheries

By the mid-1990s fish farming had developed into the cornerstone of the coastal economy. The total number of fishermen decreased from about 100,000 in 1950 to fewer than 25,000 by the mid-1990s, and the number of vessels decreased by more than three-fifths over the same period. Once a world leader in Antarctic whaling, Norway has since 1968 hunted only smaller species of toothed whales. In the late 1980s and early 1990s Norway complied with the International Whaling Commission's total ban on commercial whaling. By the mid-1990s, however, the government gradually allowed limited catches on some species, arguing that they were not endangered any longer and that they posed a serious threat to fish populations. The latter argument is also used in defense of sealing, though both whaling and sealing have declined sharply.

Finance and trade. The Bank of Norway has all the usual functions of a central bank, and it also advises the government on the practical implementation of credit policy. In 1984 foreign banks were allowed to establish branches in Norway. The country has an active stock market.

As a result of the downturn in the Norwegian economy in the late 1980s, commercial banks experienced a crisis in 1991. Many of the largest became primarily government-owned as new capital was invested by the Government Bank Security Fund; the old shares were declared worthless. Critics argued that the crisis was worsened by new rules requiring that the depreciation of property be counted as a loss, even when the property was not sold. By the mid-1990s, however, the government-rescued banks had returned to profitability.

Norway's petroleum industry has ensured a strong positive balance of payments for the national economy, despite some declines in the manufacturing and agricultural sectors. The great majority of Norway's petroleum exports go to the nations of the European Union. Other important exports are machinery and transport equipment, metals and metal products, and fish. Norway's principal trading partners are the United Kingdom, Germany, and Sweden. Principal imports include machinery, motor vehicles, ships, iron and steel, and food products, especially fruits and vegetables.

Oil and natural gas

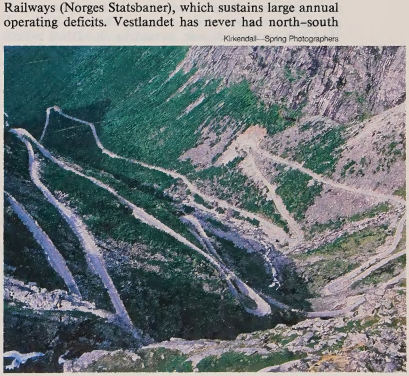
Transportation. The elongated shape of Norway and its many mountains, large areas of sparse population, and severe climate make special demands on transportation services. Only the Oslo region has sufficient traffic density to make public surface transportation profitable. A large fleet of vessels links the many fine ports along the sheltered coast. Norway's largest and busiest ports include those in Bergen, Oslo, Stavanger, Kristiansund, and Trondheim. Norwegian shipowners run one of the world's largest merchant fleets, carrying about one-tenth of the world's total tonnage. Shipping accounts for more than half of Norway's foreign-currency earnings.

Bus transport plays a key role in public transportation, aided by some 215 scheduled ferry routes. The number of private automobiles has increased rapidly, creating parking problems and traffic jams in the major cities. Of the more than 50,000 miles (80,000 km) of public roads in Norway, about two-thirds are hard-surfaced. In 2000 the Lærdal-Aurland tunnel (15.2 miles [24.5 km]) was opened along the route linking Oslo and Bergen. The world's longest road tunnel, it provides a reliable connection between the two cities, replacing mountain highways that were impassable during the winter months.

The 2,500 miles of railway, more than half of which has been electrified, are operated by the Norwegian State Railways (Norges Statsbaner), which sustains large annual operating deficits. Vestlandet has never had north–south

Railways

Kirkendall—Spring Photographers



Switchback road of Trollstigheim Pass, Møre og Romsdal *fylke* (county), western Norway.

railway connections, only routes running east from Stavanger and Bergen to Oslo and from Åndalsnes to Dombås on the line linking Oslo and Trondheim. The connection from Bodø to Trondheim was completed in 1962. Farther north, the only railway is the extension of the Swedish railway system to Narvik, which is used mainly to carry iron ore for export. Of the three other links with Swedish railways, one runs from Trondheim and two from Oslo—the southernmost connecting Norway to the Continent via the Swedish and Danish railways.

Norway is a partner in the Scandinavian Airlines System (SAS), which pioneered commercial flights across the Arctic. Two private airline companies add to the increasing domestic service among Norway's more than 40 airfields with scheduled civilian traffic. The major airports for international flights are located near Oslo, Stavanger, and Bergen.

ADMINISTRATION AND SOCIAL CONDITIONS

Norway is a constitutional hereditary monarchy. The legislative body is the 157-member Storting, elected by vote of all persons over 18 years of age. The monarch nominally selects the prime minister and State Council with the agreement of the Storting.

Government. The constitution of Norway, drafted in 1814 when Norway left the 434-year union with Denmark, was influenced by British political traditions, by the constitution of the United States, and by French revolutionary ideas. Amendments can be made by a two-thirds majority in the Storting. Unlike many parliamentary forms of legislature, the Storting cannot be dissolved during its four-year term of office. If a majority in the Storting votes against an important Cabinet issue, the minister responsible or even the whole Cabinet resigns. In legislative matters the monarch has a suspending right of veto, but this has never been exercised since the 91-year union with Sweden was dissolved in 1905.

Multi-party system

Norway's political life functions through a multiparty system. Before national elections, held every four years, political parties nominate their candidates at membership meetings in each of Norway's *fylker* (counties). According to its population, each *fylke* elects a number of representatives to the Storting, with party representation allotted on the basis of the percentage of the vote received.

The Norwegian Labour Party (Det Norske Arbeiderpartiet; DNA), the dominant party from before World War II until the mid-1960s, advocates a moderate form of socialism. In its many years of governing Norway, however, it nationalized only a few large industrial companies. The Conservative Party, which traditionally has been the major alternative to the DNA, accepts the welfare state and approves of the extensive transfers of income and of government control of the economy. Between 1945 and 1965 the government was formed by the DNA, which won clear majorities in the Storting.

After 1965, however, no single party was able to obtain a majority in the legislature, and Norway was governed by a succession of non-Socialist coalitions and minority governments. Political parties that have played important roles during this period include the Christian People's (Democratic) Party, Centre Party (called the Agrarian Party until 1958), Socialist Left Party, Progress Party, and Liberal Party.

Local administration

The city of Oslo constitutes one of the country's 19 *fylker*. The other *fylker* are divided into rural and urban municipalities, with councils elected every fourth year, two years after the Storting elections. For the country as a whole, the municipal elections tend to mirror the party division of the Storting. The municipal councils elect a board of aldermen and a mayor. Many municipalities also employ councillors for such governmental affairs as finance, schools, social affairs, and housing. Norwegians pay direct taxes to both federal and municipal governments.

The *fylker* can levy taxes on the municipalities for purposes such as roads, hospitals, secondary schools, and other joint projects. The *fylke* councils comprise delegates from the municipalities, while the *fylke* governors are appointed by the Cabinet.

Justice. Before civil cases can ordinarily be taken to court, they first must be submitted to conciliation councils, which settle many issues without recourse to more formal legal action. Decisions of the conciliation councils can be appealed to the courts, and Norway also has a formal system of courts of appeal. The Supreme Court is the final arbiter of legal decisions. The rights of the citizen are guarded also by an ombudsman, who acts on their behalf as an intermediary in matters with public administrators.

Armed forces. Military service of 12 to 15 months, plus refresher training, is compulsory for all fit Norwegian men between 22 and 44 years of age. Nonetheless, Norway's defense force is far too small to protect all of its territory against a major aggressor. Its strategy is designed to defend key areas, especially in the north, until forces from other members of the North Atlantic Treaty Organization (NATO) could be moved in. The Norwegian units have great mobility, and, with its important strategic location as NATO's northern flank and its myriad of fjords to serve as naval bases for fleets in the North Atlantic, Norway has sophisticated early-warning systems.

International military alliances

The NATO headquarters for northern Europe is located at Kolsås, near Oslo. Foreign troops and nuclear weapons, however, are excluded from Norway by law except in cases of war or immediate threat of war. The Norwegian Air Force has a number of ground-to-air missiles and various aircraft from other Western nations. The navy consists of heavy coastal artillery and such light vessels as gunboats, torpedo boats, submarines, and corvettes up to 1,800 tons. The total active military personnel number fewer than 40,000—of which nearly two-thirds are conscripts—but an additional 280,000 are members of first-line reserves and can be mobilized quickly in cases of emergency.

Education. All of Norway's municipalities require nine years of basic schooling, with an optional 10th year. Mandatory subjects include Norwegian, religion, mathematics, music, physical education, science, and English. Optional courses in the arts and in other foreign languages and vocational training in such areas as office skills, agriculture, and seamanship are available in the upper grades. With three years of additional high school, students may take the examinations leading to university study. A small percentage of college and university students study abroad. Institutions of higher education in Norway have been expanded to accommodate the doubling of the student group by the end of the 20th century. The country's four universities are located in Oslo (established 1811), Bergen (1946), Trondheim (1968), and Tromsø (1968).

As many students attend vocational schools as attend colleges and universities, and a few thousand students attend folk high schools, boarding schools offering a one-year course designed for 17-year-old students from rural areas. Only a few of Norway's schools charge tuition, and all students are eligible for government loans.

National programs in medicine and welfare

Health and welfare. Compulsory membership in a national health-insurance system secures for all Norwegians free medical care in hospitals, compensations for doctors' fees, and free medicine, as well as an allowance to compensate for lost wages. Membership fees securing cash benefits during illness or pregnancy, covered by another insurance fund, are compulsory for salaried employees and optional for the self-employed. Most Norwegian doctors work in hospitals, the majority of which are owned by the state, counties, and municipalities. Extensive programs of preventive medicine have conquered Norway's ancient nemesis, tuberculosis. There is also a well-developed system of maternal and child health care, as well as compulsory school health services and free family counseling by professionals. A public dental service provides care for 90 percent of the children between seven and 15 years of age. In some municipalities dental care has been extended downward to three years of age and upward to 20 years.

A "people's pension" was established in Norway in 1967 to ensure for the entire population a standard of living reasonably close to the level that the individual had achieved during his working life. The pension covers old age as well as cases of disability or loss of support. The premiums are paid by the individual members, employers, municipalities, and the state. The basic pension is adjusted every year, regardless of the plan's income. Supplementary

pensions vary according to income and pension-earning time. The state pays a family allowance for all children up to 16 years of age.

Housing and living standards. Until the 1970s Norway felt the housing shortage created by World War II; the shortage was aggravated by high costs in the densely populated urban areas. But housing standards have improved tremendously, and most families live in houses built since the war, a majority of them financed by state loans on favourable terms.

Norway ranks among the top 10 nations of the world in gross national product per capita. From 1945 to 1970 individual income per capita tripled in real terms. Tax rates that progress upward with income and the greatly increased social-security benefits, allocated mainly according to need, contributed to a leveling of incomes. The perennial shortage of labour, especially of skilled workers, had a parallel effect.

Norwegians spend a smaller share of their income than formerly on food, beverages, and tobacco. Travel and leisure activities have increased their share rapidly, however, as have such household goods as electrical appliances. During the 1960s the number of automobiles per inhabitant increased dramatically, from one in 21 to one in three. A four-week vacation every year with somewhat more than full wages was established by law in 1964. Working hours may not exceed nine hours a day or 40 hours per week. A five-day workweek had become the rule by the late 1960s.

CULTURAL LIFE

Located on the outskirts of Europe, and with much of its inland population almost completely isolated until the 20th century, Norway has been able to preserve much of its old folk culture. On the other hand, as seafarers and traders the Norwegians have always received fresh cultural stimuli from abroad. A number of Norwegians have made important contributions in return, notably the playwright Henrik Ibsen and the composer Edvard Grieg. The Norwegian recipients of the Nobel Prize for Literature are Bjørnstjerne Bjørnson, Knut Hamsun, and Sigrid Undset.

Literature and performing arts

Although Norway comprises one of the world's smallest language communities, the country is among the leaders in books published per capita. The annual number of new titles is about 5,000, of which two-thirds are of Norwegian origin. Literature is subsidized through a variety of means, including tax exemption, grants to writers, and government purchasing for libraries. In all, there are about 5,000 public or school libraries, which annually lend some 24,000,000 books.

Permanent theatres have been established in several cities, and the state traveling theatre, the Riksteatret, organizes tours throughout the country, giving as many as 1,200 performances annually. The Norwegian Opera, opened in 1959, requires state subsidies, as do most other theatres. Films in Norway are subject to censorship, primarily on grounds of violence and, to a lesser extent, for erotic content. The production of Norwegian-made feature films is subsidized, but they usually number about 10 each year.

Visual arts

In addition to its National Art Gallery, Oslo opened a special museum in 1963 to honour Edvard Munch, probably Norway's most famous painter. The Sonja Henie–Niels Onstad Art Centre, opened in 1968 near Oslo, contains modern art from all over the world.

Norwegian painters of the 20th century have excelled in murals to such an extent that they are rivaled only by Mexican painters. Other artists are world renowned for their multimedia assemblages, pictorial weaving, and nonfigurative art in sculpture as well as painting. The works of Gustav Vigeland have been assembled in Oslo's Vigeland sculpture park in a spectacular display centred around a 60-foot granite monolith containing 121 struggling figures.

Medieval stave churches of upright logs and houses of horizontal logs notched at the corners have inspired the architecture. Private houses, almost all of wood, are made to fit snugly into the terrain. For larger buildings, steel and glass are supplemented by concrete that often is shaped and textured with considerable imagination.

Arts and crafts and industrial design flourish side by side, often inspired by archaeological finds from the Viking Age, by the culture of the northern Lapps, and by advanced schools of design. Norway has markedly increased its exports of furniture, enamelware, textiles, tableware, and jewelry, much of which incorporates design motifs reflecting these cultural heritages as well as avant-garde styles.

Recreation. Norwegians have the special advantages of abundant space and a traditionally close contact with nature. Cross-country skiing is a national pastime in the long winter season. In the Olympic Winter Games, the tiny nation has won more medals than any country except the Soviet Union. The Norwegians have more than 200,000 second homes, mainly located along the sheltered coastline and in the mountains. Even from downtown Oslo it takes only a 20-minute drive to get into deep forests, and on a pleasant Sunday in the winter the hills surrounding the city abound with skiers.

Scientific research. Science and research have limited means in a small country. In the natural sciences, however, reflecting the country's intimacy with an overpowering physical environment, individual efforts of Norwegians have won particular acclaim. Norwegian explorers, beginning with Erik the Red and his son Leif Eriksson and continuing in modern times with such men as Fridtjof Nansen, Roald Amundsen, and Thor Heyerdahl, have been world famous.

The communications media. Some 165 newspapers are published in Norway, about half of them daily, except for Sundays and holidays. Although most of the newspapers are small, average circulations have increased. Most newspapers have affiliations with political parties, but these affiliations are reflected very little in readership. The labour press, for example, has less than a quarter of the total circulation, even though the Labour Party is supported by approximately 40 percent of the voters. Press ethics are on a high level, and the independence of the editors is universally recognized.

Broadcasting is operated by an independent government organization, with no commercial sponsors or advertising over the two radio networks and one television network. Educational and informational programs are given priority over entertainment. Every home with radio and television pays an annual fee. Regular colour-television broadcasts began in 1973. In 1982 several private radio stations began trial operations.

For statistical data on the land and people of Norway, see the *Britannica World Data* section in the BRITANNICA BOOK OF THE YEAR. (Ja.C.)

History

The earliest traces of human occupation in what is now Norway are found along the coast, where the huge ice shelf of the last ice age melted first, between 11,000 and 8000 BC. The earliest finds are stone tools of the Komsa type north of the Arctic Circle and the Fosna type from Trøndelag to the Oslo Fjord, all dating from 7000 to 6000 BC. Coastal fauna provided a means of livelihood for Arctic fishermen and hunters, who may have made their way south along the Norwegian coast about 10,000 BC, when the interior was still covered with ice. The theory has also been advanced that these peoples came from the south and followed the coast northward considerably later.

Early settlements

In the south of the country are dwelling sites dating from about 5000 BC. Finds from these sites, which include bone and stone tools from the entire coast, give a clearer idea of the life of the hunters and fishermen. The implements vary in shape and are made of different kinds of stone; those of later periods are more skillfully made. Rock carvings have been found, usually near hunting and fishing grounds. They represent game such as deer, reindeer, elk, bears, birds, seals, whales, and fish, vital for the survival of the coastal peoples. Enormous rock carvings at Alta in Finnmark were made at sea level continuously from 6200 to 2500 BC as land rose from the sea after the last ice age.

EARLIEST PEOPLES

Between 3000 and 2500 BC, new migrants settled in eastern Norway. They were farmers who grew barley and kept

cows and sheep. The hunting-fishing population of the west coast was also gradually replaced by farmers, though hunting and fishing remained useful secondary means of livelihood.

From about 1500 BC bronze was gradually introduced, but the use of stone implements continued; Norway had few riches to barter for bronze goods, and the few finds consist mostly of elaborate weapons and brooches that only chieftains could afford. Huge burial cairns built close to the sea are characteristic of this period. The motifs of the rock carvings differ from those typical of the Stone Age. Representations of the Sun, animals, trees, weapons, ships, and men were all strongly stylized, probably as fertility symbols connected with the religious ideas of the period.

Little has been found dating from the early Iron Age (the last 500 years BC). The dead were cremated, and their graves contain few burial goods. During the first four centuries AD, the people in Norway were in contact with Roman-occupied Gaul. About 70 Roman bronze caldrons, often used as burial urns, have been found. Contact with the civilized countries farther south brought a knowledge of runes; the oldest known Norwegian runic inscription dates from the 3rd century. At this time the settled areas in the country increased, a development that can be traced by coordinated studies of topography, archaeology, and place-names. The oldest root names, such as *nes, vik,* and *bø* (cape, bay, and farm), are of great antiquity, dating perhaps from the Bronze Age, while the earliest of the groups of compound names with the suffixes *vin* (meadow) or *heim* (settlement), as in Bjørgvin (Bergen) or Sæheim (Seim), usually date from the first centuries AD.

Settlements. The period of the collapse of the Roman Empire in the west (400–600) is characterized by rich finds, including chieftains' graves containing magnificent weapons and gold objects. Hill forts were built on precipitous rocks for defense. Excavation has revealed stone foundations of farmhouses 60 to 90 feet long (one even 150 feet long), the roofs of which were supported on wooden posts. These houses were family homesteads where several generations lived together, people and cattle under one roof. From this period and later (600–800), nascent communities can be traced. Defense works require cooperation and leadership, so that petty states of some kind with a defense and administrative organization must have existed.

Clan and tribal states

These states were based either on clans or tribes (*e.g.,* the Horder of Hordaland in western Norway). By the 9th century each of these small states had *thing*s, or *ting*s (local or regional assemblies), for negotiating and settling disputes. The *thing* meeting places, each eventually with a *horg* (open-air sanctuary) or a *hov* (temple), were usually situated on the oldest and best farms, belonging to the chieftains and wealthiest farmers. The regional *thing*s united to form even larger units, assemblies of deputy yeomen from several regions. In this way, the *lagting* (assemblies for negotiations and law-making) developed. The Gulating had its meeting place by the Sogne Fjord and may have been the centre of an aristocratic confederation along the western fjords and islands called the Gulatingslag. The Frostating was the meeting place for the leaders in the Trondheim Fjord area; the earls (*jarl*) of Lade near Trondheim seem to have added the coastland from the Romsdals Fjord to the Lofoten Islands to the Frostatingslag. A *lagting* developed around Lake Mjøsa in the east and eventually established its meeting place at Eidsvoll, becoming known as the Eidsvating. The area around the Oslo Fjord, although at times closely tied to Denmark, developed a *lagting,* with its meeting place at Sarpsborg, that was called the Borgarting.

The Vikings. The name Viking at first (*c.* 800) meant a man from the Vik, the huge "bay" that lies between Cape Lindesnes in Norway and the mouth of the Göta River in Sweden and that has been called Skagerrak since 1500. The term Viking Age has come to denote those years from about 800 to 1050 when Scandinavians set out on innumerable plundering expeditions abroad. Surplus population, superior ships and weapons, well-developed military organization, and a spirit of adventure seem to have combined to cause this great movement. The Norwegians mostly sailed westward, raiding and settling in Ireland, Scotland, England, France, the Shetlands, Orkneys, and Hebrides, the Isle of Man, and in the unpopulated Faeroe Islands and Iceland. Men of Norwegian descent settled in Greenland and undertook expeditions to Vinland (somewhere on the northeast coast of America). Many Vikings returned home, and this meeting with western Europe was decisive for the unification and Christianization of Norway. (C.Jo./G.Sa.)

In the second half of the 9th century, the Viking chief Harald I Fairhair from the Oslo Fjord area managed, in alliance with chiefs of the Frostatingslag and parts of the Gulatingslag, to pacify the western coast. The final battle took place in Hafrs Fjord near Stavanger sometime between 872 and 900, whereafter Harald proclaimed himself king of the Norwegians. His son and successor, Erik I Bloodax (so called because he murdered seven of his eight brothers), ruled about 930–935. He was replaced by his only surviving brother, Haakon I, who had been reared in England. Haakon was Norway's first missionary king, but his efforts failed; he died in battle in 960.

Christianization. The Viking chiefs established relations with Christian monarchies and the church, especially in Normandy and England. Thus Olaf I Tryggvason, a descendant of Harald Fairhair, led a Viking expedition to England in 991. He was baptized and returned to Norway in 995, claiming to be king and recognized as such along the coast, where Christianity was already known. These areas were Christianized by Olaf, by peaceful means if possible and by force if necessary; he also sent missionaries to Iceland, where the new religion was adopted by the parliament (Althingi) in 1000. In the same year Olaf was killed in the Battle of Svolder. Fifteen years later, another descendant of Harald Fairhair, Olaf II Haraldsson, who had returned from England, was acknowledged as king throughout Norway, including the inland areas. Olaf worked to increase royal power and to complete the Christianization of the country. In so doing, he alienated the former chieftains, who called on Canute of Denmark, now ruler of England, for help. Olaf was killed in battle with the Danes and peasant leaders at Stiklestad in 1030.

Olaf Tryggvason

Canute's rule in Norway soon proved unpopular with the chieftains, and, with support from the bishops, the deceased king Olaf became St. Olaf, the patron saint of Norway. With the death of Canute in 1035, Olaf's young son, Magnus, was elected king. He was succeeded in 1047 by his uncle, Harald III Hardraade, a former commander of Vikings in the imperial guard in Constantinople. Harald was killed during a vain attempt to conquer England in 1066.

The patron saint of Norway

The Olaf kings firmly established the Norwegian monarchy with the help of English bishops. In return, sees and abbeys received the larger part of the estates that the Fairhair "dynasty" had confiscated from the Viking chieftains during the unification of Norway.

THE 12TH, 13TH, AND 14TH CENTURIES

At the end of the Viking Age, all royal sons, legitimate or illegitimate, were considered to have equal claims on the crown if they were accepted by a *lagting.* During the 11th and early 12th centuries it was not unusual for Norway to have two or more joint kings ruling without conflict. Thus Harald Hardraade's son Olaf III reigned together with his brother Magnus II until the latter died in 1069. Olaf ruled from 1066 to 1093 without being involved in a war; by giving the dioceses (Nidaros, Bergen, Stavanger, and Oslo) permanent areas, he inspired the first Norwegian towns. Olaf's son, Magnus III Barefoot, ruled for 10 years, during which he undertook three expeditions to Scotland to establish Norwegian sovereignty over the Orkneys and the Hebrides. He was succeeded by his three sons Olaf IV (1103–15), Eystein I (1103–22), and Sigurd I Magnusson (1103–30), who ruled jointly and imposed tithes, founded the first Norwegian monasteries, built cathedrals, and incorporated the clergy of the Scottish isles into the church of Norway.

Conflict of church and state. Following the rule of Magnus III's sons, the increasing power of the church and the

Civil war

monarch contributed to the century of civil war. During the early 12th century the kings expanded their direct rule over the various provinces, and the family aristocracy in Norway grew discontented. After 1130 interest groups within Norwegian society supported pretenders, and the church was successful in exploiting civil unrest to win independence.

In 1152–53 the English cardinal Nicholas Breakspear (later Pope Adrian IV) visited Norway, resulting in the establishment of an archbishopric in Nidaros (Trondheim). In 1163 the church supported the claims of a pretender, Magnus V Erlingsson, in return for his obedience to the pope, guarantees for the reforms of 1152, and the issuance of a letter of privileges for the church. Magnus' coronation was the first at which the archbishop presided. The first written law of succession, dating from this coronation, established primogeniture in principle and the prior right of legitimate royal sons to the crown. Instead of election by the *things*, a representation, dominated by the church, served as the electoral body. The law was never applied, and Magnus was succeeded by Sverrir Sigurdsson, a priest from the Faeroe Islands, who represented himself as a grandson of the first pretender king. After seven years of fighting, Sverrir was acknowledged in 1184 as king of all Norway and set out to bring the church under royal control. He refused to recognize the reforms and privileges made since 1152, and the archbishop and most of the bishops went into exile; Sverrir was excommunicated. The exiles in Denmark established a rebellious party and allied themselves with the secular enemies of the King, who were opposed to the King's administrative reforms, which included the establishment of the *hird* as a new aristocracy composed of court officials and the heads of estates. This opposition party won control of the Oslo area and the inland areas and threatened Sverrir's rule until his death in 1202.

The "Golden Age" of Norway

Civil war continued until 1217, when Sverrir's grandson Haakon IV became king, beginning the "Golden Age" of Norway. Haakon modernized the administration by creating the chancellor's office and the royal council. He prohibited blood feuds, and a new law of succession was passed by a national assembly (1260) that established the indivisibility of the kingdom, primogeniture, the prior claim of the legitimate royal sons, and, most importantly, the hereditary right of the king's eldest legitimate son to the crown. During Haakon's reign, relations in the northern area were first regulated by a treaty with Russia (Novgorod; a similar treaty went into effect in 1326). Greenland and Iceland agreed voluntarily to personal unions with the Norwegian king in 1261 and 1262, marking the greatest extent of the Norwegian empire, which included the Faeroes and the Scottish isles. Haakon died during an unsuccessful expedition to the Hebrides in 1263, and in 1266 his successor ceded the Hebrides and the Isle of Man to Scotland in return for recognition of the Norwegian claim to the Orkney and Shetland islands.

Haakon's son and successor, Magnus VI, earned the epithet Lawmender for his work on Norway's legislation. During his reign (1263–80), a common national law code, with special chapters for the towns, replaced the earlier provincial laws in 1274–76. Haakon's law of succession was confirmed; and a hereditary nobility, exempted from taxes in return for military service, was established. The king thus took over the legislative functions, and the *thing* became courts presided over by royal judges (*lagmenn*). Such a systematic national code, prepared in the king's chancery, was unique in 13th-century Europe. It remained in force in Norway until the Norske Lov of 1687, while the version of the code for Iceland is still partly in force. In a concordat of 1277, some of the privileges of the church of Norway were curtailed, but those that were confirmed left the church essentially independent.

Magnus was succeeded by his young son Erik II (1280–99). Erik's regency was led by secular magnates who controlled central power throughout his reign. The church tried to win privileges that had been denied by Magnus, but the regency proved stronger. The magnates also tried to limit the rights of the German merchants in Norway but were answered by a blockade from the Hanse cities and were forced to agree to the German demands. Erik was succeeded by his brother Haakon V (1299–1319), who determined to renew the royal power. He built a series of fortresses, including Akershus in Oslo, marking the shift of political power from the west coast to the Oslo area. Haakon was unable to restore royal power to the extent he wished, however.

Union with Sweden. Haakon's successor was Magnus VII Eriksson, the young son of his daughter Ingeborg and Duke Erik, son of Magnus I of Sweden. The child was also elected to the Swedish crown in 1319, creating a personal union between the two countries that lasted until 1355. The countries were to be governed during the King's minority by the two national councils with the King's mother as a member of both regencies. The regency in Norway failed to prevent the increasing power of the magnates, and after the King came of age (1332), he was forced to recognize his younger son Haakon as king of Norway (1343) and to abdicate in his favour when he reached his majority (1355). Magnus' elder son Erik was designated king of Sweden. The Black Death struck Norway in 1349–50 and probably killed two-thirds of the population. The upper classes were particularly hard hit: only one of the bishops survived, and many noble families were reduced to the peasantry by the death of their workers and the decrease of their incomes.

The impact of the Black Death

The power of Haakon VI (1355–80) was also limited. The casualties of the Black Death among the high civil servants and clergy were replaced by Danes and Swedes. The central government as a whole lost control over the kingdom, and the local areas began to conduct their own affairs. Haakon VI married Margaret, the daughter of Valdemar Atterdag of Denmark, and their son, Olaf, was elected king of Denmark in 1375. Olaf also became king of Norway at his father's death (1380), but he died in 1387 at the age of 17, and his mother, who had served as regent in both kingdoms for him, now became the ruler.

Greenland. The first Nordic settlers on Greenland reached the island in 985 under the leadership of Erik the Red. Two colonies were established on the western coast, one near Godthåb and one near Julianehåb, where a few thousand Norsemen engaged in cattle breeding, fishing, and sealing. The most important export was walrus tusks. A bishopric and two cloisters were organized on Greenland. The Greenlanders lacked wood and iron for shipbuilding and could not support communications with Europe; in 1261 they submitted to the Norwegian king, to whom they would pay taxes in return for his acceptance of responsibility for the island's provision through a yearly voyage. A worsening of the climate may have occurred early in the 14th century, resulting in a decline in agriculture and livestock breeding. Plagues ravaged the populace: the Black Death alone is estimated to have halved the population. When Norway, with Greenland and Iceland, became subject to the Danish king, conditions worsened; the only ships that then sailed to Greenland belonged to pirates. Around 1350 the Godthåb settlement was apparently deserted and then occupied by Eskimo (Inuit), and in 1379 the Julianehåb area was attacked. The last certain notice of Norsemen on Greenland came in 1410: sometime during the following 150 years they disappeared from Greenland. It was not until the beginning of the 18th century that Greenland again came into the Danish sphere.

THE KALMAR UNION

With the accession of Margaret I of Denmark to power in 1387, the foundation was laid for political union with Denmark. She adopted her nephew Erik of Pomerania, then six years old, as her heir, and in 1388 she was acclaimed queen of Sweden as well. The next year Erik was proclaimed heir apparent in Norway, and in June 1397 he was crowned king of all three Scandinavian nations in a ceremony at Kalmar, Swed.

Under the Kalmar Union, Norway became an increasingly unimportant part of Scandinavia politically, and it remained in a union with Denmark until 1814. Margaret and Erik left vacant the highest Norwegian administrative position and governed Norway from Copenhagen. Most appointments made in Norway were given to Danes and

Germans. Whereas in Denmark and Sweden national councils took over the government, in Norway the council was unable to assert itself. After the accession of Christian I, Norwegian government was again centred in Copenhagen. The lower estates were also essentially powerless against the Danes, and isolated peasant uprisings had neither good leadership nor clear political goals. In 1448 Norway accepted the Swedish candidate for king, Karl Knutsson, but was forced to acknowledge Christian I of Oldenburg and to remain in the union with Denmark. In 1468 Christian pawned the Orkney and Shetland islands to the Scottish king to provide a dowry for his daughter, and the islands were never reclaimed.

Loss of the Orkney and Shetland islands

The cause of this political impotence in Norway has been a subject of considerable debate. According to one theory, the conscious policy of the kings since the 12th century of crushing the local family aristocracy to strengthen royal power deprived the country of a counterpart to the strong and often rebellious Danish and Swedish aristocracies. A second theory holds that geography was responsible for the absence of a strong aristocracy: the poorness of the soil prevented economic expansion through the creation of large estates. This geographic factor, together with the loss of population during the Black Death and subsequent epidemics, may explain why Norway's aristocracy was more affected by the plague than were the nobles in the rest of Scandinavia. The huge loss in population deprived the aristocracy of much of its labour force, which led to the abandonment of farms and the decline of many nobles into the peasant class. (H.En./G.Sa.)

THE 16TH AND 17TH CENTURIES

After 1523 the Norwegian council tried to obtain some independence for Norway within the union. But because the bishops dominated the council, they became the losers in the Norwegian parallel to the 1533–36 civil war in Denmark. As a result, the council was abolished, and the bishops lost all hope for help from Sweden, which did not want to provoke Denmark and whose king was himself leaning toward Lutheranism. Olaf Engelbrektsson, the last Norwegian archbishop and head of the council, left Norway in early 1537 for the Netherlands, taking with him the shrine of St. Olaf.

In Norwegian political history, the year 1536 is a nadir—in Copenhagen, Norway was proclaimed a Danish province forever. Norwegian topography and society, however, were very different from those of Denmark, and the hereditary Norwegian crown was viewed as a distinct monarchy. Thus, Norway was allowed to keep most of its ancient institutions and laws, and new institutions and laws had to be given in a special Norwegian version (for example, the Norske Lov of 1687). From 1550 Norway's natural resources, including fish, timber, iron ore, and copper—commodities from outside the Baltic area and most useful to all western Europe—were increasingly exploited. Consequently, a Norwegian bourgeoisie became a political factor. After 1560 Denmark had a constant fear of Swedish plans to occupy Norway. Therefore it was important that the Norwegians should not feel oppressed by rule from the political centre in Copenhagen. All this may explain the special attention the Danish government gave to Norway.

Rise of the Norwegian bourgeoisie

Most representative of this attitude was Christian IV, who visited Norway often and founded several towns (*e.g.,* Kristiansand, with the plan to control the Skagerrak; Kongsberg, with its silver mines; and Christiania, after a destructive fire in Oslo, 1624). He even went on an Arctic tour to Vardø in 1599, proclaiming the Arctic waters to be the "king's streams." This was part of his reaction to Swedish pretensions toward the Arctic Ocean.

A certain separatist policy has been attributed to Hannibal Sehested, the King's son-in-law and in the 1640s governor of Norway. He actually created an army (by conscription of peasants) and a separate financial administration, but he may have wanted a platform against the Danish nobility to work for absolutism. There were no signs of secession in the Norwegian population. When he was deposed in 1651, the financial administration was ruled from Copenhagen.

For almost a generation after 1664, Ulrik Frederick Gyldenløve, the illegitimate son of Frederick III, was governor of Norway. He courted the Norwegian peasants and at the same time gave monopolies on trade and on timber exports to restricted numbers of merchants. By applying such principles the government in Copenhagen and the Danish public servants managed to rule Norway after the Swedish annexations of Skåne, Halland, and Bohuslän. Norway's modern frontiers were established in 1660 and confirmed by treaty with Sweden in 1751, when Norway received the interior of Finnmark.

THE 18TH CENTURY

Romanticists of the later 18th century idealized Norwegian rural society, with its free peasants in a wild landscape. Certainly, their situation contrasted favourably with that of the Danish tenants; the landowning farmers in eastern Norway, especially, earned sizable incomes from their timber forests. In the east, therefore, and in the region of Trøndelag, the countryside was characterized by a class of wealthy timber merchants and farmers and a large rural proletariat. Elsewhere in the countryside, social conditions were more nearly equal. The Norwegian population consisted almost exclusively of peasants and fishermen; no city or urban agglomeration exceeded 15,000 inhabitants.

Thomas Malthus was the first demographer to see the exceptional possibilities for population studies in the Scandinavian countries, where civic registers were kept by parsons. In 1799, the year following his publication of *An Essay on the Principle of Population,* Malthus went to Norway to confirm his theories about checks on population growth. He found a late marital age, which he ascribed incorrectly to military service and a large servant class. In fact, early marriages were hindered by poverty and lack of land. Moreover, Norwegian population statistics of the 18th century indicate years of famine and epidemics, as do Swedish and Danish statistics. Malthus was correct, however, in discerning that demographic evolution in nonindustrialized countries could be studied better in Scandinavia than anywhere else in the world.

How and why the Norse community in Greenland perished at the end of the Middle Ages is an unsolved and fascinating problem. In the beginning of the 18th century there still was hope of finding Norse descendants among the Eskimo in Greenland. A Norwegian clergyman, Hans Egede, having managed to persuade the authorities that such people should be converted to the Lutheran faith, arrived in the Godthåb Fjord (in the southwest), finding only Eskimo, to begin a new European settlement in Greenland. Later in the century another colony was founded at Julianehåb (almost at the southern tip of the island).

Revival of settlement in Greenland

Two factors are visible in this activity. First, the Pietist movement, which had a considerable influence in Denmark, demanded religious conversion and stressed an obligation to bring the gospel to the heathens. A Ministry of Missions, founded in 1714, supported Egede in Greenland as it supported missionary activity among the *samer* (Lapps) in northern Norway and among Indians at Tranquebar on the Coromandel Coast. Second, missionary activity became possible because of a close alliance with commercial interests. Egede himself founded a company in Bergen for trade with Greenland. The trade later passed to the Royal Greenland Trading Company of Copenhagen. The trade with Finnmark (now the northernmost part of Norway) was reserved, in principle, for merchants of Copenhagen as well.

THE NAPOLEONIC WARS AND THE 19TH CENTURY

Denmark–Norway's attempt to remain neutral in the struggle between France and England and their respective allies early in the 19th century came to an end after England's preemptive naval actions of 1807, in which the entire Danish fleet was taken. The continental blockade of England that followed, which was against Danish interests, was a catastrophe to Norway. Fish and timber exports were stopped, as well as grain imports from Denmark. The consequences were isolation, economic crisis, and hunger. In 1810–13 England consented to some relaxation of its counterblockade against Norway. As a whole, however,

the years 1807–14 convinced leading groups in Norway that they needed a political representation of their own.

The Treaty of Kiel. Swedish foreign policy was erratic during those years, but Denmark–Norway remained an ally of Napoleon until 1814. After Napoleon's defeat at the Battle of Leipzig (1813), Sweden repeated its 17th-century strategy by attacking Denmark from the south. At the Treaty of Kiel (Jan. 14, 1814), Denmark gave up all its rights to Norway (but not to the old Norwegian dependencies of Iceland, the Faeroes, and Greenland) to Sweden.

The Danes did not intend this agreement to end the union with Norway. Officially loyal to the Treaty of Kiel, the Danish government worked for the eventual return of Norway. This probably is why the crown prince Christian Frederick, governor of Norway, in collusion with the Danish king, organized a rising against the Treaty of Kiel. In doing so he needed support in Norway, and he thus came to rely on two political forces, each with regionalist aims. The larger faction consisted of civil servants and peasants, who were loyal to Copenhagen but traditionally in opposition to its centralizing policy. The other was the small but important group of timber merchants in eastern Norway, who wanted independence from Copenhagen for their trade with western Europe. Since 1809 they had conspired for a union between Sweden and Norway.

Constitution of May 17, 1814

This was the main background of a constituent assembly, called by Christian Frederick to meet at Eidsvoll, 40 miles north of Christiania. It drew up the constitution of May 17, 1814 (which still exists), and elected Christian Frederick to the throne of Norway.

Union with Sweden. Norwegian independence got no support from the great powers, and Sweden attacked Norway in July 1814. After a fake war of 14 days, Christian Frederick resigned. Jean Bernadotte (later known as Charles XIV John; called Karl Johan in Sweden and Norway), the Swedish crown prince, accepted the Norwegian constitution, and in so doing could no longer argue on the basis of the Treaty of Kiel. This was of the greatest political importance to the Norwegians. As a constitutional monarchy, Norway entered the union with Sweden in November 1814; only minor modifications were made in its constitution—the king and foreign policy would be common; the king would be commander in chief of Norway's armed forces, which could not be used outside Norway without Norwegian consent; a government in Christiania (with a section in Stockholm) and the Storting (Norwegian parliament) would take care of national affairs. (G.Sa.)

For Norway the Treaty of Kiel meant secession from Denmark, the forming of its own separate state with complete internal self-government, and a political centre in Christiania. The history of Norway during the 19th century is marked by the struggle to assert its independence of Sweden within the union and its attempts to develop a modern Norwegian culture.

Population, trade, and industry. *Population.* Norway's population grew more rapidly during the 19th century than in any other period of its history. The population rose from 883,000 in 1801 to 2,240,000 in 1900. Whereas the urban population was only 8.8 percent in 1800, it had reached 28 percent by 1900. After Ireland, Norway had the highest relative emigration of all European countries in the 19th century. From 1840 to 1914 about 750,000 people emigrated, especially to the American Middle West.

Economic conditions. Norway was also severely hit by the economic crisis that followed the Napoleonic Wars. Norway's exports consisted mainly of wooden goods to Great Britain and, to a certain extent, of glass and iron products. After the war, when the British introduced preferential tariffs on articles of wood from Canada, Norwegian forest owners, sawmills, and export firms were badly hit. Iron and glass exports also met with marketing difficulties. Fish, which after timber was the country's most important export commodity, was only lightly hit by the slump; and by the 1820s the herring fisheries on the west coast enjoyed a period of vigorous expansion. From the 1850s on, agriculture developed rapidly. Modern methods were adopted, and an emphasis was laid on cattle breeding. Simultaneously, the building of railroads began ending the isolation of the small communities and opening the way for the sale of agricultural products. It was, however, the great expansion of merchant shipping (especially between 1850 and 1880) that gave the most powerful boost to the country's economy. Norway's percentage of world tonnage rose from 3.6 percent to 6.1 percent; and at the end of the century Norway possessed, after the United Kingdom and the United States, the largest merchant navy in the world. The economic resources that merchant shipping brought to the country laid the basis for industrialization. From 1860 Norway's industry expanded rapidly, especially in the timber and wood-pulp trade and in engineering. Socially and economically this expansion was a springboard for shipowners, manufacturers, and businessmen, all of whom began to play a much greater role in politics toward the end of the 19th century.

Merchant shipping

The age of bureaucracy (1814–84). The economic development in the decades immediately after the Napoleonic Wars meant a reduction in the power of the big business concerns and great estates. The decision to abolish the nobility in 1821 was indicative of the greatly reduced social and economic circumstances of the upper classes. At the same time, the position of the civil servants was strengthened, and from then until the latter part of the 19th century they controlled the political power of the country. Apart from the civil servants, there were only two other political factors of any importance in Norway at this time: the farmers and the monarch.

Parliamentary authority. The Eidsvoll constitution of 1814 gave the Storting greater authority than parliamentary bodies had in any other country except the United States. The king retained executive power and chose his own ministers, but legislation, the imposition of taxes, and the budget were within the authority of the Storting. The Storting had the power to initiate legislation, and the king had only a suspension veto. When the union's monarch Charles XIV John (ruled 1818–44) demanded the right of absolute veto, the Storting categorically refused, despite the King's attempt to intimidate them with shows of military strength. Faced with this unanimous resistance, the King was forced to abandon his struggle, and the Storting's dominant position became the firm defense against Swedish attempts to unite the two countries. As a national demonstration, Norway began in the 1820s to celebrate May 17, the date of the Eidsvoll constitution, as a national day. The King's attempt to outlaw the celebration resulted in violent demonstrations, and during the 1830s he conceded this point also.

Monetary problems. Norway had at the same time many major problems to resolve on the domestic front. The war, which had been to a great extent financed by an increased issue of bank notes, had brought about a reduction of the riksdaler to one-fifteenth of its original value. To ward off inflation, a severe sterling tax was imposed, and in 1816 a new bank of Norway was established that had the monopoly of issuing bank notes. In spite of strong precautionary measures, however, it was not until the currency reform of 1842 that finances were stabilized. From an economic point of view, the civil service was decidedly liberal, and the guild system and old trade regulations were abolished during the 1840s and 1850s. By 1842 it was decided to reduce tariffs, a decision that gradually made Norway a free-trade country.

Political change. The influence that the vote gave to the farmers was not exploited at first, and they continued to elect civil servants as their parliamentary representatives. About 1830, however, a demand was raised for a decrease in expenditure, and, under the leadership of Ole Gabriel Ueland, a more deliberate "class" policy began to be conducted in the Storting. In 1837 a statute regarding local self-government was enacted that offered training for grass-roots politicians. The farmers' policy led to sharp conflicts with influential groups of bureaucrats and finally became a struggle for political power on the national level. Under pressure from a radical labour movement, which arose after 1848 under the leadership of Marcus Thrane, and from the later mounting tension in the relationship with Sweden, many farmers turned to the middle classes and the minor civil servants. The intensely nationalistic attitude of this leftist coalition was expressed in its at-

tempts to strengthen national culture and language. The struggle for the introduction of the vernacular as the official language instead of the bureaucrats' Danish-influenced tongue became an important item of the coalition's policy. The coalition was organized as the Venstre (Left) political party in 1884.

The union conflict (1859–1905). Because the union's king usually resided in Sweden, he was represented in Norway by a governor general. This gave rise to the governor-general conflict, which was not resolved until 1873, when Sweden yielded to Norway's main demands. The result was that in Norway the king was regarded as Swedish, and his right to nominate the government in Norway was considered a danger to the country's autonomy. The conflict revolved around the question of the Storting's confidence in the government. During the reign of Oscar II (ruled in Norway 1872–1905), matters came to a head when a Conservative government refused to pass an amendment to the constitution that the Storting had three times accepted.

Resignation of the government

After a trial before the court of impeachment (Riksretten) the government was forced to resign in 1884. The Storting and not the king had thus acquired the decisive influence on the government, and Norway became the first country in Scandinavia to be governed by parliamentary means.

Although Norway had won full self-government on the domestic front, the union was still represented externally by the Swedish-Norwegian king, and the country's foreign policy was conducted by the Swedish foreign minister. From the 1880s, therefore, there was an increasing demand for an independent Norwegian foreign minister. In 1891, Venstre won an impressive majority at the polls with this question, among other things, on its program. In spite of this, the Venstre government headed by Johannes Steen, which the King had appointed after the election, did not take up the question of the foreign minister but raised instead a more limited demand for a Norwegian consular service. Even this was flatly refused by Sweden in 1892. When the Storting attempted to carry out this reform independently, it was forced under threat of military action to negotiate with Sweden on a revision of the whole question of the union. Though Sweden soon showed its readiness to be most compliant, the incompatibilities had become so marked that there was no real chance of a compromise.

The negotiations collapsed in 1898, and Norway at the same time demonstrated its independence by abolishing the union emblem on its merchant flag despite the King's veto. New negotiations were opened in an attempt to solve the more limited demand for an independent consular service, but when these negotiations also failed Norway took the matter into its own hands, and the Storting passed a bill establishing Norway's own consular service. When the King refused to sanction the bill, the coalition government, under the leadership of Christian Michelsen, resigned. As, under the circumstances, it was impossible for the King to form a new Norwegian government, the Storting declared "the Union with Sweden dissolved as a result of the King ceasing to function as Norwegian King," on June 7, 1905. The Swedish Parliament refused, however, to accept this unilateral Norwegian decision. Under threat of military action and partial mobilization in both countries, Norway entered into negotiations on the conditions for the dissolution of the union. A settlement was reached in Karlstad in September 1905, which embodied concessions from both sides. The Swedish-Norwegian union was thus legally dissolved, and shortly afterward Prince Charles of Denmark was elected in a referendum as Norway's king and came to the throne under the name of Haakon VII.

Dissolution of the union

THE 20TH CENTURY

Economic and industrial growth. The period 1905 to 1914 was characterized by rapid economic expansion in Norway. The development of the merchant fleet, which had begun during the second half of the 19th century, continued, and at the outbreak of World War I Norway's merchant navy was the fourth largest in the world.

From about the turn of the century, Norway's immense resources of waterpower provided a base for great industrial expansion. The large number of waterfalls bought by Norwegian and foreign companies gave rise to grave concern that the country's natural resources were falling into foreign hands or were becoming monopolized by a small number of capitalists. In 1906 three-quarters of all developed waterpower in Norway was owned by foreign concerns. Venstre and the growing Norwegian Labour Party pressed for legislation to protect the natural resources of the country. The proposed bill on concessions (later known as the Concession Laws) played a dominating role in Norwegian politics from 1905 to 1914. It led to a split in Venstre, but the majority of Venstre supported the bill, which was passed by the Storting in 1909 and remained in force despite continued criticism.

Concession Laws

The Norwegian Labour Party (DNA) had been founded in 1887, and universal suffrage was one of the principal points in the party program. In the 1890s Venstre likewise adopted this policy, and in 1898 universal male suffrage was introduced. By reforms in 1907 and 1913 the vote was extended to women. One consequence of industrialization and the introduction of universal suffrage was the growing influence of the DNA. A number of social reforms were enacted: a factory act, which included protection for women and children, accident insurance for seafaring men, health insurance, a 10-hour working day (in 1915), and a 48-hour workweek (1919); a 40-hour workweek was introduced in 1977.

World War I and the interwar years. *World War I.* With the outbreak of war in 1914, Norway, like Sweden and Denmark, issued a declaration of neutrality. Norway was badly hurt by the war at sea, about half of Norwegian merchant shipping being lost. As the Allied powers could almost totally control Norway's foreign trade, they forced it to break off exports of fish to Germany and, at the same time, forbade exports of iron pyrites and copper, which were important commodities for the German war industry. Because of the many casualties caused by submarine warfare, public feeling in Norway was strongly anti-German. The government, however, under the leadership of Venstre politician Gunnar Knudsen, insisted upon maintaining the appearance of neutrality. The war brought a distinct boom to Norway, although the prosperity was unevenly distributed. Within the DNA, the left wing formed the majority in 1918, and in 1919 the DNA, unlike the other Social Democratic parties in western and central Europe, joined the Comintern (Third Communist International). The DNA, however, was unwilling to submit to the centralization that Moscow demanded, and in 1923 it withdrew.

Dependence on foreign trade

The Great Depression. In the years up to 1935 the various governments—formed alternatively by the Conservatives, the Liberals (Venstre), and the Farmers' Party—pursued, by and large, a liberal economic policy. After the inflation caused by World War I and the postwar years, the main aim during the 1920s was to guide the currency (the krone) back to its former value. Norway received only an insignificant share in improved world market conditions, and by 1927 the unemployment figures were as high as 20 percent of the organized labour force. The Depression in the early 1930s increased unemployment still further, and by 1933 at least 33 percent of the work force, including many civil servants, was unemployed.

The government, led by the Farmers' Party (1931–33) and Venstre (1933–35), tried to combat the crisis with extensive reductions in governmental expenditure but refused to consider an expansionist financial policy or the emergency relief measures that the DNA demanded. The DNA thus enjoyed great success in the elections of 1933, although failing to gain a majority in the Storting. When the DNA formed the government in 1935, with Johan Nygaardsvold as prime minister, it needed the support of at least one other party. By a compromise with the Farmers' Party, the DNA received support for a social program that included old-age pension reform, revision of the factory act, statutory holidays, and unemployment insurance financed by increased taxation. State investments were also greatly increased. Although the situation was improved, unemployment in Norway was still as high as 20 percent of the organized labour force in 1938.

Social reforms

Despite economic difficulties, the high rate of unemploy-

ment, and the many labour conflicts, the interwar years were a period of vigorous expansion, and the country's industrial production was increased by 75 percent during the years 1913 to 1938.

Foreign policy. During the 1920s Norway acquired Svalbard and Jan Mayen, and Norwegian hunters and fishermen occupied an area on the east coast of Greenland. Denmark's demand for sovereignty of the area led to a conflict that was settled in the Permanent Court of International Justice in The Hague in 1933 in Denmark's favour. In 1939 the government proclaimed that Queen Maud Land in Antarctica was under Norwegian sovereignty. Because the League of Nations in 1936 had proved ineffective at keeping the peace, Norway's foreign minister, Halvdan Koht, attempted within the framework of the league to coordinate the policy of the smaller states in an effort to preserve peace. Norway continued to pursue a strictly neutral policy and declined Germany's invitation to join in a nonaggression pact in 1939.

World War II. With the outbreak of hostilities in 1939, Norway declared itself neutral. On April 9, 1940, German troops invaded the country and quickly occupied Oslo, Bergen, Trondheim, and Narvik. The Norwegian government rejected the German ultimatum regarding immediate capitulation. The Norwegian Army, which received help from an Allied expeditionary force, was unable to resist the superior German troops, however. After three weeks the war was abandoned in southern Norway. The Norwegian and Allied forces succeeded in recapturing Narvik but withdrew again on June 7, when the Allied troops were needed in France. The same day, the King, the Crown Prince, and the government left for London, and on June 10 the Norwegian troops in northern Norway capitulated. The government, through the Norwegian Shipping and Trade Mission (Nortraship), directed the merchant fleet, which made an important contribution to the Allied cause. The war, however, caused the loss of half of the fleet.

The German invasion

In Norway, Vidkun Quisling, leader of the small Norwegian National Socialist party (Nasjonal Samling, or National Union), which had never obtained a seat in the Storting, proclaimed on April 9 a "national government." This aroused such strong resistance, however, that the Germans thrust him aside on April 15, and an administrative council, consisting of high civil servants, was organized for the occupied territories. Political power was wielded by the German commissioner, Josef Terboven. In September 1940 the administrative council was replaced by a number of "commissarial counselors" who in 1942 formed a Nazi government under the leadership of Quisling. The "Nazification" attempt aroused strong resistance, however. Initially, this took the form of passive resistance and general strikes, which the Germans countered with martial law and death sentences. Once the resistance movement became more firmly organized, its members undertook large-scale industrial sabotage, of which the most important was that against the production of heavy water in Rjukan in southern Norway.

At the end of the war, the German troops in Norway capitulated without offering resistance. On their retreat from Finland in the winter of 1944–45, however, the Germans burned and ravaged Finnmark and northern Troms. The Soviet troops who liberated eastern Finnmark in November 1944 withdrew during the summer of 1945.

The postwar period. The liberation was followed by trials of collaborators; 24 Norwegians, including Quisling (whose name has gone down in history as a byword for a traitor), were sentenced to death and executed, and 19,000 received prison sentences. By a strict policy that gave priority to the reconstruction of productive capacity in preference to consumer goods, Norway quickly succeeded in repairing the ravages left by the war. By 1949 the merchant fleet had attained its prewar size, and the figures for both industrial production and housing were greater than in the 1930s. Until the 1980s, Norway had full or nearly full employment and a swiftly rising standard of living.

Political and social change. After the liberation in 1945, a coalition government was formed under the leadership of Einar Gerhardsen. The general election in the autumn of 1945 gave the DNA a decisive majority, and a purely Labour government was formed with Gerhardsen as prime minister. The DNA governed almost continuously from 1945 to 1965. King Haakon VII died in 1957 and was succeeded by his son, Olaf V. The Labour governments continued the social policies initiated in the 1930s. A general retirement pension law was passed in 1956, and a law on social welfare replaced the former "poor law" in 1964. The election of 1965 resulted in a clear majority for the four centre and right-wing parties, which formed a coalition government under the leadership of Per Borten. In 1971 the coalition government split, and the DNA again came to power, headed by Trygve Bratteli.

As a consequence of the referendum on the European Economic Community (EEC, or Common Market; see below), the Labour government resigned and was followed by a non-Socialist coalition government under the leadership of Lars Korvald. The DNA returned to power in 1973 with Bratteli again as prime minister. When he resigned as leader of the party and prime minister in 1976, he was succeeded by Odvar Nordli. Gro Harlem Brundtland, Norway's first woman prime minister, took over the government and party leadership from Nordli in February 1981. Her government was defeated at the polls in September of that year, and a Conservative, Kåre Willoch, became prime minister. Brundtland returned as prime minister in May 1986 but was again defeated three years later. The Conservatives formed a three-party coalition government under Jan Peder Syse but resigned after one year over the issue of Norway's future relationship with the EEC. Brundtland again formed a minority Labour government. King Olaf V died in 1991 and was succeeded by his son, Harald V.

Since the 1970s a central issue in Norwegian politics has been the exploitation of the rich natural gas and petroleum deposits in the Norwegian part of the North Sea. The petroleum industry made possible continued high employment until the 1980s, but it also caused a sharp rise in domestic prices. In addition, the industry has become so dominant in Norway that fluctuations in the world petroleum market have profound effects on the Norwegian economy.

North Sea petroleum

Postwar foreign policy. When the antagonisms between the great powers came to a head in 1948, Norway took part in the negotiations set in motion by Sweden on a Nordic defense union. The negotiations produced a tacit Cold War "Nordic balance." For instance, in 1949 Norway, followed by Denmark, joined the newly formed North Atlantic Treaty Organization (NATO), but NATO was not allowed to establish military bases or stockpile nuclear weapons on their territories; Sweden remained neutral. The compensation for these self-imposed restrictions was a gradual improvement in relations between the Soviet Union and the Nordic countries.

The dissolution of the Soviet Union in the early 1990s revived an old problem concerning the boundary between Norway and Russia in the Barents Sea of the Arctic Ocean. Once merely an esoteric legal issue, the boundary took on great importance because of its strategic naval relevance to Russia and because extensive deposits of petroleum and natural gas may lie beneath the shallow waters.

(Jö.We./G.Sa.)

Since the 1960s the question of Norway's relations with the EEC (from 1993 the European Community within the European Union [EU]) has split the country's citizenry across traditional party lines and even within families. A member of the European Free Trade Association (EFTA) from its formal inception in 1960, Norway decided to follow the lead of fellow EFTA member Great Britain from 1961 by entering into negotiations for membership in the EEC. These initiatives were thwarted in 1963 and 1967 by the strong opposition of French president Charles de Gaulle. Norwegian orientation toward the EEC was suspended until 1969, when the country again followed Britain's lead (along with Ireland and EFTA member Denmark) in applying for EEC membership. All four were accepted, but in 1972 Norwegian voters defeated the referendum on membership by more than 53 percent; the other three nations joined the organization in 1973.

For some 10 years thereafter Norway joined the remaining EFTA countries in signing a variety of free-trade agree-

ments with members of the EEC that, though they were bilateral, incorporated the economic liberalism of the EEC. Negotiations begun in 1989 between the two organizations culminated in 1991 in an agreement to form a free-trade zone called the European Economic Area (EEA). Norway became a member of the EEA when it came into effect in 1994.

Meanwhile, the dissolution of the communist governments of the Soviet bloc countries of central and eastern Europe and the breakup of the Soviet Union itself in 1989–91 changed the European political scene as well as the plans inherent in the inauguration of the EEA. EFTA members Austria, Finland, and Sweden suddenly felt politically free to apply for full membership in what soon would become the EU. Norway followed suit, applying for membership in November 1992. In a national referendum in November 1994, however, the Norwegian electorate again rejected the treaty negotiated by the government, albeit by a slightly smaller margin than in 1972.

It may seem contradictory that Norway has continued to reject EU membership. Norway, as a founding member of NATO, has been solidly integrated into Western security politics since 1949. The export of petroleum and natural gas from the North Sea has greatly strengthened Norway's economy and has more fully integrated it into the global economy. Nonetheless, the movement toward European political, monetary, and military unity that found expression in the Maastricht Treaty and establishment of the EU reminded too many Norwegians of the unions in their past that had subjugated Norway for more than half a millennium. The proponents of EU membership could not convince the opponents that Norway had obtained favourable concessions in its negotiations with the EU regarding fisheries, agriculture, and the exploitation of petroleum and natural gas. Moreover, the opponents were fearful that Norway would once more lose its national independence. Thus, at the beginning of the 21st century Norway found itself in a much-diminished EFTA (with Iceland, Liechtenstein, and Switzerland) but, through its affiliation with the EEA, strongly tied economically to the EU. (G.Sa.)

For later developments in the history of Norway, see the BRITANNICA BOOK OF THE YEAR.

For coverage of related topics in the *Macropædia* and *Micropædia*, see the *Propædia*, sections 921, 923, 961, 963, and 972.

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